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2009 Formula SAE Race Car

Adam C. Panzica  
*Worcester Polytechnic Institute*

Christopher Aho  
*Worcester Polytechnic Institute*

Christopher John Putnam  
*Worcester Polytechnic Institute*

Cody Miles Wojcik  
*Worcester Polytechnic Institute*

Daniel E. Swan  
*Worcester Polytechnic Institute*

*See next page for additional authors*

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2009 Formula SAE Racecar

A Major Qualifying Project Report:

Submitted to the Faculty of

WORCESTER POLYTECHNIC INSTITUTE

In partial fulfillment of the requirements for the

Degree of Bachelor of Science

by

Christopher Aho

Daniel Cullen

Scott Duncan

Adam Panzica

Christopher Putnam

Daniel Swan

Cody Wojcik

Date: May 1, 2009

Approved by:

Professor Eben C. Cobb
Acknowledgements

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Abstract

Design and fabrication of the 2009 Formula Society of Automotive Engineers (SAE) race car focuses on developing a simple, lightweight and easily operated vehicle. Compliance with SAE rules is compulsory and governs a significant portion of the objectives. Aspects of ergonomics, safety, ease of manufacture, and reliability are incorporated into the design specifications. Analyses are conducted on all major components to optimize strength and rigidity, improve vehicle performance, and to reduce complexity and manufacturing costs.
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<td><strong>Scott Duncan</strong></td>
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Introduction

The 2009 WPI Formula Society of Automotive Engineering (FSAE) racecar represents a dramatic departure from WPI’s previous designs. Rather than attempting to build on previous vehicles, this year’s team decided to start from scratch with a new design built around new rules and a new engine and drivetrain. Beginning with a few important design goals for the car, the team began to brainstorm various engine and transmission combinations, chassis, and suspension possibilities. These concepts included a lightweight design that would be comfortable for the driver and easy to manufacture.

The team wanted to use a continuously variable transmission (CVT) due to its reduced weight compared to the traditional motorcycle gearbox used in cars past. The next step was finding an engine that could be easily integrated with a CVT. Rather than designing a system to link an engine with no transmission to the CVT, the team decided that it would be advantageous to use an engine that already utilizes a CVT. Again going with a lightweight theme, the team chose the two cylinder, 500cc Genesis 80FI engine out of a 2008 Yamaha Phazer snowmobile which was purchased direct from the factory. Procuring a sled from Yamaha meant that the team could be sure the engine, transmission and wiring harness would work together which would ultimately save time towards the end of the project.

Instead of going with independent suspension in the rear as was typical for previous FSAE racecars, the team wanted to utilize a solid rear axle. The idea behind this decision was that by eliminating CV joints and a differential there would be fewer frictional losses. A sprint car parts supplier was found to provide the team with most of the components for the rear end. It still had to be determined what sort of rear suspension would be coupled with the solid axle to provide the team the best competitive advantage.
By making these design decisions early, the team was able to focus on other aspects of the car and spend more time optimizing designs. The new design templates, dictated by the 2009 FSAE rule book, provided most of the constraints for chassis design. It was important to consider the taller drivers for ergonomic issues that came up during cockpit design and for most of the design process, a six-foot-tall driver model was used. By simplifying the design and reducing the number of parts used on the car, it was the team’s hope to get the car finished earlier than any of the past teams so that a significant portion of time could be spent testing.
Design Objectives

The 2009 WPI FSAE racecar was designed with specific objectives in mind to provide an ultimate direction to guide the team through the design process. Some of the most important design objectives for this year’s team included the following:

- **Ergonomics and driver comfort**

  In addition to fitting templates dictated by the rules, all relevant parts of the car would be designed with driver comfort in mind. The cockpit area and foot box would be as large as necessary and would be designed to easily accommodate the largest and smallest drivers on the team. Keeping the spirit of the competition in mind, the car should be designed for the “weekend racer” and needs to be comfortable for the driver for an entire day of racing.

- **Manufacturability**

  FSAE states that the goal of the competition is to design and manufacture a prototype of a small-scale production vehicle. In the interest of completing the car for testing, all parts of the vehicle were designed with manufacturability and affordability in mind. Parts are positioned both for packaging and performance and easy access for tuning and replacement. A strong emphasis was placed on integrating a number of stock parts from the Yamaha Phazer snowmobile—engine, transmission, wiring harness, and center console. Using an outside supplier also played an important role in developing the rear swing arm.

- **Simplicity**

  In the interest of reliability, affordability and weight reduction, the number of parts and systems on the car were kept to a minimum. This idea was most prevalent in the design of the solid rear axle. Using readily available parts also contributed to the team’s achievement of a simple design.
Manufacturing

Design for manufacturability was a main concern for the design of the 2009 car. In the initial stages of component design, the manufacturability of the part was refined until the part could be made in a minimum amount of setups, and with a small number of tool changes. Throughout the design stages of the project, it was kept in mind that the team was designing a small-run production vehicle. Even though the car the team manufactured was made using single prototype manufacturing techniques, the components had to be designed so that the manufacturing processes could be easily scaled to larger production runs. A small savings in time or tool life in prototype manufacturing translate into large savings of time and money in a full scale production setting.

All components were manufactured in the CNC Machining Labs in Washburn Shops at WPI with the exception of parts suited to water jetting. The 2009 team was sponsored by Vangy Tool, who provided water jetting services at no cost to the team. All other machined parts were manufactured using the Haas CNC milling centers and lathes.

Figure 1: HAAS VF-4 CNC milling machine (source: www.haascnc.com)
The CAM software used for milled parts was SURFCAM. SURFCAM increased productivity through its simplified interface and its unique tool path generation system, called TrueMill. Conventional CAM packages determine tool paths based on the part shape and a given tool step over value. Depending on the shape of the part being machined, this can lead to a sharp increase in tool load entering inside corners and other part features. TrueMill essentially eliminates this by generating the tool path based on radial engagement of the tool instead of using a fixed linear step over. This allows feeds and speeds to be increased by up to 100% over conventional tool paths, while decreasing tool wear. Figure 2 shows a unique TrueMill tool path generated for an adjustment insert.

![TrueMill tool path generated for a front suspension adjustment insert](image)

*Figure 2: TrueMill tool path generated for a front suspension adjustment insert*
Design, Analysis and Fabrication

Keeping the design objectives developed early in the design process in mind, the team sought to design, manufacture, and analyze the 2009 racecar with the idea that the car would be competitive due to refined designs, thorough analysis and careful manufacturing. The car was designed to not only perform competitively, but also to be cost effective. The team was mindful throughout the entire design phase that the car was being designed and manufactured for the “weekend racer,” an individual who demands top-notch racing performance from a reasonably priced and reliable vehicle. To accomplish these goals, the car was designed to be as simple as possible. A simple design would allow ample time for manufacturing and testing of the vehicle. Reducing manufacturing time was not only important for the team in the prototype stage, but would be many times more important for a company producing these vehicles on a larger scale. Less time spent manufacturing saves funding and other resources. Even with careful design and manufacturing, testing the car would expose it weaknesses. This would also allow the team to become accustomed to how the car drove and to practice driving in a competitive environment. The following sections detail the design, fabrication, and analysis processes for each of the car’s subsystems.
Suspension

In recent years, Formula SAE race cars produced by WPI were found to be uncompetitive in competition. Therefore, it was decided that an original design would be best. To do this, an iterative process was formulated to aid in designing a completely new suspension system in under six months by a team with no FSAE experience. We followed the following process steps.

1. Wheel Size Selection
2. Tire Selection
3. Track Width and Wheel Base Selection
4. Packaging Constraints
5. Roll Center Location and Movement Optimization
6. Camber Change Optimization
7. Steering Geometry

Wheel Size Selection

FSAE rules set the minimum wheel size to be eight inches in diameter. For the purposes of this design, the smallest applicable wheel size was ten inches. Using a wheel with an inner diameter smaller than ten inches makes packaging of the wheel upright difficult, and greatly increases the loading conditions on the upper and lower control arms.

Pneumatic tires are incredibly complex devices. Much of what is known about their dynamic behavior, and also manufacturing techniques, are trade secrets. As such, it is unrealistic for a group of students to attempt to design and manufacture their own tires, in addition to the race car. The choices for tires were limited to what is available for purchase. The tires available for purchase that are appropriate for FSAE cars are available in only ten or thirteen inch sizes; there are no appropriate tires between ten and thirteen inches available for purchase. Based on
data collected from previous FSAE teams, it is hard to consider using a tire size larger than thirteen inches.

Based on our two tire size options of ten and thirteen inches, it was necessary to determine which was going to benefit the team and car more. There are many considerations to be made. Choosing one over the other is a tradeoff and there are many compromises that are made. To assist in making this design choice, a decision matrix was created.

![Designing the wheel size selection matrix](image)

The decision matrix has two parts; one which assigns a weighting factor to each consideration, and another which assigns the value for the ten and thirteen inch tire, in each consideration.

The consideration categories were based on factors deemed important to the size of the wheel and tire. They were:

1. **Mass Moment of Inertia** – The rotating mass of different tire sizes varies and affects dynamic performance.
2. **Tire Data** – Using information from the Tire Consortium is critical to selecting the optimal tire.
3. **Tire Availability** – As we are limited to using what is available for purchase, the selection matters.

4. **Upright Packaging** – Different size wheels dictate how much room there is to place components such as uprights and brake rotors inside of them.

5. **Chassis Impact** – The tire size ultimately affects the positioning and packaging of the rest of the chassis.

6. **Wheel Availability** – Less important than tire availability since making a wheel is much easier than making a tire, but this is still a consideration.

7. **Cost** – The budget is limited for this project and it does play a role in the decision.

8. **Mass Effect** – This is how the larger mass moment of inertia affects the car with respect to acceleration and braking.

9. **Mass Addition** – This is the total mass difference of the tire and wheel package.

<table>
<thead>
<tr>
<th>Category</th>
<th>Moment of Inertia</th>
<th>Tire Data</th>
<th>Tire Availability</th>
<th>Upright Packaging</th>
<th>Chassis Impact</th>
<th>Wheel Availability</th>
<th>Cost</th>
<th>Mass Effect</th>
<th>Mass Addition</th>
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<td>1</td>
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<td>1</td>
<td>x</td>
<td>8</td>
<td>22.22</td>
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In creating the weight matrix, one looks at a row, and goes across determining whether the item in the row is more important than the item in the column. If the row item is more important, a “1” is assigned and conversely, if the column item is determined to be more important a “0” is assigned. By adding up the row and then summing all of the row totals, a weighting factor can be determined. After determining these weighting values they can be plugged into a decision matrix which compares the ten and thirteen inch options. The decision matrix (see Table 2) takes into account the weighting factor and also the value determined to distribute. For example, in the mass addition category, a thirteen inch package was determined to be 1.5 times as heavy as ten inch. All of the values were obtained using a method that was as objective as possible.

Table 2: Wheel size selection decision matrix

<table>
<thead>
<tr>
<th>Category</th>
<th>Weight (%)</th>
<th>13 inch Unweighted</th>
<th>13 inch Weighted</th>
<th>10 inch Unweighted</th>
<th>10 inch Weighted</th>
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<td>Moment of Inertia</td>
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<td>4</td>
<td>44.4</td>
<td>6</td>
<td>66.7</td>
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<tr>
<td>Tire Data</td>
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<td>8</td>
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The results from the decision matrix yielded that the thirteen inch choice was 19.5% “better” than the 10 inch. Using these results, a consensus was reached with the team members that a thirteen inch tire/wheel package was the best choice.
Tire Selection

With the decision made to use the 13 inch wheels, the choice on which tires to use was almost made for us. The only tire available in the 13 x 6 inch size is the Hoosier 43128 FSAE Slick (and corresponding rain tire). Although Avon does produce a 13 inch tire, these are only available in Europe, thus making economical use of them unlikely due to shipping costs. Within the FSAE competition, being limited to one tire is not a bad thing. By having the tire chosen, focus could be put on analyzing the tire data available to help optimize the suspension design. With all the tires produced for FSAE cars between Goodyear, Michelin, Hoosier and Avon, they have fairly similar tractive limits but the difference is that the suspensions need to be tuned differently to approach that limit. Factors like Bias Ply tires versus Radial tires have a large effect on the amount of camber desired when running that construction of tire. For example, bias ply tires use less camber than radials. When dealing with tire choices, the team had to keep in mind that far greater gains can be found by choosing a tire and making the car work around it rather than spending a large amount of time analyzing every tire available.

Initial Kinematic Design

Design began with a 2D design in SolidWorks outlining chassis dimensions. Here, constraints could be incorporated from the beginning and ensure that all later designs would comply with rules. The first constraint applied was incorporating the dimensions of the forward template. With the template dimensions and diameter of the chassis tubes included, the minimum pick-up separation would have to be 15 inches or there would be issues with the template clearing the forward tunnel. Each control arm pickup could be no closer to the center line of the chassis than 7.5 inches.

Next, representations of the remaining components of the front suspension were added, including wheels, tires, and control arms. At this point, the iterative tuning process began. With
this simple 2D model, changes can be made to track width, control arm lengths, ride height, instant centers, roll center, wheel camber, and kingpin inclination easily. Data can also be exported to Microsoft Excel to determine how these changes affect chamber gain and roll center migration. To aid in this, construction lines can be added to represent instant center locations, with an intersection for the roll center. An example of this preliminary design is shown in Figure 4.

![Figure 4: 2D Kinematic model of 2009 FSAE race car front suspension](image)

With this model there is complete control over making adjustments to optimize roll center location, migration, and camber curves as well as their effects on roll rate and lateral load distribution. When making changes to different dimensions, it was important to keep in mind compromises that take place. For example, increasing track width can help reduce lateral load transfer; however it will also make navigation through the narrow autocross course more difficult. Raising the roll center location can decrease the lever arm that the rolling moment applies to the vehicle; however, raising the roll center will also increase jacking forces. A calculated medium needs to be found for everything. We started the front suspension design by
determining the desired vehicle roll rate. Typical FSAE cars have a roll rate around 0.7 to 1 deg/g. The equation for vehicle roll rate is shown below:

\[ K_{\phi} = \frac{\pi(t_f^2)(K_w^2)}{180(2*K_w)} \]

- \( K_{\phi} \) = Roll Rate (Nm/Deg)
- \( K_w \) = Wheel Rate (N/m)
- \( t_f \) = Track Width (m)

Given this equation, it can be seen that roll rate can be manipulated through changing the roll center to center of gravity (CG) distance. This can be influenced by changing the stationary angle of the control arms to change the vertical location of the instant centers and thus the roll center height. Although the roll rate would be effected by the incorporation of some form of anti-roll bar, that factor was left out of the equation at first, allowing the roll bar to be added later for fine tuning of the roll rate. Anti-roll bars will be discussed later in this chapter.

Vehicle roll rate was largely affected by the design of the rear swing arm and chassis. Unlike most cars with rear short long arm (SLA) suspension (also called double wishbone), the rear roll rate is determined by the torsional stiffness of the chassis and the rear swing arm. A Finite Element Analysis (FEA) analysis program, CosmosWorks, was used to determine the torsional stiffness of the rear assembly. Given the general design of this system, it had an unavoidably higher roll rate than a typical SLA suspension. This was mitigated, though, by the chassis design which had a lower torsional stiffness in the rear than in the front.

At this point, the design was checked to make sure it complied with all FSAE rules; mainly that ground clearance was maintained throughout the 1 inch of bump and 1 inch of rebound travel. It is also worth checking that the roll center does not cross the ground plane.
throughout this travel as this changes the way the vehicle will roll when cornering. If the roll center changes planes during driving, it can lead to unsettling handling characteristics.

With the desired roll rate determined, and dimensions iterated to meet these specifications, the springs and dampers were then considered. The important factor to keep in mind when determining the kinematics of the damper assembly is the motion ratio. This is the ratio of vertical wheel travel to damper compression, i.e. if the wheel bumps up 0.5 inches and this causes the damper to compress 0.375 inches then the motion ratio is 0.75. The motion ratio does not need to be linear. Rising rate motion ratios are commonly designed since the increasing rate will help prevent the suspension from bottoming out. The equation for motion ratio is given below:

\[ M_r = \Delta H / \Delta S \]

\[ M_r = \text{Motion Ratio} \]

\[ \Delta H = \text{Change in Wheel height} \]

\[ \Delta S = \text{Change in Spring Length} \]

Original designs incorporated an outboard mounted damper tied directly inline between the lower control arm and chassis. This design was considered due its simplicity, reduction in number of parts that needed to be made, and conceptual similarity to many common consumer production cars. This design also incorporated a custom shock with 1 inch of total travel. This was necessary since the motion ratio of this design was 0.42. When the manufacturer fell through on their production, a new design was needed since another damper could not be found that had the desired adjustment features.
This second design incorporated a more traditional formula car rocker arm system. The rocker arm is a linkage that provides different length lever arms between the suspension assembly and the damper. A typical rocker arm design is pictured in Figure 5.

![Figure 5: Typical rocker arm design](image)

When determining the kinematics of the rocker arm, an increasing motion ratio was incorporated, averaging a motion ratio of 0.85. This was done to allow effective use of the Cane Creek FSAE modified dampers obtained from the 2008 FSAE team. The ratio increased from 0.8 to 0.9 through the suspension travel. The 2D design of this system is shown in Figure 6.
Finally, the steering system can be added to the model. From this 2D perspective, the factor to be optimized is bump steer. This is when bump and rebound suspension travel changes the angle of the wheel even though the steering wheel angle is not being changed. This is caused by the instant center of the control arms not being matched to the instant center of the tie rod. As such, when the wheel travels up and down the tie rod will essentially protrude or retract in relation to the upright, causing the wheel angle to change. The best way to prevent this is to draw a line from the instant center on one side to the desired tie rod pickup point on the other wheel and have the tie rod lie along this line. Although the instant center of the tie rod will not match
up with the instant center of the control arms throughout the entire range of suspension travel, it will be close enough to limit bump steer to under a tenth of a degree.

**Kinematic Design Optimization and Packaging**

Using SolidWorks, transitioning from a 2D model to 3D is not difficult. With the 2D model previously discussed nearing an optimized state, it was now time to convert this to a 3D model. This is necessary not only to start designing the actual parts for manufacturing, but also to make sure that there are no packaging issues between any components. For example, in the 2D model, the tie rod and damper push rod essentially pass through each other. When developing the 3D model it is important to make sure there is no interference between these parts while still maintaining the optimized geometry that had already been developed. Sometimes, this may not be possible and compromises may need to be made.

Development of the 3D model allows for many aspects of the final design to be tackled; first being methods of interaction. In the 2D model, every time one component coupled with another, it simply consisted of a point. With the 3D model, a joint type needs to be determined. Although there are many different methodologies that can be used to determine how components to, an axiomatic design process was used for the team's application. For the front suspension, emphasis was put on independence and decoupling, since adjustment is needed in the suspension for factors such as camber, caster and toe. The method of adjustment is typically contained within the connection between various components, i.e. Heim joints on the ends of control arms to adjust camber. The important factor to remember here though is that depending on how the adjustment method is designed, it may end up changing more than one suspension parameter when adjusted. In Figure 7, a control arm design that uses Heim joints on the ends of the control arms to adjust both caster and camber.
The problem here is that it adjusts both at the same time, while also putting stress on the control arm members during adjustment. This is a coupled design since multiple functional requirements are controlled by one design parameter. As such, when designing the front suspension for this year, it was decided that all suspension parameters would be decoupled.

Adjustment for camber is controlled by a one piece offset plate. Two of these are incorporated into each upper control arm pickup. By changing the location of the hole in the plate, the distance the upper control arm pivots from the chassis can be adjusted, in turn adjusting camber. Although this has a slight effect on roll center location and migration, analysis was performed using an updated version of the 2D model and it was determined that the changes that took place were not significant enough to have an effect on the handling of the vehicle. This plate system is shown in Figure 8.
Adjustment for Ackermann angle used the exact same type of plate design. Here, an adjustment path was made collinear to the tie rod when at parallel steer. This system is shown below as an attachment to the upright in Figure 9.

The system for adjusting caster in a decoupled manner was slightly more complex. This required adjustment in both the upright and in the upper control arm pickups on the chassis. Instead of adjusting caster like on many production cars, where one end of a control arm is essentially wedged out at an angle compared to the other control arm, creating a difference in the longitudinal location of the ball joint, the 2009 car's system moves the entire upper control arm
longitudinally in relation to the rest of the suspension. This incorporates both the offset plates described before as well as spacers that control the longitudinal location of the control arm within the control arm pickup. By changing the plate in the upright and the spacers in the pickups, you can change the location of the steering axis without affecting any of the other suspension parameters. This system is shown below in Figure 10.

![Figure 10: Upright and chassis caster adjustment (respectively) on the 2009 FSAE car](image)

With the incorporation of the bell crank, room is left for a number of points for optional adjustment. The primary means of adjustment desired from this system was decoupling stationary shock travel location from ride height. This means that you can adjust how much the shock is compressed when at ride height, thereby changing the available ratio of bump and rebound travel. With 2.2 inches of damper travel available, this can be allocated to either bump or rebound. This is performed by lengthening the push rod going from the lower control arm to the bell crank and raising the spring on the damper, thus keeping the spring at the same preload.

Furthermore, the bell crank design used allows for adjustment of the amount that the motion ratio increases over travel. Since the transmission angle changes throughout suspension travel when changing the angle that the bell crank is at ride height, the section of the total range
being used can be changed. Figure 11 shows the total available range with the red lines indicating the length of section to be used at any one time.

![Motion ratio through Bell Crank Travel](image1)

*Figure 11: Total bell crank motion ratio with available used motion ratio indicated*

Lastly ride height can be changed independently. Due to the fact that an extension was needed for the damper, this allowed for the length of the damper shaft after the spring perch to be changed, thereby raising or lowering ride height. This part is shown in Figure 12.

![Shock extension on the 2009 FSAE racecar](image2)

*Figure 12: Shock extension on the 2009 FSAE racecar*
The only compromise in packaging the front suspension was with the orientation of the dampers. Ideally, the bell crank would be mounted so that all forces were on a single plane instead of multiple planes which would create moments on the bell crank. This scenario was necessary since the chassis and control arms had already been made. Had this criterion not been in place, a push rod system would have been used, locating the shock horizontally near the upper control arm mounts, thereby lowering the CG of the assembly and keeping all the forces in a single plane.

**Load Calculations**
In order to determine appropriate dimensions and materials for components to be used, we first needed to determine the forces they would be loaded under. Milliken's Race Car Vehicle Dynamics book contains both equations and methods to aid in calculating these loads. With this information, a MathCAD file was created allowing easy reference for forces in the uprights, control arms, and pick-ups under braking, acceleration and cornering. The scenarios used were 1.5 g lateral and 2.0 g longitudinal braking along with a "worst case scenario" 2.0 g bump where it was assumed that the entire vehicle was lifted by one corner. This provided the information necessary to perform FEA of all suspension components. Stresses and buckling loads could then be calculated. These loads and calculations can be found in Appendix K.

**Structural Design**
As this is a design competition and not an assembly competition, everything that goes into the car should be properly tested and analyzed before it is ever manufactured into a tangible form. To aid in this, the SolidWorks program comes with an FEA add-on, CosmosWorks. CosmosWorks makes FEA analysis of parts and assemblies extremely simple. The main components being dealt with in the front end are the control arms. Since these are the parts that connect the wheel to the chassis, they are critical to performance and safety. Beyond that, flexing
of the control arms will change the intended geometry of the suspension and cause it to act differently from intended. Therefore, both Factor of Safety (FOS) and deflection were of concern.

When designing the control arms, one of the first aspects considered is the included angle between each of the arms. From a loading perspective, having a 90° angle is ideal since this minimizes the buckling load on the arm. Figure 13 demonstrates how the wider angle can prevent failure. Under FEA, wide angle control arms were found to have a FOS of 2.88 while the narrow control arm had a FOS of 2.44. Unfortunately this is not always possible from a packaging standpoint since, depending on the desired track width, this could cause the pick-ups to be too far apart to fit onto the chassis. With geometry and loads determined, the tube diameter and wall thickness needed to be chosen. Since tubing only comes in certain sizes, it is unlikely that the desired Factor of Safety (FOS) will be exactly achieved. Control arms with larger outer diameters and thin walls can be advantageous since they will be less likely to buckle, however the larger outside diameter (OD) can lead to packaging issues. This choice came down to some compromise between, FOS, buckling, weight, and packaging. For the car’s suspension, this came out to 0.625 inch OD with a 0.049 inch wall thickness (from here on out written as x.xxx inch x.xxx inch wall) for the lower control arms and 0.5 inch 0.049 inch wall for the upper control arms.
Pick-ups for the control arms for the suspension were somewhat more complicated than many other teams due to the means of adjustments that were incorporated in to them. Here, fixturing and welding were just as important as FOS of weight reduction. For this reason, simple box tubing was used. This can be easily machined for the desired hole locations and then notched to fit the chassis. Just as important though is the accuracy with which it is attached to the chassis. A means of fixturing is needed to insure that the pickups for each of the control arms have their pivots on the same axis. If this is not done, the control arm may not be able to travel through the full range of motion needed. The fixture used on this year’s pick-ups is shown in Figure 14.
The most difficult part on this year’s suspension to design properly was the bell crank. This is due to the multi-planar forces acting upon it, which cause moments. Many well designed bell cranks feature a one piece aluminum structure that is typically CNC machined. These tend to work quite well given the precise control over geometry and lightweight design, however no functional design could be found to withstand the multi-planar forces and still stay within packaging constraints. Given this, a steel design was pursued. When using steel, most designs featured two plates with all connections fitted between the two, placing them in double shear. Given multiple axes being dealt with in this design, a slightly different approach would be needed. Since the damper shaft was off axis from the rest of the bell crank, this joint was placed in between the two plates, slightly off center to help minimize the moment. Although this design does put the push rod into single shear, the grade 5 hardware required by FSAE rulings to be used in all suspension components is strong enough to withstand the bending forces being applied. This final design is shown previously in Figure 12 (x being the figure that shows the shock extension piece i.e. the small aluminum rod that extends the damper shaft).
With all parts optimized in FEA, it is important to make sure that there are still no packaging issues. Ideally, a full model should be maintained in order to allow easy replacement with updated parts to make sure interference and range of motion are not affected.

**Anti-Roll Bars**

The rear axle acts as a large anti-roll bar. The car’s rear roll stiffness is based on swing arm and chassis stiffness. FEA analysis was performed on these parts with a resultant torsional stiffness of 1009 Nm/deg (compared to 275 Nm/deg in the front). This should theoretically be our rear roll rate. Given this, the front anti-roll bar will be used to adjust yaw stability rather than reduce body roll.

**Uprights**

Design of the uprights was done as part of a graduate student project, separate from the MQP. The uprights were made from 7075 aluminum and were analyzed using the loading scenario in Appendix K.

The uprights were the most complex machined components on the 2009 car. Because of their complexity, each upright required six setups to complete. While not ideal from a machining standpoint, this allowed the uprights to be lightweight while still having the strength necessary to take the loading on the front suspension.

Another difficulty with machining the uprights was the featuring required in each setup. During some operations, multiple vises had to be used to support the unique shape of the part, requiring additional setup time. Many of the smaller pockets on the uprights required end mills with small diameters to be used which increased the machining time because the smaller end mills remove material at a slower rate than larger ones. Also, the complexity of the part required extensive programming time.
Despite these drawbacks, the uprights were effectively machined in the Manufacturing Labs, and would easily scale to production. Saving time was a major concern when manufacturing the prototype uprights. Designing a fixture for the uprights was not advantageous for the team, but in a production environment it would allow these components to be quickly manufactured without the previously mentioned difficulties. Figure 15 shows a screenshot from SURFCAM, and displays the intricate tool path for one part setup for the uprights.

**Figure 15: Tool path for one part setup for the uprights**

**Front Hubs**

The front wheel hubs for the 2009 car were designed as a graduate student project. Key design factors were strength, resistance to fatigue, and fitment within the front wheels. They are made of 6061-T6 aluminum and mount to hardened steel spindles with tapered roller bearings. The loading scenarios for the hubs are presented in appendix K.
Swing Arm Rear End

In the designing the rear suspension, there were several different types that played into the decision process. Initial design ideas stated that the car needed to be lightweight and simple. The rear suspension of the car could have been a traditional double A-arm set-up which, although proven to work well, had several drawbacks. Double A-arm suspensions require six points of pivot to be fixed to the chassis, per side. One point of pivot for each leg of each A-arm, a pivot for the toe link, and pivot for the shock; a total of twelve for both sides. To add to the complexity, two constant velocity joints mounted to each half-shaft must allow for vertical displacement between the fixed center section and the wheel. All of these components combine to create a heavy, complex, and potentially expensive suspension.

A unique solution, among FSAE teams, is a system that imitates what is commonly found on dirt bikes, road motorcycles, and all terrain vehicles; a swing-arm. A swing-arm pivots about one axis and, in terms of the kinematics, completely locks the left and right wheel together. Both wheels pivot in unison about an axis parallel to the rear roll hoop and the ground. A swing arm system can utilize one or more shocks, and in the design of this car, dual shocks were selected for packaging and strength reasons. Combining these two swing arm pivots and two shock pivots, there are a total of four pivot points that need to be rigidly fixed to the chassis; a \( \frac{3}{5} \) reduction compared to a conventional double A-arm. Additionally, the swing arm design allows the space frame chassis to end much closer to the rear roll hoop since all four pivots are located fore of the tires. Furthermore, a swing arm design eliminates the need for constant velocity joints.

A swing-arm may seem like the obvious winner given these advantages but there are several limitations and downfalls. A swing arm design does not allow the use of a differential, that is, both wheels are coupled in rotation. The swing arm also does not allow changes to be
made in toe, camber, or roll stiffness. Toe and camber are both fixed at 0°, and roll stiffness is close to infinite. Moreover, the amount of un-sprung weight on the rear tires is exceptionally high in comparison with a double A-arm. The downsides are not to be taken lightly and likely play a large part in their limited use in FSAE.

The third suspension system that was considered was a four link. Four link suspension systems are commonly used in off-road vehicles and purpose built drag cars. They allow for easy adjustments for anti-squat and motion ratios. The downside to a four-link suspension system is that the complexity in designing a custom one did not appeal to the team, and did not coincide with the ultimate goal of a simple car. Additionally, the amount of moving parts increases. The number of total pivot points increases up to 16, with as many as 8 being fixed at the chassis, depending on the configuration.

The swing arm system went ahead with design and there were several key components that played into the finished product. The location of the front suspension, relative to the chassis was already chosen and having a goal of a 60 inch wheelbase, it defined the location of the rear axle. Anything larger than 60 inches would increase the amount of steering angle necessary to negotiate a turn of a given radius. The location of the driven CVT sheave was defined by an arc centered at the output shaft of the engine. The distance between the two was fixed by the manufacturer and has to be between 10.51 - 10.63 inches, a window of 0.12 inches. With the axis of the front sprocket common to the axis of the driven sheave, enough of the parameters were at least partially defined to begin with design.

**Swing Arm Design**

The swing arm that was going to be used on the car needed to allow for at least one inch of bump (compression) and one inch of rebound (extension), as per FSAE rules. This swing arm also needed to house the 1.75 inch diameter splined axle, and the bearings which came with it.
The other design consideration not mentioned so far, is the chain tension across the sprockets. The location of the front and rear sprocket were both partially fixed and the amount of drive reduction necessary was also defined by the drive train design process. The tension in the chain played a part in the kinematics as it could work to either compress or extend the suspension. The pivot of the swing arm, the size of the sprockets, and the location of the front sprocket on the arc centered on the output shaft of the engine all had to be defined through the design process.

To take all of these factors into account at the same time required many iterations and a comparison between them to be made. Ultimately, anti-squat values, change in chain length, change in anti-squat values, and motion ratio were major players in the decision.

**Anti-squat Calculation**

Values of anti-squat can be determined by constructing two lines, and comparing the included angle relative to the ground of these two lines. Line one, called the weight transfer angle ($\tau$), is formed by two points. One point at the contact patch of the rear tire, the second point located vertically over the front tire contact patch, at the same height as the center of gravity of the vehicle. Line two, called the chain pull angle ($\sigma$), is again formed by two points. Point one is at the contact patch of the rear tire. Point two is at the intersection of a line drawn collinear with topside of the chain and a line drawn through the rear axle, and swing arm pivot. See Figure 16.
The aforementioned method to determine values of anti-squat for a given geometry was employed in the design of the swing arm. The method applies to the car’s swing arm just as it does to the motorcycle swing arm because, in side view, the kinematics are the same with only slightly different dimensions.

The same sketch as above was created using the known geometry of the axle position, and sprocket locations, as shown in Figure 17.
In Figure 17, the construction lines $\tau$ and $\sigma$ can be seen. The weight transfer angle, $\tau$, is the longer line extending to the front of the car. The chain pull angle, $\sigma$, and the shorter line also originating at the contact patch. As shown, the chain pull angle is larger than the weight transfer angle. The physical meaning of this is that under forward acceleration, the force working to extend the suspension is greater than the added weight transfer to the rear that would otherwise cause the suspension to compress.

The equation for $\%$ anti-squat is given by (Cocco, 1999):

$$\% \text{antisquat} = \frac{\sigma}{\tau} \times 100$$

Over the given range of suspension travel, the anti-squat values stay fairly consistent with a range of 104% to 111%, from full compression to full extension, respectively. These greater than 100% values mean that the suspension will extend slightly under acceleration. This action of the suspension acts to push the rear axle into the ground and is employed to enhance traction (Cocco, 1999). These desired values of anti-squat were obtained by moving the location of the swing arm pivot and also by changing the sizes of the sprockets until they yielded good numbers. The drive train and the rear suspension kinematics were developed concurrently, as their design and effects were heavily interleaved with each other.

**Rear End Stress Analysis**

To analyze the rear sing-arm assembly, finite element analysis was used. Two FEA suites were used, both CosmosWorks and Abaqus. Each suite has its advantages and disadvantages:

- **CosmosWorks**

  CosmosWorks is integrated into SolidWorks, and is just as intuitive and user-friendly as the rest of SolidWorks. The user is not given many advanced options as far as mesh size and type, or constraints. CosmosWorks also tends to suggest very high stress concentrations, but it produces
results very quickly, possibly this is due to the software not making as many iterations as other FEA packages. In order to design a part, the user can make a preliminary design, create a load study in CosmosWorks, and update the part to reflect the stress concentrations and safety factor. The user can then quickly go back to CosmosWorks, and rerun the study with a few clicks. This quick and seamless integration allows for multiple design iterations in a short time frame, possibly leading to faster designs. CosmosWorks, as part of SolidWorks, accepts value with units and converts them internally. In SolidWorks, a user can specify one dimension of a part in inches and another in millimeters, and the program will automatically dimension the part correctly without the user having to make conversions. Similarly, CosmosWorks is able to take forces in English or SI units, and convert them internally. This makes it very easy to work with.

- **Abaqus**

  Abaqus is a standalone FEA suite designed for more complex and advanced modeling. Its interface is complex, and the user is presented with many options and great control over the behavior of the software. Although the user is able to create parts within Abaqus using its own modeling program, it is also able to accept parts made in other programs in IGES or STEP format. The team felt that the SolidWorks modeling program is easier and more flexible, so parts analyzed in Abaqus were imported from SolidWorks. Abaqus is very flexible in constraining parts, and spherical bearings and snap-rings were readily simulated. In CosmosWorks, these constraints were impossible or cumbersome to simulate. The user is given control over mesh type (shape), seeded faces, and mesh density (although the academic license of Abaqus used by the team was limited to 100,000 nodes, which was sufficient). Abaqus requires the user to define the material’s properties, rather than simply choosing from a library of predefined materials like in CosmosWorks. It is also important to note that Abaqus is unit-less: the user would input a
Young’s Modulus of 40,000,000 psi as simply 4e7. This makes Abaqus more difficult to use if mixed units have been used in the design and requires more attention to detail from the user. However, it yields extremely accurate results, and its flexibility allows for complex loading scenarios to be simulated.

Important to note in the design of the rear end are the loading scenarios used. In preliminary design, loads under acceleration, braking, cornering, and bump were analyzed. However, it quickly became apparent that the rear end would be under the most stress during cornering. Increasing strength to account for cornering loads would more than satisfy the strength requirements for other scenarios. For this reason, early design iterations were performed with CosmosWorks, and later, only cornering loads were analyzed with Abaqus. Additionally, since many of the parts were cut with a water jet which can leave a poor finish and has loose tolerances, and because the assembly was to be welded with a dissimilar filler material (4000 series aluminum) a safety factor of at least 2 was selected. Much of the wall thicknesses of the parts were also selected to allow for easy welding.

For early design and analysis of bump loads, CosmosWorks was used. One benefit of CosmosWorks is that it calculates available Von Mises stresses, reducing the work that the user must do. The rear end in a 2 g bump, analyzed with CosmosWorks is shown in Figure 18.
A lateral load of 900 lbf, calculated using a lateral acceleration of 1.5 g’s and a vehicle/driver weight of 600 lb, was used as the load in the lateral acceleration. This is shown in Figure 19. For the lateral load, a maximum Von Mises Stress of 3,739 psi is shown. The Von Mises yield stress of 6061-T6 aluminum is 7,999 psi, yielding a safety factor of approximately 2.1 (Solidworks Corporation, 2008).
Rear suspension mounting clevises

The rear end is mounted to the chassis with two clevises. These clamp around two spherical bearings secured inside the rear end with shoulders and snap rings. Kinematically, it would have been possible to use needle bearings or another type which provides only one degree of freedom. However, by using spherical bearings, alignment is not as critical, allowing for easier construction. Additionally, twisting in the rear end would load the bearings, which could lead to them wearing out quickly. In order to attach the rear end to the chassis, a special clevis is used. It is manufactured from folded sheet 0.063 inch 4130 sheet metal. When making folded sheet metal parts, positioning of the bend is very difficult. In a production environment, it is easier to make accurate bends than with a smaller sheet metal brake. It is recommended that, if these clevises were made again, they be made from 6 water-jet cut pieces with no bends. The accuracy of the water jet is much greater than the accuracy of a sheet metal brake. More welding
is required, but the part will be more accurate. The clevises are analyzed in the same way that the rear end is analyzed, with the same forces, in Abaqus.

**Retaining Rings**

Retaining rings, also known as circlips, or snap rings are a device used to capture a cylindrical object. For the purposes of building the FSAE car, retaining rings have been used to hold bearings within housings. Recommendations from Rotor Clip, and Machinery’s Handbook indicate that an edge margin of three or more times the groove width will allow the ring to provide full strength (Oberg, Jones, Horton, & Ryffel, 2004). And edge margin less than that will reduce the strength and requires analysis to see how much of a reduction is caused. A hand calculation can be used to determine the maximum axial load that the ring & groove will be able to support (Rotor Clip, 2009).

For the swing arm on the car, there are two retaining rings that hold the axle bearings on the side plates. The edge margin is approximately the same thickness as the rings and the calculations were done to see how much strength was lost. The 80 mm rings from Rotor Clip (#DHO-80) are rated for an axial load of 27,000 pounds, each. The reduced axial load rating with a FOS of 1.6 is approximately 3000 pounds. That 3000 pound force is considerably less than the loading values used in the analysis of the swing arm and these edge margins are deemed safe. For complete formulae and calculations, see Appendix D.
Chassis

Chassis Design Considerations

Design of the 2009 WPI Formula SAE racecar began with the frame. There are several factors that must be considered when designing the frame.

- **Stiffness**

  Normally, a racecar chassis should be as stiff as possible torsionally. This is to facilitate easier suspension tuning. When determining the handling qualities of a racecar, one of the most effective methods of adjusting the amount of oversteer and understeer is the adjustment of roll stiffness front-to-rear. By increasing front roll stiffness while decreasing rear roll stiffness, both rear tires are more equally weighted than the front tires. The force on the outside front tire quickly overwhelms the traction available to it, and the car understeers. Conversely, with a large amount of rear roll stiffness and a small amount of front roll stiffness, the inside rear tire is lifted during a turn, the amount of available rear traction is reduced, and the car oversteers. By tuning the stiffness of the anti-roll bars, it is possible to affect the balance of the car. However, torsional flex in the frame adds another spring to this two-spring system. This makes tuning much more difficult, and in extreme cases, impossible.

  It is important to note, however, that the 2009 WPI Formula SAE racecar uses a swing-arm style fully dependent rear suspension. Kinematically, the rear roll stiffness is infinite. For this reason, frame stiffness is not important in the same way as on a fully independent car. Some torsional compliance in the frame is actually desirable with this year’s suspension design.

- **Weight**

  As discussed earlier, wherever possible, weight should be minimized. All tubing sizes not dictated by the rules were chosen to be as light as possible while remaining structurally sound and suitably stiff. Just as important as weight is mass moment of inertia. A car with a lower mass
moment of inertia will be able to turn more quickly. In order to reduce mass moment of inertia, all weight on the chassis is pushed as far as possible towards the center of the vehicle.

- **Fitment and Packaging**

  Possibly the most difficult criterion to satisfy is fitment. This criterion determines the functionality of the chassis. The chassis must accommodate the driver, as well as the engine, suspension components, and templates while remaining as light and small as possible. While a problem with structural integrity or stiffness can usually be solved by simply varying the wall thickness or diameter of a tube, the challenge of fitting all components into the smallest space possible rarely has clear or straightforward solutions. Multiple iterations and brainstorming sessions are usually required for fitment problems.

**Chassis Construction Methods**

The team had several choices for construction methods for the frame:

- **Tubular spaceframe**

  The most common frame type, the tubular spaceframe, is a structure composed of many small, usually round tubes bent to shape and welded together. Tubular spaceframes do not require specialized machinery or equipment for manufacture, and they are inexpensive and can be constructed from a wide variety of readily available materials. The Formula SAE rules dictate many of the tubing sizes for a steel tubular spaceframe, and construction of any other type of chassis requires proof that the alternate structure is as strong or stronger than a similar tubular spaceframe structure.

- **Metal Monocoque**

  A monocoque chassis is a structure that constitutes both the frame and the body. By combining these two critical components into one piece, it is sometimes possible to build a light
car. In a metal monocoque design, the chassis and body are fabricated from aluminum or steel sheet, welded or riveted together.

- **Composite Monocoque**

  Composite monocoque frames are usually among the lightest. The strength to weight and stiffness to weight ratios of carbon fiber and similar composite materials are generally much higher than those of steel or aluminum, and the non-uniform nature of a molded frame allows for a great deal of optimization. However, composite monocoques usually require a unique mold for production, and a design change generally requires a new mold to be made. Composite monocoques are rarely easily repairable, and the materials required for their construction are expensive and often difficult to work with.

**Chassis Material Considerations**

The 2009 team decided to use a tubular spaceframe due to cost, ease of construction, and facilities available. Additionally, no extra analysis is required for Structural Equivalency Forms, which affords the team extra time for further analysis and testing. Because the chassis is a tubular spaceframe design, the materials used in its construction were limited to readily available, easily weldable materials. In the interest of simplicity, it was decided that all tube members would be made from the same type of material. The following materials were considered:

- **Steel**

  The most common material for tubular spaceframes, steel retains its strength and ductility after welding. It is inexpensive, easy to find, and easy to cut and grind. The Formula SAE rules dictate tubing sizes for steel, and the use of any other material requires the completion of a structural equivalency form.
• **Aluminum**

Aluminum, while not as strong as steel, is lighter. Its stiffness is roughly one third that of steel; however, so is its weight. It can be welded with common TIG and MIG processes; however, it loses significant strength unless heat treated. When used on a tubular spaceframe chassis, it must be accompanied by a structural equivalency form. Additionally, the main and front hoops must be made from steel.

For ease of construction, the chassis is made from steel. In order to determine the type of steel to be used, further analysis is necessary. In the interest of safety, the Formula SAE rules dictate most of the tubing sizes used. The chassis can be broken up into three bulkhead-style planes and two tubular sections that connect them. Starting from the front of the chassis and working back, these sections are:

• **Front Bulkhead**

The front bulkhead, as defined by the FSAE rules, is “a planar structure that defines the forward plane of the Major Structure of the Frame and functions to provide protection for the driver’s feet” (SAE International, 2008). The front bulkhead is to be made from 1.0 inch diameter 0.065 inch wall thickness steel. On the 2009 car, the front bulkhead is simply a rectangular structure which is 12 inches tall by 11 inches wide, measured at the tubing centerline. The joints are mitered at 45 degrees for easy welding. The size and shape of the front bulkhead are determined by ease of construction and in order to give the driver ample foot room, as well as the ability to easily accommodate the template, seen in Figure 22, for the front of the chassis. This template must be passed through the driver’s foot and leg compartment to a point 4 inches rearward of the rear most pedal adjusted to its forward most position.
• **Front Roll Hoop**

According to the 2009 FSAE Rules, the front roll hoop is “a roll bar located above the driver’s legs, in proximity to the steering wheel.” The front roll hoop is to be made from 1.0 inch diameter 0.095 inch wall thickness steel. The front roll hoop is probably the most complex tube on the 2009 car, as it has five bends, two of which are not coplanar with the other three. The difficulty in making bends which are not coplanar stems from the necessity to not only
position the bend correctly and bend to the correct angle, but to measure and position the tube so that the bend will be oriented correctly. The front roll hoop must be able to accommodate both of the templates, as well as position the pick-up points of the front suspension members. In addition, it must be tall enough to allow drivers to fit into the chassis while passing the “2-inch rule,” which states that a line drawn from the top of the main hoop to the top of the front hoop must be at least 2 inches from the top of any seated driver’s helmet.

![2 inch rule for helmet clearance](image)

**Figure 23:** “2 inch rule” for helmet clearance

- **Front Bulkhead Support System and Front Hoop Supports**

  This is the structure which connects the front hoop and front bulkhead. The rules state that the front bulkhead support system must be made from 1.0 inch diameter 0.049 inch wall thickness steel tubing properly triangulated node-to-node (no tubes in bending). Additionally, the
front hoop must be supported by front hoop supports, integrated securely into the rest of the structure, and made from 1.0 inch diameter 0.065 inch wall thickness steel tubing. These tubing members are shown in Figure 25 and must also support the front suspension attachment points, as well as shock attachments. They must also be placed to accommodate the foot well template.

There were several choices for the front hoop supports. One option was to simply make the upper rear front bulkhead support structure tubes out of 0.065 inch steel and call them the front bulkhead support. This would have been the lightest and simplest option. However, it would have been possible that the driver’s legs or feet would have not been fully contained
within the primary structure of the frame, unless the front bulkhead is made larger. Additionally, under braking and cornering, some of the loads of the front suspension upper control arms would be transferred into tubes which would be loaded purely in bending, as there would be nothing to stop the front bulkhead bending forward when the nodes are pushed in. This would probably not result in plastic deformation of the material; however, it is possible that deflections would be high enough to cause an unacceptable change in suspension geometry.

Another option is to simply run the braces all the way to the front bulkhead. This is heavier than the previous option. However, it allows all forces to be fully resolved without putting any frame members in bending. Additionally, it easily contains the driver’s legs and feet in all situations, and allows for easier mounting of the brake pedal and other hardware.

- **Main Hoop, Main Hoop Bracing, Shoulder Harness Mounting Bar**

  The main hoop is “a roll bar located alongside or just behind the driver’s torso.” The main hoop is to be constructed from 1.0 inch diameter 0.095 inch wall thickness steel, the same material as the front hoop. It is constructed from a single piece, bent to shape. There are five bends, which are all coplanar, facilitating easy manufacturing. The shape of the main hoop is designed to accommodate the templates when attached to the main hoop braces, as well as the side impact members. The main hoop height dimension is only tall enough to facilitate passing the 2-inch rule. The main hoop braces are 1.0 inch diameter 0.065 inch wall thickness tubing, per the rules.

  The main hoop braces can be routed towards the front or back of the chassis, but they must be securely integrated into the primary structure. In most cars, the braces are routed rearwards. If the braces are routed rearwards, they are usually attached to the rear suspension pick-ups in some way, increasing the torsional rigidity of the chassis. However, because of the
solid-axle rear-suspension design, there are no rear suspension points or rear suspension structure into which to run the braces. For this reason, it was decided to run the braces forward, and terminate them at the node where the side impact diagonal members meet. This creates a clear load path, making the chassis stronger. Just as importantly, it reduces the mass moment of inertia of the chassis significantly. Without a rear structure into which to run the main hoop braces, the overall weight and mass moment of inertia of the chassis are significantly reduced.

The shoulder mounting bar is made from 1.0 inch diameter 0.065 inch wall thickness tubing, placed at shoulder height.

- **Side Impact Structure**

  According to the rules, the driver must be protected by a side impact structure, composed of at least three tubes. There must be one upper side impact member, one lower side impact member, and one diagonal side impact member. The diagonal member can be more than one tube if it is properly triangulated, and the lower and upper side impact members can be the upper and lower frame rails if they satisfy the tubing requirements.

![Side Impact Structure Diagram](image)
The team chose to use the upper and lower side impact members as the upper and lower frame rails. The side impact member is composed of two tubes, their intersection forming a node into which the main hoop brace is run. In this way, the side impact structure is fully triangulated. The diagonal side impact member could have been made from a bent tube (see Figure 28) rather than two separate tubes. However, the load paths are not as direct with this, and it is difficult to weld along the outside edge of the bend.

Figure 28: Bent diagonal side impact member from previous FSAE car
Important to note is that the upper side impact member is a bent piece. This allows extra hip room for the driver without increasing the size of the heavy main hoop. There is a small amount of strength lost as opposed to a straight piece. However, since the bend angle is shallow, the design is still valid.

- **Other frame members**

  Some remainder of the chassis members are made from 1.0 inch diameter 0.035 inch wall thickness tubing. This includes the diagonal bracing along the bottom of the chassis, and the auxiliary bracing along from the front hoop to the main hoop brace nodes. The driver’s restraint harness attachment crossmember, per the rules, is made from 1.0 inch diameter 0.065 inch wall thickness tubing, and the analysis in the CosmosWorks FEA suite was used to choose and validate this.

**Structural Analysis**

CosmosWorks was used to validate the structural integrity of the frame. The beam mesh technique was used for analysis. In a beam mesh, all structural members of a tubular structure are approximated as a series of small beams, rather than a mesh of triangles or tetrahedrons. This is
much less processor-intensive and much faster than a solid mesh or shell mesh, though obviously not suited for parts that are not composed of beam-like elements (for example, a machined part could be analyzed with solid mesh, a sheet metal part could be analyzed with a shell mesh, and a tubular spaceframe such as this one could be analyzed with a beam mesh). It is important to note, however, that a beam mesh is incapable of analyzing the effects of welding on tube. Additionally, it only gives results for axial stress, not shear or Von Mises stress.

For most analysis, the rear suspension pick-up nodes were fixed while loads were applied to front suspension nodes. Forces are found at the tires of the chassis through simple Newtonian mechanics using $F = ma$. For this, 2 g of longitudinal acceleration (braking) and 1.5 g of lateral acceleration (cornering) were used to find forces, and a vehicle weight of 600 lbf was used. For all of the equations used in the static calculations, please see Appendix K. For maximum braking, the resulting maximum axial stress on the chassis is 4,655 psi. This is very low when compared to the yield strength of even mild steel; however, this is an idealized, static situation. Additionally, this is during braking only, and does not take into account effects from the weight of the vehicle, or the vehicle hitting a bump during braking. Additionally, the tubing sizes used are mostly dictated by the rules, so significant weight savings are not possible without resorting to very thin tubing, which is very difficult to weld to the thicker tubing used on the front hoop. The real value in using CosmosWorks is in finding the deflections of the chassis points.
Figure 30: FEA beam mesh study during hard braking (displacement)

Figure 31: FEA beam mesh study during hard braking (stress)
Using the same study, deflections can also be displayed. In this case of braking, the maximum deflection amount occurs at the upper front suspension attachment nodes. The deflection in this case is approximately 0.007 inches, which, although probably negligible in suspension geometry changes, is accounted for in calculations. The chassis is more than capable of withstanding any and all loads encountered during normal driving. However, it cannot be made lighter because of the rules and manufacturability.

One of the most important FEA studies done with this car is the torsional rigidity study. In this study, the front suspension pick-up points are fixed and a torque is applied to the rear pick-up points. This will yield the torsional spring rate $k$ of the chassis when calculations are performed using the equation:

$$k = \frac{T}{\theta}$$

where $T$ is the torque applied to the pick-up points and $\theta$ is the angle that the rear of the chassis makes with respect to the front of the chassis. The plot is shown in Figure 32 showing stress. In this case, the maximum stress is 47,000 psi in a worst-case scenario. When a FOS of 1.5 is applied to this stress and compared to the fatigue stresses of various steels at infinite life, it becomes clear that AISI 4130 in condition N is most appropriate for the chassis. This spring rate is added in series with the spring rate of the rear end, yielding the effective rear roll stiffness.
It should be noted that AISI 4130 was selected because this chassis is expected to have high deflections, which imply high stresses. If the chassis were designed for low deflections and high stiffness, mild steel would probably be appropriate, as the elastic modulus of mild steel is almost identical to that of carbon steel, even though their yield and tensile strengths are higher.

**Chassis fabrication**

The 4130 tubular space-frame steel chassis was manufactured using a world coordinate system with its origin located at the center of the base of the main hoop on the tube axis. Using a world coordinate system, all measurements were taken from one point. This decreases the inaccuracies that can occur from measuring locations based on other previously measured locations.
If the chassis was not constructed in this manner the stacking of tolerances would yield grossly inaccurate locations of key points. Another tool employed was the use of 24 inch vernier scale calipers. These calipers are accurate to 0.001 inches. Although measurements were made with this tool, jigged parts can move during welding. The ability to accommodate these manufacturing tolerances needed to be considered when mounting key components to the chassis such as the rear swing arm.

The frame table used for construction was leveled and a centerline was constructed perpendicular to the base of the main hoop. This proved to be a valuable manufacturing method as our critical points, such as suspension pickup nodes, were accurately reproduced based on our CAD model.

The three main sections of the chassis were fixed to the table at their exact positions. The main hoop, front hoop and front bulkhead were the first sections on the table and all other members were fitted between them. Shown in Figure 34 is the fixture used to hold the front bulkhead and front roll hoop in position.
On the top of the fixture there are two shaft collar halves which clamp the tube into the groove cut in the aluminum fixture. These fixtures were extremely rigid and kept the chassis exactly located throughout the fabrication process. The base of the main hoop was fixed to the table with steel plugs that stuck out of each end of the main hoop base tube. These plugs were bolted to the table and can be seen in Figure 34.
Cockpit

The focus for the car’s cockpit was to be comfortable enough for the team’s tallest drivers while adhering to the rules and designing everything to be as light as possible. Each subsystem was designed with each of overarching design objectives in mind.

Steering System

With the location and geometry of the steering rack determined, the steering column and column support could be designed. The steering wheel was to be located in a position that put the driver’s arms at a ninety degree angle at the elbows. However, the 2009 FSAE rules mandate that the steering wheel must not extend above the front hoop in any position, and that the forward-most surface of the steering wheel must not be more than 9.8 inches rearward of the rear-most surface of the front hoop. The cockpit opening template also had to be able to pass with the steering column remove. With these constraints in mind, the steering wheel was positioned approximately in SolidWorks, and then bench tested for driver comfort in the unfinished chassis. The steering wheel was positioned as rearward as possible while remaining within the constraints of the rules so that the angle of the driver’s arms approached ninety degrees. The steering shaft was mounted in a Delrin bushing inside of a machined aluminum hanger, and attached to the frame at two points using 0.625 x 0.049 inch 4130 steel tubing. The steering column support assembly (without steering column) is shown in Figure 35.
The steering column consists of two sections of 0.75 inch OD 4130 steel tubing connected with a universal joint. Because of the location of the column support and the maximum joint angle of thirty five degrees, the universal joint is mounted in the column support and serves as the bearing surface inside the Delrin bushing. The steering wheel is mounted using a splined quick disconnect for ease of entry and exit from the cockpit.

**Braking System**

The braking system for the 2009 FSAE car was designed to be lightweight and compact while still providing adequate stopping power. The braking system had to provide enough braking force to completely lock the wheels at the end of a specified acceleration run, but remain small enough to fit inside of the front wheels and also prove to be cost effective. The braking system was designed by first determining parameters necessary to produce a given deceleration, and comparing to the deceleration that a known braking system would produce.

Certain assumptions about the car had to be made before the necessary calculations could be performed. It was assumed that the car would weigh 600 pounds with driver, and the location of the car’s CG was approximated based on the positions of the engine and driver. Following
this, a basic model of the car was drawn, including the weight of the car, the locations of the center of gravity and axles, and also the distances between these points and ground. A worst case deceleration of 1.5 g was assumed, since the car would not likely be decelerating at a rate faster than this. Using this information, the amount of the car’s weight on both the front and rear set of tires under deceleration could be determined.

This number was then used as the normal force experienced by the tires to determine the necessary friction force required to produce the given deceleration. With the friction force applied by the front and rear tires determined, the next step was to determine the required “brake torque.” Brake torque is simply the amount of torque that the braking system needs to develop in order to produce the given deceleration, shown in the following formula:

\[ \text{Torque}_{\text{brake}} = r_{\text{tire}} * f_{\text{friction}} \]

Brake torque is the product of the radius of the tire and the friction force the tire is providing. With the brake torque necessary at the front and rear wheels determined, the next step is to compare these numbers with the brake torque that will be provided by a given set of brake system components.

A number of variables come into play when choosing components for the braking system. The first step in the design is to choose appropriate values for these variables based on several factors, including what components are currently available from racing supply companies, component size, and driver input.

Since the brake torque at both the front and rear wheels had been determined and the coefficients of friction for various brake pads were known, the clamping force necessary for the front and rear calipers could be determined. The clamping force is the force with which the brake
caliper clamps on the brake rotor. The size of the brake rotor was also chosen based on what was available from vendors.

Manufacturers only make brake calipers with certain piston sizes, so these sizes were used to determine the hydraulic pressure needed to provide the specified clamping force. Working backwards in the system from the caliper, a similar procedure was carried out to size the master cylinder since only several piston sizes were available. Using the hydraulic ratio between the caliper and master cylinder, the amount of force applied to the master cylinder necessary to produce the given line pressure could be determined. Since the pedal ratio, or lever ratio, of the brake pedal was known, the amount of force the driver would need to apply to the brake pedal to produce the given deceleration could be determined. This input force was compared to industry guidelines for driver comfort and also testing carried out to determine the preferences of each team member to determine whether or not the force required was reasonable.

After using this braking system model with many different components, the following parameters were chosen:

**Brake System Specifications**

**Brake System: Front**

Calipers: Wilwood Single Piston 1.75 inch diameter

Master Cylinder: Wilwood Remote Reservoir - Bore: 0.625 inches

Rotor: 7.0 inches

**Pedal Ratio:** 6:1

**Brake System: Rear**

Caliper: Wilwood DynaPro Single Billet. Bore: 1.75 inches

Master Cylinder: Wilwood Remote Master Cylinder - Bore: 0.75 inches

Rotor: Diameter: 7.9 inches
Brake Pedal

The brake pedal is designed with a 6:1 motion ratio, and is designed to be used as a first-class lever. This allows the brake master cylinders to be located further rearward in the car, reducing the chassis length and mass moment of inertia. To determine the loads for the pedal, several team members attempted to push as hard as possible on a scale while in a seated position. It was determined that the maximum force produced in this panic situation was 350 pounds. Because it was a machined part with some welding in a non-critical area, a safety factor of 1.3 was selected. The plot for the stress on the brake pedal is shown in Figure 36.

![Figure 36: FEA study on brake pedal (CosmosWorks)](image)

Body

There are many options for construction of the body, each depending upon the approach of the designers and the goals for the car. In past years there have been various materials used for the body of the race car. Fiberglass has been the most common type of material and last year (2008) the team used carbon fiber. Carbon fiber is expensive, but has a high strength to weight ratio, which is appropriate considering that the 2008 body was designed with aerodynamic
devices. This year, the team took a minimalist approach to the body, and identified these as important features:

- Ease of manufacturing
- Affordability
- Light weight

With fiberglass or carbon fiber, a mold of the part must first be made and shaped. The material chosen for this year’s car was 5052-H32 Aluminum. Often, when fabricating sheet aluminum body work, an English wheel is used to create compound curves and bends, in convex or concave shape. This is time consuming, and when performed on a production scale, is usually done with a sheet metal stamp, which requires a significant investment. However, in the 2009 racecar, all bends are in one dimension. This allows the body to be bent with an inexpensive and commonly available sheet metal brake. The thickness used was .060 inches which was selected to resist denting and to be stiff enough so that fewer body fasteners were needed to keep the body rigid under aerodynamic loads. The front body of the car was fabricated to fit tightly against the chassis and was clearanced to fit the suspension pickups and dampers.
The body was designed using SolidWorks sheet metal shown in Figure 37. With SolidWorks sheet metal the three dimensional part can be unfolded allowing a scale print to be made. With this scale print, shown in Figure 38, the stock material can be cut to exact dimensions and the guide lines for bending from SolidWorks makes it simple to bend the body in the appropriate locations.

Figure 39 shows the manufacturing method used to bend the sheet metal into the desired shape. It should be noted that only straight line bends of a small radius (about 0.125 inches) were
possible with the equipment available so large radius bends were made by breaking the bend into many smaller appropriately spaced bends with the sum of their angles equal the desired bend.

![Figure 39: Aluminum sheet metal cut to size and prepared for bending](image)

The side panels are made in the same way as the front body.

![Figure 40: Side panel model and flattened drawing](image)

The nosecone is manufactured from fiberglass. In a production environment, fiberglass parts are made in several steps. First, a male mold of the desired part is made, often from foam covered in fiberglass and then polished and finished. From this, a female mold is made by coating the male mold in mold release and laying fiberglass over the female mold. The female mold is separated from the male mold, and then more mold release is put on the female mold. Fiberglass and resin are then laid inside the female mold, vacuum-bagged, and allowed to cure.
The vacuum bagging is removed and the fiberglass part is removed from the female mold. The female mold can be used many times. For this car, as a prototype, the nosecone is made by simply laying fiberglass over a foam mold. The foam is carved out and the excess is dissolved with acetone, quickly creating a part. This method is practical for one-off fiberglass parts, but not for production.

**Seat**

The seat in the 2009 Formula SAE racecar is designed to be light, easily removable, and to fit all drivers and templates. It is constructed from 0.060 inch thick 5052-H32 aluminum, which is selected to facilitate easy welding. The shape of the seat is not ergonomic, but a foam insert is made to fit the driver snugly. The shape is designed to fit the 95th percentile male template (Percy) and the driver’s compartment template. An important part of the seat design is that it can be easily removed by unfastening quarter-turn fasteners, which allows easy access to the engine for maintenance. A picture of the seat is shown in Figure 41.
**Impact Attenuator**

In accordance with rules 3.20-3.21.8, all FSAE vehicles wishing to compete must have an energy absorbing impact attenuator mounted to the front of the vehicle. The basic specifications for the impact attenuator are as follows:

**3.20.1** The Impact Attenuator must be:

a. Installed forward of the Front Bulkhead.

b. At least 200 mm (7.8 in) long, with its length oriented along the fore/aft axis of the Frame.

c. At least 100 mm (3.9 in) high and 200 mm (7.8 in) wide for a minimum distance of 200 mm (7.8 in) forward of the Front Bulkhead.

d. Such that it cannot penetrate the Front Bulkhead in the event of an impact.

e. Attached securely and directly to the Front Bulkhead and not by being part of nonstructural bodywork.

In addition, in accordance with rule 3.21.1, the impact attenuator must be able to:

**3.21.1** … [when] mounted on the front of a vehicle with a total mass of 300 kgs (661 lbs) and run into a solid, non-yielding impact barrier with a velocity of impact of 7.0 meters/second (23.0 ft/sec), [will] give an average deceleration of the vehicle not to exceed 20 g, with a peak deceleration less than or equal to 40 g.

**Design Specifications**

Before design of the impact attenuator could begin, a comprehensive list of design specifications had to be formulated that would ensure that it would be in compliance with rules 3.20.1 and 3.21.1. Based on these rules, a table of design specifications was generated which can be seen in table 1.
Given the requirements of stopping a mass of 300 kg traveling at 7 m/s, the total energy absorption needed was calculated using the basic equation:

\[ K_E = \frac{1}{2} m \cdot v^2 \]

In addition, maximum and maximum average forces of deceleration were calculated using the mass and the given accelerations. Finally, assuming the minimum detentions given by rule 3.20.1, maximum and maximum average allowable stress were calculated using \( \sigma = \frac{F}{A} \)

**Material Selection Research**

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<td>Average pressure of impact</td>
<td>2.943 MPa</td>
<td>426 PSI</td>
</tr>
<tr>
<td>Max pressure of impact</td>
<td>5.886 MPa</td>
<td>854 PSI</td>
</tr>
</tbody>
</table>

With the design specifications laid out, the next task was to determine an appropriate material or materials to be used for the construction of the energy absorbing component of the impact attenuator. Research was conducted both through the internet and through engineering texts. Based on the findings of this research, it was determined that a honeycomb structure, either made of aluminum or of a carbon-composite, would be the ideal material from which to construct the impact attenuator, due to its nearly linear crush resistance force versus
displacement, rate independence, and high energy absorption per volume. This idea was corroborated by the fact that the past several WPI FSAE cars had used a honeycomb structure for their impact attenuator. Due to the high expense of carbon-composite honeycomb, and the fact that there was still a large supply of material left over from previous years, aluminum honeycomb was chosen as the primary material for the impact attenuator.

**Testing Methodology and Results**

In order to prove compliance with rule 3.21.1, various tests had to be performed on the impact attenuator. These consisted of an initial small sample test the aluminum honeycomb to determine its material properties, and then a full scale test based on the attenuator design formulated from the material property data generated by the small sample test.

**Small Sample Test**

To determine the material properties of the aluminum honeycomb that was to be used to construct the impact attenuator, a sample was crushed using an Instron 5500R testing device. The Instron 5500R was rated to 50,000 lbf, far above the maximum 26,465 lbf allowed by the rules, ensuring that it would provide a valid test for rules compliance. The Instron outputs data in the form of force vs. displacement. This data was then converted to energy absorbed by calculating the differential energy absorbed between two data points:

\[ \Delta E_n = F_n \cdot (S_n - S_{n-1}) \]

where \( F_n \) is the force at point \( n \), and \( S_n \) is the displacement at point \( n \). Energy absorbed vs. displacement was then calculated by taking the sum of the differential energies up to that point:

\[ E_t = \sum_{0}^{n} \Delta E_n \]

Maximum average and maximum deceleration rules compliance can be check by ensuring that \( F_n \leq F_{max} \) at all points in the force vs. displacement graph, and \( \bar{F}_n \leq F_{average} \). From the energy
absorbed vs. displacement data, volumetric energy absorption \( \frac{J}{\text{in}^3} \) can be easily calculated so long as the dimensions of the sample are known:

\[
E_v = \frac{E_t}{A \cdot T}
\]

where \( A \) is the area of the sample and \( T \) is its thickness. This method of testing the honeycomb was chosen because it was deemed to be far safer and more accurate (due to the improbability of test variation) than doing other dynamic testing such as dropping a mass from an appropriate height onto the sample to get the equivalent kinetic energy and measuring acceleration data via an accelerometer, or displacement vs. time with a high speed camera.

For the small sample test, a section of honeycomb fitting to the minimum area requirements (4 x 8 inches) was used. The honeycomb that we decided to utilize came in 3 inch thick ‘sheets’, and a single thickness was used for the small sample test, with the knowledge from our research that additional layers could be stacked (with anti-knifing plates between them) to provide the needed energy absorption in the final design. The crush rate for the Instron was set to 0.2 in/min.

**Small Sample Test Results**

The results of the small sample test can be seen in Figure 42 and Figure 43. In these graphs, the zero point is the bottom of the testing machine, so a displacement of -2 inches corresponds to the point at which
there are 2 inches of thickness left in the sample to be crushed.

**Small Sample Analysis**

Based on the results from the small sample test, the material properties of the aluminum honeycomb were determined using the equations presented in section 3.1. The load spike at the start of the test was caused by the aluminum honeycomb buckling and the spike at the end by the
material being crushed to its maximum crush point. In addition, maximum allowable area to meet the average force requirement based on the stress maintained by the sample was calculated. The results of these calculations can be seen in Table 4 and Table 5.

**Table 4: Force limitation calculations**

<table>
<thead>
<tr>
<th>Force limitation calculations</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Average Force usable</td>
<td>4702.48</td>
<td>lbf</td>
</tr>
<tr>
<td>Area</td>
<td>32.00</td>
<td>in^2</td>
</tr>
<tr>
<td>Force/Area</td>
<td>146.95</td>
<td>lbf/in^2</td>
</tr>
<tr>
<td>Maximum Average Force</td>
<td>13232.00</td>
<td>lbf</td>
</tr>
<tr>
<td>Maximum Area</td>
<td>90.04</td>
<td>in^2</td>
</tr>
</tbody>
</table>

**Table 5: Energy/volume calculations**

<table>
<thead>
<tr>
<th>Energy/Volume Calculations</th>
<th>Length (in)</th>
<th>Width (in)</th>
<th>Height (in)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sample</td>
<td>4</td>
<td>8</td>
<td>3</td>
</tr>
<tr>
<td>Usable</td>
<td>4</td>
<td>8</td>
<td>2.25</td>
</tr>
<tr>
<td>Volume</td>
<td>96.00</td>
<td>in^3</td>
<td></td>
</tr>
<tr>
<td>Height Unusable</td>
<td>0.75</td>
<td>in/slice</td>
<td></td>
</tr>
<tr>
<td>Total Energy Absorbed</td>
<td>1353.65</td>
<td>j</td>
<td></td>
</tr>
<tr>
<td>Usable Energy Absorbed</td>
<td>1228.25</td>
<td>j</td>
<td></td>
</tr>
<tr>
<td>Energy Per Volume</td>
<td>12.79</td>
<td>j/in^3</td>
<td></td>
</tr>
<tr>
<td>Needed Energy</td>
<td>7350.00</td>
<td>j</td>
<td></td>
</tr>
<tr>
<td>Needed Volume</td>
<td>574.47</td>
<td>in^3</td>
<td></td>
</tr>
</tbody>
</table>

Using these parameters, a calculator was created in Microsoft Excel which would calculate a thickness (in number of 3 inch slices) for the impact attenuator for a given length and width. It would also warn the user if the resultant area would cause the design to exceed the average force requirement, and clamped the minimum thickness to the number of slices that would meet the 8 inch minimum thickness specified by rule 3.20.1. The decision to constrain the calculator to whole slices was to ensure predictability of performance when stacking slices, and due to the difficulty of ensuring an even cut of the honeycomb across its thickness with the cutting tools.
available to the team (which would also affect predictability of performance). The output from this calculator for various dimensions can be seen in Table 6. Using this calculator, the impact attenuator could be optimized to fit into the smallest total volume.

Table 6: Optimization calculations

<table>
<thead>
<tr>
<th>Optimization Calculations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Height @ max area (in)</td>
</tr>
<tr>
<td>Height @ min area (in)</td>
</tr>
<tr>
<td>Min Height (in)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Custom Size</th>
<th>Length (in)</th>
<th>Width (in)</th>
<th>Area (in^2)</th>
<th>Usable Height (in)</th>
<th>Number of Samples High</th>
</tr>
</thead>
<tbody>
<tr>
<td>Custom 1</td>
<td>5.00</td>
<td>8.00</td>
<td>40.00</td>
<td>14.36</td>
<td>7</td>
</tr>
<tr>
<td>Custom 2</td>
<td>7.00</td>
<td>8.00</td>
<td>56.00</td>
<td>10.26</td>
<td>5</td>
</tr>
<tr>
<td>Custom 3</td>
<td>8.00</td>
<td>8.00</td>
<td>64.00</td>
<td>8.98</td>
<td>4</td>
</tr>
<tr>
<td>Custom 4</td>
<td>10.00</td>
<td>9.00</td>
<td>90.00</td>
<td>8.00</td>
<td>4</td>
</tr>
<tr>
<td>Custom 5</td>
<td>10.00</td>
<td>10.00</td>
<td>100.00</td>
<td>area too big</td>
<td>#VALUE!</td>
</tr>
</tbody>
</table>

**Full Scale Test**

Based on the results from the dimension calculator, it was determined that an eight inch by eight inch area would be the optimal dimensions for the impact attenuator, as this gave the lowest number of slices with the smallest overall size. Increasing the area to larger than eight by eight did not reduce the thickness due to the 8 inch minimum thickness limitation and the whole number of slices constraint, and increasing it past ten by nine exceeded the maximum average force requirement. Therefore, for the full scale test, four eight by eight inch slices of aluminum honeycomb were used. To prevent knifing between the honeycomb slices, sheets of 0.002 inch thick aluminum were cut to size and placed between the layers. In addition, to comply with rule 3.20.2, and to hold the impact attenuator together when not vertical (such as when mounted on the car) four straps of the same 0.002 inch thick aluminum sheet were crosshatched over the top layer of honeycomb and fastened to the anti-intrusion plate. A picture of the full scale mockup can be seen in Figure 44. The full scale mockup was tested in the same manner as the small size sample, but with the crush rate increased to 0.5 in/min.
Full Scale Test Results

The results of the full scale test can be seen in Figure 45 and Figure 46. In these graphs, the zero point is the top of the sample being crushed, so in the case of the full scale mockup a displacement of 10 inches corresponds to 10 inches of material crushed.
Full Scale Test Analysis

The test results for the full scale mockup corresponded very favorably with the expected results based on the small sample test. The average force was slightly higher than expected, at 9,910 lbf instead of the calculated 9,700 lbf. This could be attributed to the construction of the test mockup (the dimensions were not exactly 8 x 8 inches at all points for all slices, and they were not perfectly aligned) causing some areas to buckle after others, leading to higher average loads. This fact is corroborated by the fact that the load spikes were lower than expected, at 14,478 lbf or less instead of the calculated 16,600 lbf, which would be explained by not all of the 8 x 8 inch area of a slice buckling at once. However, these results are still well within the maximum and average force requirements from rule 3.21.1.

The total energy absorbed by the full scale mockup was well above the required 7350 J, at 10,875 J over approximately 10 inches of crush depth. Therefore, the full scale mockup proved that the dimensions calculated by the dimension calculator would be adequate for compliance with rule 3.21.1. To optimize the design further, the amount of pre-crush that could be performed on the impact attenuator and still provide adequate energy absorption was calculated using the
energy vs. displacement data from figure 5. The results of these calculations can be seen in Table 7.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy Absorbed</td>
<td>10875.55</td>
<td>J</td>
</tr>
<tr>
<td>Displacement</td>
<td>9.83</td>
<td>in</td>
</tr>
<tr>
<td>Energy/in</td>
<td>1106.84</td>
<td>J/in</td>
</tr>
<tr>
<td>Energy Needed</td>
<td>7350.00</td>
<td>J</td>
</tr>
<tr>
<td>Needed Displacement</td>
<td>6.64</td>
<td>in</td>
</tr>
<tr>
<td>Starting Thickness</td>
<td>12.00</td>
<td>in</td>
</tr>
<tr>
<td>End Thickness</td>
<td>2.17</td>
<td>in</td>
</tr>
<tr>
<td>Needed IA Thickness</td>
<td>8.81</td>
<td>in</td>
</tr>
<tr>
<td>Max Pre-Crush</td>
<td>3.19</td>
<td>in</td>
</tr>
</tbody>
</table>

The maximum allowable pre-crush was calculated to be 3.19 inches, which is more than the thickness of a slice of the honeycomb. However, to allow for a reasonable FOS, it was determined that approximately two inches of pre-crush should be used for the final unit that would be mounted on the car. This gives the best compromise between size concerns and ensuring adequate energy absorption.
Engine

The engine chosen for the 2009 FSAE car was the Yamaha Genesis 80FI. This engine is transplanted from a 2008 Yamaha Phazer snowmobile. In choosing an engine for this year’s car the major design goals set forth at the beginning of the project were used to narrow the search. The major rule for the engine set by the FSAE sanctioning body is; "The engine(s) used to power the car must be four-stroke piston engine(s) with a displacement not exceeding 610 cc per cycle."

The other major rules for the engine concern the air intake and are as follows:

8.6.1 In order to limit the power capability from the engine, a single circular restrictor must be placed in the intake system between the throttle and the engine and all engine airflow must pass through the restrictor.

8.6.3 The maximum restrictor diameters are:

- Gasoline fueled cars - 20.0 mm (0.7874 inch)
- E-85 fueled cars – 19.0 mm (0.7480 inch)

The most important restriction to consider is the displacement because the nearly all stock engines in this displacement range have significantly larger throttle bodies than the restrictor size of 20 mm dictated by FSAE, thus the intake of any engine chosen will require redesign and fabrication of an intake to incorporate the restrictor.

Based on the rules dictated by the competition and our design goals of a simple, lightweight car with a CVT, several engines fit the aforementioned criteria. The Yamaha WR450 dirt bike engine, Jawa 600cc dirt track motorcycle engine and the Yamaha Genesis 80FI snowmobile engine were the engines that best fit the design goals and displacement restriction.
The WR450 engine has been used in other FSAE cars and is a solid platform for this application. However, it is carbureted and the five speed transmission is integrated into the engine case. To use a CVT with the WR450 the standard 5 speed transmission would have to either be gutted to act as only an output source for the engine or the portion of the engine case which housed the transmission would need to be machined off and a new output shaft from the engine constructed. Both options would require extensive research and potential fabrication time.
The Jawa 600cc dirt track motorcycle engine does not have transmission built into the engine case which would allow the CVT to be easily attached to the output shaft of the engine or a reduction off the engine output shaft. These engines weigh approximately 61 pounds which is a significant weight savings over the traditionally used Honda F4i engine which weighs 135 pounds with a transmission. A CVT assembly weighs approximately 17 pounds for both the primary and secondary sheaves and the belt bringing the engine/transmission assembly weight to 78 pounds which is a 57 pound weight savings for this engine configuration. On methanol fuel and no intake restrictor these engines make approximately 65 horsepower. A Honda F4i engine has been recorded as making approximately 100 horsepower with the restrictor making its approximate horsepower per pound rating 0.74 hp/lb. From speaking with users of the Jawa making 50 horsepower on the restrictor and unleaded fuel would be a reasonable estimate. This would make the horse power per pound rating 0.64 hp/lb. They are also carbureted rather than fuel injected.

Another concern with the Jawa engine is the maintenance intervals. These engines are intended for short races and are rebuilt often. The other consideration for this engine is its cost. The cost of this engine is significantly higher than the other engines considered. This engine would cost approximately $4,000 and would need to be imported. Besides the initial investment, purchasing parts and getting support from other users of these engines would be difficult. Due to the frequent maintenance required, high cost and limited accessibility of parts the team chose not to use this engine.

While a horsepower per pound rating is helpful for engine comparison it must also be considered that these types of cars are severely traction limited and therefore can only put a certain amount of power to the ground at a given speed. Any power above and beyond what can
be used is waste in track events and will only yield better scoring in the high horsepower portion of the competition. The Yamaha Genesis 80FI fit all of the team’s needs. The motor weighs 80 pounds and makes approximately 80 horsepower in stock configuration without a restrictor. A conservative estimate for power with the restrictor is 55 horsepower. For an engine/ transmission assembly weight of 97 pounds, the approximate power per unit weight is 0.58 hp/lb. The engine is already setup for use with a CVT as this is the transmission used in the snowmobile. The engine also features a dry sump lubrication system allowing the engine to be placed lower in the vehicle helping to keep the center of gravity low. The parallel twin configuration gives the engine a small volume allowing easier placement of the engine and packaging of drive train components. The engine also features fuel injection which will allow more precise tuning of fuel delivery compared to a carburetor.

A new snowmobile was purchased to take the engine out of. Once the engine was out an engine test stand was constructed, shown in Figure 49 so the engine could be tested. A picture of the test setup is shown in Figure 50.
Figure 50: Engine test setup

**Throttle body**

In prior years the FSAE team has experimented with several different types of throttle body/ intake manifold/ restrictor configurations and designs. Through these iterations it was found that there are only small gains to be had from the restrictor and throttle body designs and that the focus of design should be on the intake manifold. The runner lengths for each cylinder and the plenum volumes are the best places to make gains with design time. Due to the time constraints of the project the team chose to purchase and throttle body with integrated restrictor from a British company called Active Technologies.
The team worked closely with the designers at Active Technologies to integrate the stock throttle positions sensor (TPS) from the Yamaha Genesis 80FI. This lessened the amount of work required to wire in a new throttle position sensor and calibrate it, and potential problems occurring from conflicts between hardware.

A computer model of the throttle position sensor was created and scale drawings were sent to Active Technologies with critical dimensions labeled. These drawings can be seen in Appendix G. The final product was a throttle body and restrictor that were purchased assembled and with the correct mounting pattern and shape for the stock Yamaha Genesis 80FI throttle position sensor.
**Engine Mounting**

The placement of the engine was determined through an iterative process. The chassis and seat were set based on our ergonomic design which considered the measurements of our team members and fitting the rules. The main issues with the engine mounting were leaving enough room behind the seat for the engine intake, keeping the output shaft as far forward as possible, and also keeping the engine as low to keep the center of gravity low. These three constraints conflicted with each other greatly. The team spoke with an engineer at Yamaha about how much the angle of the engine could change compared to its stock orientation. The engineer told the team that 20 degrees forward or aft would be safe for the operation of the engine. An intake was constructed and measured to find what the smallest amount of room between the intake ports and the back of the seat was necessary. In addition to this measurement of approximately 2.5 inches a clearance of 0.5 inches was added to account for the movement of the engine as it is rubber mounted and as a precaution incase the fabricated chassis and other components are not perfectly reproduced according to the CAD model. The needs of the rear end chain pull angle and appropriate swing arm clearance for the jackshaft were checked at each iteration of engine placement.

The loading scenarios were generated based on two situations; maximum pull on the output shaft from the CVT and the force of the engine on the mounts in a bump which was estimated and two times the weight of the engine. The engine weight is 80 pounds, therefore the force used for analysis was 160 lbf, directed toward the ground. The calculations used to find the force generated by the output of the engine and the force generated back through the system from the tractive force is shown in Appendix H. The tension in the belt found from the two methods of loading was then multiplied by three to find the force pulling along the centerline between the primary and secondary sheaves. This multiplier of three was given by a CVT specialist as a safe
over estimate of the force generated between the sheave centers. Therefore, the overestimate of three was decided to be an adequate method of finding the force used for the analysis. The torque output from the engine was roughly calculated from a small horsepower graph given on Yamaha’s website. The derived unrestricted, stock power numbers are shown in Appendix I. The resulting graph from the calculated torque output is shown in Figure 53.

These power numbers, while much larger than the numbers we are expecting, give us a worst case scenario for our calculations.

The front engine mount was integrated into the existing frame of the chassis to utilize the existing nodes for critical load requirements. The resulting front engine mount design is highlighted in Figure 54.
Figure 54: Front motor mount

Figure 55: Motor mount configuration side
Due to a lack of FEA resources, the chassis with motor mounts assembly was not analyzed. The front motor mount was loaded with 800 lbf in the rearward direction and 80 lbf downward. This loading scenario replicates a worst case scenario of the maximum pull on the output shaft and bump causing two times the force of gravity. These values are half of the calculated forces because the forces are split with the rear motor mounts. The stress plot for the front motor mount is shown in Figure 57. Figure 57 also shows the loading for the pickup points for the rear motor mounts to check the strength of the chassis and make sure that the placement of these loads on the tubes is acceptable. The lower right rear corner of chassis shows a stress concentration slightly over the yield strength of the 4130 used for the chassis. To reduce this stress concentration and spread the load out in this region, gussets were welded in. Aside from this location the rest of the chassis and front motor mount show a FOS of approximately 2. The green arrows in Figure 57 are the fixed points that are held when the FEA is run. These points were
chosen as they are pickup points for the suspension and fix the chassis as close to how it will be in practice as possible.

![Figure 57: Chassis Motor mount stress plot](image)

The same loading scenarios were used for each of the rear "boomerang" shaped motor mounts. In addition to these loads, the mount was loaded with a force perpendicular to the length of the car. This out of plane load was used to simulate the force caused by the change in angle that can occur when the motor mounts flex. Based on a deflection of the approximate flex in the rubber motor mounts, the simple trigonometry was done to find the out of plane loading on the mount. From these calculations, it was determined that 100 lbf was adequate to represent this load. Each of the two rear motor mounts were loaded out of plane with 50 lbf. The material used for this application was 7075 -T651 Aluminum. The yield strength used for analysis was 54,000 psi.
Shown in Figure 56 is a support between the rear motor mounts. This was put in place to help evenly load the two motor mounts. This allows the motor mounts to work as one unit rather than passing loads through the engine block casting.

**Engine Integration**

The Yamaha Genesis 80FI engine wiring harness was modified to be used in the 2009 FSAE car. Few modifications we needed to adapt the harness for our uses aside from lengthening sections of wire to accommodate the different layout compared to the donor Phazer snowmobile.

Modifications needed included:

- Brake over travel kill switch
- Master kill switch
- Headlight wiring removal
- Heated thumb/ hand warmers removal
- Brake light switch
The stock Yamaha Genesis 80FI wiring diagram is shown in Appendix E. The safety and kill switch diagrams are shown in Appendix F. The master kill switch must be located at shoulder height on the driver’s right.

**Fuel Tank**

In accordance with rule 9.4-9.9.2 of the FSAE rulebook, all vehicles must have a fuel tank which meets various guidelines. The rules primarily govern the location and mounting restrictions for the tank; it must be located within the boundaries of the side impact structure or protected by a frame made to the same specifications, and must either be non load bearing if it is a rigid tank, or must be contained within a rigid structure that may be load bearing if it is of a bladder type. The rules also place restrictions on the fuel filler neck, governing its minimum length and maximum angle from horizontal at the fill-port, and providing adequate provision to prevent leakage in the event of a tip over. Finally, the tank must have a vent, drain, and a sightline mounted to the filler neck to display the maximum fuel level for the tank. Beyond these restrictions, the fuel tank design is left open, and so its design beyond complying with the rules is primarily focused upon minimizing weight and packaging concerns.

**Material Selection**

The material to be used in the construction of the fuel tank had to be selected not only with the goal of minimizing weight, but also taking into consideration its corrosion resistance, as it must be in constant contact with gasoline for extended periods of time. Aluminum sheet metal was selected for the primary tank material due to its light weight, low price, and ease of manufacturability due to our sponsorship from Howard Products. A sheet thickness of 0.060 inch was chosen to provide sufficient strength to contain the required weight of fuel in a non-load bearing tank while minimizing weight.
**Location and Packaging**

The location and packaging of the fuel tank were the primary considerations in its final design. The decision was made to use the stock fuel pump from the Phazer snowmobile to ensure compatibility and reduce cost. The stock pump is of an in-tank design (the whole of the fuel pump must be physically inside the fuel tank), and is quite large, occupying a space of a cylinder roughly 4 inches in diameter and 6 inches in length. In addition, the stock mounting system had to be re-utilized; this increased the needed area at the out-of-tank end of the pump to approximately 5.5 inches. In addition, there had to be enough space to fit approximately 2 gallons of fuel, a number which was reached after researching other teams and the capacity of previous year’s cars. Determining a location on the car which met these requirements that was completely inside the appropriate crash protection zones and did not interfere with the engine packaging, proved to be very difficult. The only space on the car which proved suitable was located between the seat and the engine at the bottom of the car. The location can be seen highlighted in Figure 59.

![Figure 59: Fuel Tank Location](image)

**Design**

With a suitable location chosen, the fuel tank could be designed to meet the required specifications. The design went through three iterations to reach a finalized state. The initial
design was two pieces, one a simple wedge box shape which served as the main volume of the tank and the other a very complicated (in terms of sheet metal geometry) bracket for holding the fuel pump and attaching it to the main body of the tank. This design was abandoned as it was deemed overly complicated and difficult to fabricate.

The second design also required two pieces. However the mounting for the pump was integrated into the main body of the tank, which itself was further optimized to better utilize the available space for the tank, greatly simplifying the design. The second piece was simply a shaped plate needed to fill a gap created by the limitations of sheet metal fabrication. This design also incorporated internal baffling made from sheets of aluminum cut to fit inside the tank with many small holes in them. Holes for the vent and drain were also included in this design. Baffling was deemed necessary as the fuel tank was very long and flat, and this would cause fuel to slosh around the tank during cornering, potentially starving the fuel pump and potentially damaging the engine and fuel pump.

In addition, in order to comply with the tip over rules, a check valve was needed on the vent to prevent fuel from spilling out during the tip test, where the vehicle is tipped to 45° and 60° to simulate a high-g turn and a rollover, respectively. A check valve utilizes a small ball-bearing contained in a plastic enclosure on the in-tank side of the valve which plugs the valve opening in the event of a rollover to prevent spillage. However, upon receiving the actual check valve that was to be used, it was discovered that it was far larger than expected, and would interfere with the fuel pump if it were to be placed in any place in the tank that would allow it to fill completely.

Therefore, a third iteration of the fuel tank was devised based on the second version, which incorporated a third piece: a ‘check valve box’ that attached onto and extended a portion
of the existing design. The check valve box allowed the check valve to be placed on the optimal portion of the fuel tank without interfering with the fuel pump. The third iteration of the fuel tank also changed the fuel baffling. After doing some cost estimates, it was determined that the hole filled sheets of aluminum would be extremely expensive to manufacture. An alternative was devised which used the same aluminum honeycomb utilized in the impact attenuator, as there was a large quantity still remaining. The honeycomb was cut to size to fit into the same area as the original baffling, and small channels were cut into the bottom of the honeycomb to allow for fuel flow between the combs. A rendering of the fuel tank in the chassis can be seen in Figure 60.
**Cooling**

One of the major obstacles in using a new, unfamiliar engine is the lack of data available in FSAE applications. The engine is designed to be in a cold environment as is apparent by the large snow cooled heat exchanger on the snowmobile. In order to use the Genesis 80FI engine, a conservative approach was taken and an oversized radiator was selected. A custom aluminum radiator from Griffin Radiators was left over from the 2007 FSAE team and it looked to be a possible match for the cooling system. The team searched out motorsport vehicles that used the Genesis 80FI engine to inquire about overall cooling system problems and concerns. A Stadium-Lite truck racer was able to provide testimonial for the radiator he was using. Under desert racing conditions and using a radiator similar in size and fin geometry and strictly cooling with a 1600 CFM electric fan, he was able to keep the engine running at safe operating temperatures. The radiator was pressure tested at 15 psi to ensure that no damage had been done to the radiator since 2007. The radiator dimensions and specifications are as follows:

- 15.0 x 11.0 x 1.5 inches
- Dry Weight: 6.4 lb = 2.9 kg
- Wet weight: 9.2 lb = 4.2 kg
- Volume = 1.3 L
- Frontal area=165.69 cu. in. = 1.15 cu. ft.
- Single core
- Louvered plate-fin surface
- Fin pitch=13 fins/inch = 512 fins/meter
- Plate spacing, b = 0.343 inches
- Fin metal thickness = 0.007 inches
Rather than designing a complicated side pod or mounting the radiator on the side of the car in an inefficient manner (see Figure 61), it was decided to place the radiator along the side of the car and using a Permacool electric fan to provide a forced air flow (see Figure 62 and Figure 63).

Figure 61: Initial mounting position of radiator

Figure 62: Final mounting position of radiator
Figure 63: Permacool electric fan (PRM-19122)
**Drivetrain**

Once the Genesis 80 FI engine and matching CVT were selected for use, design began on a system that would transfer the power from the driven sheave to the rear tires. A rear wheel drive configuration was considered to be the obvious choice. Given the relatively short wheel base, weight transfer to the rear tires enhances forward thrust potential in a rear wheel drive vehicle and thus, maximizes forward acceleration. A four wheel drive system introduces complexities not desired on this car.

Once the rear suspension type of a swing arm was selected, a chain drive was chosen for simplicity and effectiveness. A chain drive allows for easy changes in the amount of reduction, can accommodate changes in sprocket distance, and is relatively inexpensive, in comparison with shaft drives.

Being that the center distance of the two CVT sheaves was fixed, the only options for placement of the driven sheave was on an arc, centered at the output shaft of the engine. In designing the rear suspension, it was discovered that positioning the front sprocket closer to the ground provided more desirable kinematics. With this in mind, the driven sheave was rotated on that arc and moved as low as possible while keeping a safe amount of ground clearance. The amount of ground clearance was selected by placing a horizontal plane tangent to the bottom side of the chassis tube that runs laterally between the vertical sections of the rear roll hoop. The outside diameter of the driven sheave was then placed tangent to this plane. If the car were to bottom-out, the driven sheave would be unlikely to get damaged.

**Design**

To determine the desired reduction ratio, a maximum estimated vehicle speed of 90 miles per hour was chosen. This value was based on descriptions of the race course in the FSAE Rules. Gearing for a higher maximum speed would reduce the mechanical advantage that the CVT had
on the axle until the point that the CVT began shifting, and reduce maximum possible acceleration at lower speeds. Additionally, gearing for a lower maximum speed could create the possibility of attempting to over-rev the engine on the course and cause increased lap times. With a desired maximum top speed of the 90 miles per hour, a reduction ratio of 6.1:1 was required between the driven sheave, and the rear axle; more than typical of a single reduction through a chain, but not unobtainable.

Knowing that a single chain reduction would work, the team devised a configuration where a secondary shaft connected to the output of the CVT would extend over the longitudinal left arm of the swing arm, and on the outboard end of the shaft would be the smaller front sprocket. A chain would wrap around the front sprocket and attach to the larger rear sprocket which would be rigidly fixed to the axle. The chain needed to be selected such that it would withstand the given loads and also provide adequate ground clearance.

To develop the loading scenario to use in the chain selection process, the team chose to use the traction method, as opposed to the engine method. Going from the tire side and assuming that the vehicle has a traction limited condition. Vehicle speed, and thus power, does not play into the equation using this method. The loading situation has to assume some variables to take into account weight transfer under acceleration, and ultimately produce a valid number for thrust at the tire, and consequently tension in the chain.

With a coefficient of friction of 1.6, total vehicle weight of 600 pounds, wheelbase of 60 inches, a 40/60 % weight distribution (front and rear, respectively), and a center of gravity height of 13 inches, the maximum thrust at the perimeter of the tire is 881 pounds. This number is estimated to be slightly conservative, but does not have any specified FOS built in. To get chain tension, the diameter of the sprocket needs to be taken into account. The pitch diameter of the
sprocket is a function of the chain pitch, and the number of teeth. The number of teeth on the rear sprocket is related to the number of teeth on the front sprocket by the desired 6.1:1 ratio. The pitch length of the chain link varies depending on the size of the chain.

For the purposes of simplicity and ease of finding parts, the decision landed on using a chain style typically found on motor bikes. Double and even triple row chains offer ease of packaging with smaller chain pitches but their less common availability and limited commercial development meant that they would not be as suited to the needs of the car as one that is readily available. From looking at load ratings on chains, and how they are designed to be used, the loading scenario placed the chain selection somewhere between the load ratings of a 428 series, and a 520 series chain. A 428 series has the advantage of a shorter 0.5 inch pitch compared to the 0.625 inch found on the 520. The smaller pitch meant that for a given tooth count a sprocket could be smaller and allow for more ground clearance. The smaller diameter sprocket also meant that the chain would see a higher loading. The 428 and 520 series chain are typically rated in terms of tension required to yield the chain, and numbers vary depending on the chain manufacturer. Given the lack of actual hard numbers for chain specs, and the lack of knowledge of the accuracy of the loading scenario, a 520 series chain was selected for its increased strength and higher life expectancy.

In designing a sprocket system, it is undesirable to use less than 11 teeth on a sprocket (Tsubakimoto Chain Co., 2006). With an 11 tooth front sprocket, a rear sprocket would need to be 67 teeth for the desired 6.1:1 reduction. The outside diameter of a 67 tooth sprocket, with a 520 chain wrapped around it would be approximately 14 inches (Johns, 2003). This allows for slightly more than three inches of ground clearance; close but feasible. With the given size of the sprocket, the chain tension is 1350 pounds. This is approximately 1/3 of the stated yield tension.
for most sealed 520 roller drive chains. The 520 chain could be safely chosen and effectively packaged.

The secondary shaft mentioned previously had several elements that needed to be incorporated. It needed to be capable of spinning at close to 9000 rpm, be able to support both the sprocket and the driven sheave, and withstand the torque of each as they acted on it. The driven sheave employed a spline to engage with the shaft it was originally mounted on. In an effort to keep availability of parts high, and costs low the front sprocket was chosen as an off-the-shelf part, made for Honda CBR600 sport bikes; also splined. At 11 teeth, it is not an original Honda part but it is manufactured and kept in stock by several aftermarket sprocket makers. The shaft needed to accommodate the spline type of the driven sheave, and the spline of the small sprocket. These splines were dimensionally different and introduced undesirable manufacturing complexities. The was done to accommodate the different spline types to eliminate the need for a custom sprocket. This decision was made based on the fact that sprockets wear out and an off-the-shelf replacement was more logical than making a custom one each time.

The shaft was designed using SolidWorks and the design reviewed by Robert Norton, P.E. The stress analysis was performed by doing simple hand calculations making approximations and also using CosmosWorks. The shaft drawing was sent to Mark Williams Enterprises, a company that specializes in custom shaft manufacture. The material is 4340, hardened to Rockwell C 44. See Figure 64.
The rear sprocket was made by Sprocket Specialists out of 7075 Aluminum, and hard anodized. Its unusually large tooth count and particular bolt pattern made using an off-the-shelf component difficult, so it was custom made.

The rear axle is the final component in the drive train. The rear axle is a 1.75 inch diameter splined unit. It is made from 7075 Aluminum and was purchased with spline matching wheel hubs, rotor carrier, and sprocket carrier. Bearings and spacer material were also purchased with the axle from Hyper Racing, Inc. The nearly fully splined design of the axle allows for flexibility in mounting bearings, sprockets, rotors and wheel hubs. See Figure 65. This feature allows it to be adapted to many different designs.
**Figure 65**: Rear axle in top view, oriented in car

**Table 8**: Bill of materials for rear axle (see Figure 65)

<table>
<thead>
<tr>
<th>Item Number</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Hyper Racing 1.9 inch nut &amp; 30° spacer</td>
</tr>
<tr>
<td>2</td>
<td>Hyper Racing wheel hub</td>
</tr>
<tr>
<td>3</td>
<td>Hyper Racing rotor carrier</td>
</tr>
<tr>
<td>4</td>
<td>Hyper Racing 7 7/8 inch brake rotor</td>
</tr>
<tr>
<td>5</td>
<td>Wilwood Dynalite brake caliper</td>
</tr>
<tr>
<td>6</td>
<td>Hyper Racing dual angular contact bearing</td>
</tr>
<tr>
<td>7</td>
<td>Hyper Racing 1 ¾ inch universal splined axle</td>
</tr>
<tr>
<td>8</td>
<td>Hyper Racing sprocket carrier</td>
</tr>
<tr>
<td>9</td>
<td>Sprocket Specialists 67 tooth, 520 sprocket</td>
</tr>
<tr>
<td>10</td>
<td>13 inch Keizer Wheel &amp; Hoosier tire package</td>
</tr>
</tbody>
</table>
Conclusion and Recommendations

Although the 2009 FSAE team was unable to complete the car in time for competition, the academic intent of the Major Qualifying Project was fulfilled. Each student on the project gained firsthand knowledge and real world experience solving complex engineering problems, working as a member on a team and working with budgetary and time restrictions. From these experiences, the 2009 team would like to pass on some of its collective knowledge from the past year. Recommendations for future teams include:

- Reinventing the wheel is a futile task. Using already proven designs, and purchased parts is always a better option than trying to make it yourself.
- Management of the project is not a task to be taken lightly. With the amount of work involved and number of people, it can very easily become a full time job.
- Deadlines, clear accountability, and consequences need to be imposed for team members.
- A process of vetoing decisions should be set up. Disagreements and difference of opinion can lead to animosity if
- Justify decisions with logical reason based in good engineering practices.
- It will be important to set hard and fast deadlines early in the year and stick to those deadlines. Have a design freeze date, where design should stop and manufacturing should begin.
- At the beginning of the year, the shop should be cleaned out, organized, and scrubbed. Everyone should be familiar with where everything is so there is less time spent looking for tools.
- It could be recommended that a Management or Management Engineering student be part of the team to organize and manage team activities. This is a real project with real money involved. It would provide the student with relevant experience.
• Each member of the team should be responsible for at least one design (coming up with a model and engineering drawings) and one component analysis (structural or thermofluid). This would give each student experience with CAD, engineering design, and engineering analysis.

• Base your design around the products you know you will be using. This relates back to the tire discussion earlier. Determine what parts you will be purchasing and then design the front suspension around those. Typically these will be tires and dampers.

• Determine the desired roll rates, camber gain, and other suspension factors first. With these known, then begin designing a suspension system that incorporates these factors as well as the packaging constraints. If you reverse this order, i.e. designing for packaging constraints first and then suspension characteristics, you can essentially design yourself into a dead end, leaving you with a suspension that does not have the exact characteristics you want.
Works Cited


Appendix A: Cost Report
The cost report was completed as part of an Interactive Qualifying Project. Please refer to the FSAE Cost Report 2009.
Appendix B: Design Report

2009 Worcester Polytechnic Institute Formula SAE Design Report

Introduction
The 2009 WPI Formula SAE racecar represents a dramatic departure from WPI’s previous designs. Rather than attempting to build on previous vehicles, this year’s team decided to start from scratch with a new design built around new rules and a new engine and drivetrain.

Design Philosophy
In formulating a design philosophy, this year’s team performed testing with older vehicles and identified areas of concern that would be paid special attention during the design and construction of the 2009 car. The team noticed that the older cars were uncomfortable for larger drivers. Knee room had to be improved. Additionally, the foot box was too small, even for drivers who fit well otherwise. Because of this, it was difficult to find and feel the pedals, leading to a lack of confidence and unnecessarily cautious driving. While the shifter was firm and easy to reach, using it necessitated removing one’s hand from the steering wheel; not easy to do during a tight and frantic autocross run. As a result, drivers were hesitant to shift, and it was difficult to consistently use the power available. Older WPI teams encountered problems in completing and testing the car on time due to manufacturing difficulties. Recognizing that testing is a necessity for producing a reliable car, it became apparent that all parts of the vehicle had to be easily and quickly manufactured. With all of these factors in mind, the following criteria became the main focus of this year’s design:

**ERGONOMICS AND DRIVER COMFORT:** In addition to fitting the new templates, all relevant parts of the car would be designed with driver comfort in mind. The cockpit area and foot box would be as large as necessary and would be designed to easily accommodate the largest and smallest drivers on the team.

**MANUFACTURABILITY:** In the spirit of the competition (a prototype of a small-scale production vehicle) and in the interest of completing the car for testing, all parts of the vehicle were designed with manufacturability and affordability in mind. Parts are positioned not just for packaging and performance, but for easy access for tuning and replacement.

**SIMPLICITY:** In the interest of reliability, affordability, and weight reduction, the number of parts and systems on the car were kept as low as possible.

**KEY FEATURES:** In the interest of ergonomics, manufacturability, and simplicity, the following features were chosen:

- Yamaha Genesis 80Fi parallel twin engine
- Continuously variable transmission (CVT)
- Solid rear axle with swing-arm style suspension

Frame Design
The design of the frame began with careful observation of the rules. First, several key choices had to be made. The first was the direction of the main roll hoop braces. This year’s team chose to route the main roll hoop braces forward. By doing this, the frame can be stiffened by triangulating the main hoop braces to the intersection of the side impact diagonals. Additionally, because of the design of the rear suspension, there is no structure in the back of the frame to connect the main braces. Running the main hoop braces forward also helps to centralize the mass of the vehicle, resulting in a lower mass moment of inertia and quicker turning capabilities. The frame was then analyzed with the CosmosWorks finite element analysis software package to validate the integrity of the frame and to find the effective roll stiffness for suspension calculations.
Chassis Construction

The 4130 tubular space-frame steel chassis was manufactured using a world coordinate system with its origin located at the center of the base of the main hoop on the tube axis. Using a world coordinate system, where all measurements are taken from one point, decreases the inaccuracies that can occur from measuring locations based on other previously measured locations. The frame table used for construction was leveled and a centerline was constructed perpendicular to the base of the main hoop. The main hoop, front hoop and front bulkhead were first constructed and fixtureed to the table in their respective locations. The structural members which connect these three components were then fabricated to fit. This proved to be a valuable manufacturing method as our critical points, such as suspension pickup nodes, were accurately reproduced based on our computer generated model.

Suspension

Design Approach

Due to no recent cars produced by WPI being competitive, it was decided that an original design would be best. To produce this, an iterative process was formulated to aid in designing a completely new suspension system in under six months by a team with no SAE experience. The team followed the following process steps:

1. Tire Selection
2. Wheel Selection
3. Track Width and Wheel Base Selection
4. Packaging Constraints
5. Roll Center Location and Movement Optimization
6. Camber Change Optimization
7. Steering Geometry

INITIAL KINEMATIC DESIGN: Design began with a 2D design in Solidworks outlining chassis dimensions (determined by the forward template), track width, control arm lengths, ride height, instant centers, roll center, wheel camber, kingpin inclination, motion ratio, and tie rod instant center location (to minimize bump steer).

Tech Racing #063

KINEMATIC DESIGN OPTIMIZATION AND PACKAGING:
Using Solidworks, hard-points were first optimized to make sure there would be no packaging issues or interference with chassis members. They were then adjusted for their effects on roll center movement, camber control, and motion ratios. An SLA style suspension naturally evolved from the criteria set forth. From this, a 3D model was created in Solidworks consisting of all the parts contained within the front suspension. When assembling these parts, an axiomatic design approach was used. Emphasis was put on independence and decoupling, the first axiom. Using this, every adjustment in the front suspension was decoupled from the others giving the system completely independent control over caster, camber, toe, Ackermann geometry, ride height, shock compression at ride height, AR8 motion ratio and AR8 motion ratio rate of change.

LOAD CALCULATION: Data obtained using calculations from Milliken’s Race Car Vehicle Dynamics were imported into MathCAD to determine forces through the suspension members and chassis under specified scenarios. 1.5 g’s lateral and 2.0 g’s longitudinal braking were used along with a "worst case scenario" 2g bump where it was assumed that the entire vehicle was lifted by one corner. This provided the information necessary to perform finite element analysis of all suspension components. Stresses and buckling loads could then be calculated.

STRUCTURAL DESIGN: Individual suspension components were tested in Solidworks CosmosWorks for the previously calculated loads, with a minimum Factor of Safety of 1.4 at a specified failure point and an average FOS of around 2 for all other components. Part designs were iterated to reduce weight while maintaining FOS. This was done by first choosing the appropriate material type, and then working with dimensions. Finally, optimized parts were put back into the complete suspension assembly in Solidworks to make sure no parts interfered throughout suspension travel.

BELL CRANK: In an initial design iteration, the front suspension used an inline shock mounted directly from the lower control arm near the upright to the same member as the upper control arm pickups. This design incorporated a custom shock travel shock being built by a sponsor. When the sponsorship fell through later in
the year, a different shock needed to be used; this necessitated the use of a system increasing the motion ratio. Since the chassis was already built, the team needed to still use the same members that had originally been designed to be loaded. Because of the constrained locations, the team had to use a bell crank with inverted rods (axes crossing each other) that would have moments imparted on it. Other than this one flaw, the bell crank design provided the rising rate motion ratio desired as well as still providing decoupling of ride height and shock travel.

ANTI-ROLL BARS: The rear axle housing and swing arms work in conjunction as an anti-roll bar. The rear roll stiffness is based on housing, swing arm and chassis stiffness. FEA analysis was performed on these parts with a resultant torsional stiffness of 1099Nm/deg (compared to 275 Nm/deg in the front). This should theoretically be the rear roll rate. Given this, the front anti-roll bar will be used to adjust yaw stability rather than reduce body roll.

REAR SWING ARM:
The rear suspension on the car is a swing arm with a solid rear axle. This suspension type is similar in function to those found on ATVs and motorcycles. The final drive is a chain and sprocket set-up and incorporates a 520 series drive chain and a final ratio of approximately 6.1:1. The kinematic design of the suspension takes into account the chain pull angle, and swing-arm angle to enable a range of 103% to 113 % anti-squat under full jounce and rebound, respectively. The design of the structure for the rear suspension member resolves lateral forces into two spherical bearings mounted to flanges near the base of the main roll hoop on both sides of the vehicle. Air sprung shocks which attach to the topside of the swing arm are loaded in compression and maintain a nearly linear wheel to shock motion ratio of approximately 0.54:1. The non-linear spring rate of the two air shocks is intended to reduce the likelihood of the suspension bottoming out over rough pavement. The axle is CNC machined and splined 7075 T-5 aluminum. The splines on the axle allow a range of rear track widths from as narrow as 57in to 48in. The design intention is to use a rear track width of 46in. Adjustment of chain tension is accomplished by sliding the pivot point longitudinally in a 1in long slot in the mounting flange. The notched cam also serves the purpose of maintaining even alignment as adjustments are made.

Engine
The engine selection for the 2009 car is a significant departure from previous years. In the past, WPI has almost exclusively used four cylinder motorcycle engines, typically a Honda CBR 600 F4i. For the 2009 car, to keep with the overarching design goals of a lightweight, compact car, an engine which was lighter and smaller than the CBR 600 derivatives was desired, but that still had a comparable or improved specific output to the F4i. After much research, the team selected the Yamaha Genesis 80Fi. The Genesis 80Fi is a fuel injected, 500cc, inline twin, 5 valve per cylinder engine with dry sump lubrication and water cooling. It is rated at 80 horsepower unrestricted from the factory at 11,250 RPM through a continuously variable transmission, and offers many advantages over the F4i that outweighed the disadvantages of using a relatively uncommon engine in the car’s design. The Genesis is approximately 40 lbs lighter than the F4i dry.

Transmission
Another advantage of the Genesis 80Fi is its continuously variable transmission. One of the greatest challenges facing previous year’s cars was the inability to properly select gear ratios in the transmissions of the F4is for the light auto crossing courses of an FSAE competition. This led to the engine often running outside its optimal RPM range, and also imposed large amounts of driver strain due to the need to be constantly shifting. The CVT alleviates all of these problems. It ensures that the engine is always operating in its optimal RPM range, and allows for a selection of a final drive which gives a speed range that is appropriate for the courses that the car will be competing on. It also eliminates the need for the driver to shift or operate a clutch, significantly reducing driver strain and allowing more of the driver’s attention to be focused completely on driving the car.
Brakes
The brake system was designed to be simple and easily packaged. In addition, the components chosen needed to be readily available and cost effective for the weekend racer. Instead of using a caliper at all four corners, the car has two calipers at the front of the car and a single caliper at the rear. The single rear caliper is easy to mount on the solid rear axle and reduces the overall weight of the brake system. The brake pedal is machined 6061 aluminum and provides a pedal ratio of 6:1. The pedal is mounted in a reverse swing mount configuration to make it easier to package within the frame. The system is designed so that a maximum force of 180 pounds can be applied to the pedal before line pressure becomes an issue.

Dashboard Integration
The Phazer snowmobile that the Genesis 80Fi engine was taken from, has a powerful dashboard module that is capable of monitoring and displaying various engine operating parameters (vehicle speed, RPM, water temp, etc), as well as a powerful diagnostics system that is integrated into the factory ECU. Therefore, utilizing the dashboard into the car was seen as a high priority. One of the biggest hurdles to integrating the dashboard into the car was the vehicle speed sensor. The snowmobile’s speed sensor was a Hall effect type running off of a cog on the driveshaft. Calculations were done to mimic this cog on the jackshaft of the car, but with the tooth count adjusted to represent the difference in jackshaft speed vs. vehicle speed from snowmobile to car. Allowing the driver to be able to see vehicle speed in real time was seen as important because it would allow them to have an additional reference besides simple driver intuition for optimal corner speed judgment.

Body
The body is manufactured from aluminum sheet metal for ease of fabrication and design. This significantly reduces the amount of research and fabrication time required to make a functional body as compared to a composite body, as well as the cost.

Data Acquisition
In order to properly tune all aspects of the car, as well as improve driver performance, data acquisition was seen as an important aspect of the car. With the goal of significantly reducing engineering time and allowing for the possibility of migration to future WPI SAE cars, a commercial data acquisition system was chosen over a custom implementation. The data acquisition system chosen was the Race Technology DL-1. The DL-1 is a powerful system capable of logging 3 axis accelerometer, GPS, 4 wheel speed, and eight 12 bit analog inputs simultaneously to a compact flash card. It also has powerful and intuitive data analysis software included. Measured parameters in our implementation include accelerometer and GPS data, wheel speed, suspension travel, steering angle and throttle/brake pedal position.
### Appendix C: Specification Sheet

**FSAE Design Spec Sheet**  
Note: SI units  
2009

Competitors please replace the sample specification values in the table below with those appropriate for your vehicle and submit this with your design report. This information will be reviewed by the design judges and may be referred to during the design event.

--Please do not modify format of this sheet. Common formatting will help keep the judges happy!

--The sample values are fictional and should not be used as the baseline for your designs.

<table>
<thead>
<tr>
<th>Car No.</th>
<th>63</th>
</tr>
</thead>
<tbody>
<tr>
<td>School</td>
<td>Worcester Polytechnic Institute</td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>Dimensions</th>
<th>Front</th>
<th>Rear</th>
</tr>
</thead>
<tbody>
<tr>
<td>Overall Length, Width, Height</td>
<td>2338mm long, 1476mm wide, 1404mm high</td>
<td></td>
</tr>
<tr>
<td>Wheelbase</td>
<td>1549mm</td>
<td></td>
</tr>
<tr>
<td>Track Width</td>
<td>1219mm</td>
<td>1168mm</td>
</tr>
<tr>
<td>Weight with 68kg driver</td>
<td>111kg</td>
<td>136kg</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Suspension Parameters</th>
<th>Front</th>
<th>Rear</th>
</tr>
</thead>
<tbody>
<tr>
<td>Suspension Type</td>
<td>Double unequal length A-Arm. Push rod actuated vertically oriented spring and damper</td>
<td>Fully dependent Swing-arm, solid rear axle</td>
</tr>
<tr>
<td>Tire Size and Compound Type</td>
<td>20.5x6-13 R25B Hoosier</td>
<td>20.5x6-13 R25B Hoosier</td>
</tr>
<tr>
<td>Wheels (width, construction)</td>
<td>6 inch wide, 3 pc Al Rim, 21.5 mm pos. offset</td>
<td>6 inch wide, 3 pc Al Rim, 21.5 mm pos. offset</td>
</tr>
<tr>
<td>Center of Gravity Design Height</td>
<td>317 mm</td>
<td></td>
</tr>
<tr>
<td>Suspension design travel</td>
<td>35mm jounce/ 26 mm rebound</td>
<td>32mm jounce/ 32 mm rebound</td>
</tr>
<tr>
<td>Wheel rate (chassis to wheel center)</td>
<td>21 N/mm</td>
<td>18N/mm (does not apply to roll)</td>
</tr>
<tr>
<td>Roll rate (chassis to wheel center)</td>
<td>.7 degrees per g</td>
<td></td>
</tr>
<tr>
<td>Sprung mass natural frequency</td>
<td>2.1 Hz</td>
<td>3.9 Hz</td>
</tr>
<tr>
<td>Jounce Damping</td>
<td>To be determined during vehicle tuning</td>
<td>To be determined during vehicle tuning</td>
</tr>
<tr>
<td>Rebound Damping</td>
<td>To be determined during vehicle tuning</td>
<td>To be determined during vehicle tuning</td>
</tr>
<tr>
<td>Motion ratio / type</td>
<td>0.83 / progressive</td>
<td>0.56 /linear</td>
</tr>
<tr>
<td>Camber coefficient in bump (deg / m)</td>
<td>.051 deg / mm</td>
<td>NA</td>
</tr>
<tr>
<td>Camber coefficient in roll (deg / deg)</td>
<td>.47 deg / deg</td>
<td>NA</td>
</tr>
<tr>
<td>Static Toe</td>
<td>0 deg toe, adjustable +/- 2 deg</td>
<td>NA</td>
</tr>
<tr>
<td>Static camber and adjustment method</td>
<td>-1.5 deg, adj. via shim plates on A-arm from 0 to -3</td>
<td>0 , non-adjustable</td>
</tr>
<tr>
<td>Front Caster and adjustment method</td>
<td>5 deg, adjustable from 2 -7deg</td>
<td></td>
</tr>
<tr>
<td>Front Kingpin Axis</td>
<td>2 deg, non-adjustable</td>
<td></td>
</tr>
<tr>
<td>Kingpin offset and trail</td>
<td>38mm offset, 14mm trail</td>
<td></td>
</tr>
<tr>
<td>Static Ackermann and adjustment method</td>
<td>parallel steer, adjustable</td>
<td></td>
</tr>
<tr>
<td><strong>Anti dive / Anti Squat</strong></td>
<td>0</td>
<td>109%</td>
</tr>
<tr>
<td>---------------------------</td>
<td>---</td>
<td>------</td>
</tr>
<tr>
<td><strong>Roll center position static</strong></td>
<td>41mm above ground</td>
<td>NA</td>
</tr>
<tr>
<td><strong>Roll center position at 1g lateral acc</strong></td>
<td>40mm above ground, 45mm toward unladen side</td>
<td>NA</td>
</tr>
<tr>
<td><strong>Steer location, Gear ratio, Steer Arm Length</strong></td>
<td>Rear steer, Stiletto Woodhaven 6.4:1 &quot;Fast Rack&quot;, 71mm steer arm</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th><strong>Brake System / Hub &amp; Axle</strong></th>
<th><strong>Front</strong></th>
<th><strong>Rear</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Rotors</strong></td>
<td>Steel, hub mounted, 178mm dia. x 4.1mm, vented</td>
<td>Steel, 200 mm dia. x 4.7mm, vented</td>
</tr>
<tr>
<td><strong>Master Cylinder</strong></td>
<td>Wilwood 15.9 mm bore front / 19mm bore rear with driver adjustable bias bar</td>
<td></td>
</tr>
<tr>
<td><strong>Calipers</strong></td>
<td>44mm dia., floating, single piston</td>
<td>44mm dia., fixed mtg, opposing piston,</td>
</tr>
<tr>
<td><strong>Hub Bearings</strong></td>
<td>Tapered roller bearings. Separate rubber lip seal</td>
<td>(2) Dbl. row ang. contact bearings with integral seal</td>
</tr>
<tr>
<td><strong>Upright Assembly</strong></td>
<td>CNC 7075-Al, integral caliper mount</td>
<td>NA</td>
</tr>
<tr>
<td><strong>Axle type, size, and material</strong></td>
<td>Fixed spindle, 25mm dia, 4140 steel , RC 32</td>
<td>Rotating solid axle,44.5mm OD x 9.5mm wall, 7075 T6 Al</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th><strong>Ergonomics</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Driver Size Adjustments</strong></td>
</tr>
<tr>
<td><strong>Seat (materials, padding)</strong></td>
</tr>
<tr>
<td><strong>Driver Visibility (angle of side view, mirrors?)</strong></td>
</tr>
<tr>
<td><strong>Shift Actuator (type, location)</strong></td>
</tr>
<tr>
<td><strong>Clutch Actuator (type, location)</strong></td>
</tr>
<tr>
<td><strong>Instrumentation</strong></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th><strong>Frame</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Frame Construction</strong></td>
</tr>
<tr>
<td><strong>Material</strong></td>
</tr>
<tr>
<td><strong>Joining method and material</strong></td>
</tr>
<tr>
<td><strong>Targets (Torsional Stiffness or other)</strong></td>
</tr>
<tr>
<td><strong>Torsional stiffness and validation method</strong></td>
</tr>
<tr>
<td><strong>Bare frame weight with brackets and paint</strong></td>
</tr>
<tr>
<td><strong>Crush zone material</strong></td>
</tr>
<tr>
<td><strong>Crush zone length</strong></td>
</tr>
<tr>
<td><strong>Crush zone energy capacity</strong></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th><strong>Powertrain</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Manufacture / Model</strong></td>
</tr>
<tr>
<td><strong>Bore / Stroke / Cylinders / Displacement</strong></td>
</tr>
<tr>
<td><strong>Compression ratio</strong></td>
</tr>
<tr>
<td><strong>Induction</strong></td>
</tr>
<tr>
<td><strong>Throttle Body / Mechanism</strong></td>
</tr>
<tr>
<td><strong>Fuel Type</strong></td>
</tr>
<tr>
<td><strong>Max Power design RPM</strong></td>
</tr>
<tr>
<td><strong>Max Torque design RPM</strong></td>
</tr>
<tr>
<td>--------------------------</td>
</tr>
<tr>
<td><strong>Min RPM for 80% max torque</strong></td>
</tr>
<tr>
<td><strong>Fuel System (manf’, and type)</strong></td>
</tr>
<tr>
<td><strong>Fuel System Sensors (used in fuel mapping)</strong></td>
</tr>
<tr>
<td><strong>Fuel Pressure</strong></td>
</tr>
<tr>
<td><strong>Injector location</strong></td>
</tr>
<tr>
<td><strong>Intake Plenum volume and runner length(s)</strong></td>
</tr>
<tr>
<td><strong>Exhaust header design</strong></td>
</tr>
<tr>
<td><strong>Effective Exhaust runner length</strong></td>
</tr>
<tr>
<td><strong>Ignition System</strong></td>
</tr>
<tr>
<td><strong>Ignition Timing</strong></td>
</tr>
<tr>
<td><strong>Fuel System (manf’, and type)</strong></td>
</tr>
<tr>
<td><strong>Fuel System Sensors (used in fuel mapping)</strong></td>
</tr>
<tr>
<td><strong>Fuel Pressure</strong></td>
</tr>
<tr>
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</tr>
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</tr>
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<td><strong>Ignition System</strong></td>
</tr>
<tr>
<td><strong>Ignition Timing</strong></td>
</tr>
<tr>
<td><strong>Fuel System (manf’, and type)</strong></td>
</tr>
<tr>
<td><strong>Fuel System Sensors (used in fuel mapping)</strong></td>
</tr>
<tr>
<td><strong>Fuel Pressure</strong></td>
</tr>
<tr>
<td><strong>Injector location</strong></td>
</tr>
<tr>
<td><strong>Intake Plenum volume and runner length(s)</strong></td>
</tr>
<tr>
<td><strong>Exhaust header design</strong></td>
</tr>
<tr>
<td><strong>Effective Exhaust runner length</strong></td>
</tr>
<tr>
<td><strong>Ignition System</strong></td>
</tr>
<tr>
<td><strong>Ignition Timing</strong></td>
</tr>
<tr>
<td><strong>Coolant System and Radiator location</strong></td>
</tr>
<tr>
<td><strong>Fuel Tank Location, Type</strong></td>
</tr>
<tr>
<td><strong>Muffler</strong></td>
</tr>
<tr>
<td><strong>Other significant engine modifications</strong></td>
</tr>
</tbody>
</table>

**Drivetrain**

<table>
<thead>
<tr>
<th><strong>Drive Type</strong></th>
<th>Belted CVT</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Differential Type</strong></td>
<td>NA</td>
</tr>
<tr>
<td><strong>Final Drive Ratio</strong></td>
<td>6.09 - 520 series Chain</td>
</tr>
<tr>
<td><strong>Vehicle Speed @ max power (design) rpm</strong></td>
<td>81 mph, Ratio range: 3.8 - .95</td>
</tr>
<tr>
<td><strong>1st gear</strong></td>
<td>NA</td>
</tr>
<tr>
<td><strong>2nd gear</strong></td>
<td>NA</td>
</tr>
<tr>
<td><strong>3rd gear</strong></td>
<td>NA</td>
</tr>
<tr>
<td><strong>4th gear</strong></td>
<td>NA</td>
</tr>
<tr>
<td><strong>5th gear</strong></td>
<td>NA</td>
</tr>
<tr>
<td><strong>6th gear</strong></td>
<td>NA</td>
</tr>
<tr>
<td><strong>Half shaft size and material</strong></td>
<td>NA</td>
</tr>
<tr>
<td><strong>Joint type</strong></td>
<td>NA</td>
</tr>
</tbody>
</table>

**Aerodynamics (if applicable)**

| **Front Wing (lift/drag coef., material, weight)** | NA |
| **Rear Wing (lift/drag coef., material, weight)** | NA |
| **Undertray (downforce/speed)** | NA |
| **Wing mounting** | NA |

**Optional Information**

| **Body Work** | Multi-piece sheet aluminum |
| **Special Bit A?** |
| **Special Bit B?** |
Appendix D: Swing Arm Calculations for Snap Ring Groove Strength

Inputs

- **Correction Factor** \( G_f := 1.2 \)
- **Housing Diameter** \( D_s := 3.14 \) inches
- **Groove Depth** \( d := .0689 \) inches
- **Edge Margin Distance** \( y := .066 \) inches
- **Tensile yield strength of groove material** \( \sigma_y := 35000 \) \( \text{lb/inch}^2 \)
- **Edge Margin Factor (extrapolated)** \( K_1 := 6 \)
- **Factor of Safety** \( F_s := 1.6 \)

Calculations

Calculate \( y/d \) to get \( K \) from Table

\[
\frac{y}{d} = 0.943
\]

Maximum Thrust load for reduced edge margin

\[
P_g := G_f \cdot D_s \cdot d \cdot 3.14 \cdot \frac{\sigma_y}{K_1 \cdot F_s}
\]

\[
P_g = 2.972 \times 10^3 \text{ pounds}
\]
**Yield Strength of Groove Material**

<table>
<thead>
<tr>
<th>Groove Material</th>
<th>Yield Strength (psi)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cold-drawn steel (SAE 1010)</td>
<td>45,000</td>
</tr>
<tr>
<td>Steel (SAE 1045, Rc 42)</td>
<td>185,000</td>
</tr>
<tr>
<td>Steel (SAE 1045, Rc 46)</td>
<td>220,000</td>
</tr>
<tr>
<td>Aluminum (2042-T4, Rb 75)</td>
<td>48,000</td>
</tr>
<tr>
<td>Naval Brass (Rb 82)</td>
<td>53,000</td>
</tr>
</tbody>
</table>

**Correction Factors**

<table>
<thead>
<tr>
<th>Ring Series</th>
<th>Correction Factor, G</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>HO, MHO</td>
<td>1.20</td>
<td></td>
</tr>
<tr>
<td>SH, H01</td>
<td>0.50</td>
<td></td>
</tr>
<tr>
<td>SH, MSH</td>
<td>1.00</td>
<td></td>
</tr>
<tr>
<td>C, MC</td>
<td>0.50</td>
<td></td>
</tr>
<tr>
<td>E, ME</td>
<td>0.33</td>
<td></td>
</tr>
<tr>
<td>RE, MRE</td>
<td>0.25</td>
<td></td>
</tr>
<tr>
<td>SHR, MSR</td>
<td>2.00</td>
<td></td>
</tr>
<tr>
<td>PO</td>
<td>0.50</td>
<td></td>
</tr>
<tr>
<td>SHM</td>
<td>1.00</td>
<td></td>
</tr>
</tbody>
</table>

**Nomenclature Table**

- \( d \): Groove depth, in.
- \( D_s \): Shaft or housing diameter, in.
- \( F_s \): Safety Factor
- \( G_r \): Correction Factor
- \( K_e \): Edge Margin
- \( P_t \): Thrust Load on Groove, lb.
- \( \sigma_y \): Tensile Yield Strength of groove material, psi

\[
P_t = \frac{G_r D_s d \pi \sigma_y}{K_e F_s}
\]
Appendix F: Safety and Kill Switch Diagram
Appendix G: Throttle Position Sensor Mount Drawings
**Title:**

TPS mounting on Throttle body

**Scale:** 2:1

**Weight:**

**Sheet:** 1 of 1

---

**Dimensions are in millimeters.**

- **Diameter:** 
  - Ø10 THRU
  - Ø12.66
  - Ø2.20

- **Length:** 27.94

---

**By Daniel Cullen**

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**Proprietary and Confidential:**

The information contained in this drawing is the sole property of [Company Name], and is not to be used in whole or in part, or any manner whatsoever, without the prior written consent of [Company Name].

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**Notes:**

- "This diameter will depend on your current shaft diameter."
Appendix H: Engine and Drivetrain Force Calculations

\[
\begin{align*}
  r_1 &= 1.3 \text{ in} \\
  r_2 &= 3.66 \text{ in} \\
  r_3 &= 1.045 \text{ in} \\
  r_4 &= 6.37 \text{ in} \\
  r_5 &= 10 \text{ in} \\
  \mu &= 1.6
\end{align*}
\]

**Worst case for tractive force**

Tractive force at rear tires (combined) = 881.61 lb = 2 * \( F_{\text{traction}} \)

\[
881.61 \text{ lb} \left( \frac{10 \text{ in}}{6.37 \text{ in}} \right) = 1385 \text{ lb} = T_{\text{chain}}
\]

Approximately 1400 lb of tension on chain.
\[ 1400 \text{ lb} \times \left( \frac{1.045 \text{ in}}{3.66 \text{ in}} \right) = 400 \text{ lb} = T_{\text{belt}} \]

From speaking with a CVT specialist, approximate force between sheave centers should be \( 3T_{\text{belt}} \):

\[ F_{\text{center to center}} = \text{Sheave center to center force} = 400 \text{ lb} \times 3 = 1200 \text{ lb} \]

**Worst case for engine output**

Internal reduction \(= \frac{50}{35} \)

Max torque output of engine \(= (490 \text{ in} \times \text{ lb}) \times \text{(Internal reduction)} = 700 \text{ in} \times \text{ lbs} \)

\[ (700 \text{ in} \times \text{ lb}) \times \left( \frac{1}{1.3 \text{ in}} \right) = 538 \text{ lb} \]

\[ F_{\text{center to center}} = 3 \times 538 \text{ lb} = 1616 \text{ lb} \]
Appendix I: Stock Yamaha Genesis 80FI Engine Power Output

<table>
<thead>
<tr>
<th>RPM</th>
<th>HP</th>
<th>Torque (ft*lbs)</th>
<th>Torque (in*lbs)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1000</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>1500</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>2000</td>
<td>5</td>
<td>13</td>
<td>158</td>
</tr>
<tr>
<td>2500</td>
<td>10</td>
<td>21</td>
<td>252</td>
</tr>
<tr>
<td>3000</td>
<td>15</td>
<td>26</td>
<td>315</td>
</tr>
<tr>
<td>3500</td>
<td>20</td>
<td>30</td>
<td>360</td>
</tr>
<tr>
<td>4000</td>
<td>25</td>
<td>33</td>
<td>394</td>
</tr>
<tr>
<td>4500</td>
<td>30</td>
<td>35</td>
<td>420</td>
</tr>
<tr>
<td>5000</td>
<td>35</td>
<td>37</td>
<td>441</td>
</tr>
<tr>
<td>5500</td>
<td>40</td>
<td>38</td>
<td>458</td>
</tr>
<tr>
<td>6000</td>
<td>45</td>
<td>39</td>
<td>473</td>
</tr>
<tr>
<td>6500</td>
<td>47</td>
<td>38</td>
<td>456</td>
</tr>
<tr>
<td>7000</td>
<td>48</td>
<td>36</td>
<td>432</td>
</tr>
<tr>
<td>7500</td>
<td>52</td>
<td>36</td>
<td>437</td>
</tr>
<tr>
<td>8000</td>
<td>57</td>
<td>37</td>
<td>449</td>
</tr>
<tr>
<td>8500</td>
<td>63</td>
<td>39</td>
<td>467</td>
</tr>
<tr>
<td>9000</td>
<td>70</td>
<td>41</td>
<td>490</td>
</tr>
<tr>
<td>9500</td>
<td>72</td>
<td>40</td>
<td>478</td>
</tr>
<tr>
<td>10000</td>
<td>74</td>
<td>39</td>
<td>466</td>
</tr>
<tr>
<td>10500</td>
<td>76</td>
<td>38</td>
<td>456</td>
</tr>
<tr>
<td>11000</td>
<td>80</td>
<td>38</td>
<td>458</td>
</tr>
<tr>
<td>11500</td>
<td>80</td>
<td>37</td>
<td>438</td>
</tr>
</tbody>
</table>
Appendix J: Brake Calculation Sheet

Weight Transfer Calculation

Deceleration :

CG Height
Distance of CG from front Axle
Wheel Base:
Mass of Car:
Tire Rolling Radius:

\[
N_{\text{rear}} := \frac{(m \cdot g \cdot x_{\text{cg}} - m \cdot a \cdot y_{\text{cg}})}{1} = 756.198 \text{N}
\]

\[
N_{\text{front}} := m \cdot g - N_{\text{rear}} = 1.913 \times 10^3 \text{N}
\]

\[
\left( \frac{N_{\text{front}}}{N_{\text{front}} + N_{\text{rear}}} \right) \cdot 100 = 71.667
\]

Brake Torque Required

\[
\mu := \frac{a}{g} = 1.5
\]

\[
f_f := N_{\text{front}} \cdot \mu = 2.869 \times 10^3 \text{N}
\]

\[
f_r := N_{\text{rear}} \cdot \mu = 1.134 \times 10^3 \text{N}
\]

\[
T_f := r_{\text{tire}} \cdot f_f = 765.19 \text{ft}
\]

\[
T_r := r_{\text{tire}} \cdot f_r = 302.517 \text{ft}
\]

Line Pressure Developed

\[
F_{\text{pedal}} := 80 \text{lbf}
\]

\[
PR := \frac{6}{1}
\]

Normal force on front & rear tires

% on front tires

Friction Force on front and rear tires

Brake Torque Required

Force Applied To Pedal

Pedal Ratio
Brake Balance

Forces on MC input shafts

MC Piston Diameters

Line Pressures Developed

Brake Torque Developed

Front

Effective Rotor Radius

Brake Pad Friction Coefficient

Caliper Piston Diameter

Number of Pistons per Caliper

Number of Calipers

Total Caliper Piston Area

Front Clamp Force

\[ \text{balance}_f := 1 \]
\[ \text{balance}_r := 1 \]

\[ \text{Fm}_q := F_{\text{pedal}} \cdot \text{PR} \cdot \text{balance}_f = 2.135 \times 10^3 \text{ N} \]
\[ \text{Fm}_r := F_{\text{pedal}} \cdot \text{PR} \cdot \text{balance}_r = 2.135 \times 10^3 \text{ N} \]

\[ \text{Dm}_f := .625 \text{ in} \]
\[ \text{Dm}_r := .75 \text{ in} \]

\[ \text{P}_f := \frac{\text{Fm}_q}{\pi \left( \frac{\text{Dm}_f}{2} \right)^2} = 1.565 \times 10^3 \text{ psi} \]

\[ \text{P}_r := \frac{\text{Fm}_q}{\pi \left( \frac{\text{Dm}_r}{2} \right)^2} = 1.086 \times 10^3 \text{ psi} \]

\[ \text{r}_{\text{rotor}, f} := 3.0 \text{ in} \]
\[ \mu_{\text{pad}} := .35 \]
\[ \text{Dcp}_f := 1.75 \text{ in} \]
\[ \text{Np}_f := 1 \]
\[ \text{Nc}_f := 2 \]

\[ \text{Acp}_f := \pi \left( \frac{\text{Dcp}_f}{2} \right)^2 \cdot \text{Np}_f \cdot \text{Nc}_f = 3.104 \times 10^{-3} \text{ m}^2 \]

\[ \text{F}_{\text{clamp}} := \text{P}_f \cdot \text{Acp}_f = 3.348 \times 10^4 \text{ N} \]
Front Brake Torque Developed
\[ T_d = 765.1 \, \text{J} \]

Rear Brake Torque Developed
\[ T_r = 302.5 \, \text{J} \]

Effective Rotor Diameter
\[ r_{\text{rotor}, f} \]

Caliper Piston Diameter
\[ D_{c, r} \]

Number of Pistons per Caliper
\[ N_{p, r} \]

Number of Calipers
\[ N_{c, r} \]

Total Caliper Piston Area
\[ A_{c, r} = \pi \left( \frac{D_{c, r}}{2} \right)^2 \cdot N_{p, r} \cdot N_{c, r} = 1.552 \times 10^{-3} \, \text{m}^2 \]

Rear Clamp Force
\[ F_{\text{clamp}, r} = P_r \cdot A_{c, r} = 1.162 \times 10^4 \, \text{N} \]

Front Brake Torque Developed
\[ T_d = \mu_{\text{pad}} \cdot F_{\text{clamp}, f} \cdot r_{\text{rotor}, f} = 892.88 \, \text{J} \]

Rear
\[ r_{\text{rotor}, f} := 3.5 \, \text{in} = 0.089 \, \text{m} \]
\[ D_{c, r} := 1.75 \, \text{in} = 0.044 \, \text{m} \]
\[ N_{p, r} := 1 \]
\[ N_{c, r} := 1 \]
\[ A_{c, r} = \pi \left( \frac{D_{c, r}}{2} \right)^2 \cdot N_{p, r} \cdot N_{c, r} = 1.552 \times 10^{-3} \, \text{m}^2 \]
Appendix K: Front suspension loading scenario

CodysCar - Force Calculations on Suspension Components
(A=front, B=rear,+x=forward, +y=inward)

Car Data
\[ m := 550\text{lb} = 249.476\text{kg} \]
\[ a_x := 1.5g = 14.71\frac{m}{s^2} \]
\[ a_y := 0g = 0 \text{g} \]
\[ x_{cg} := 30\text{in} \]
\[ y_{cg} := 13.5\text{in} \]
\[ L_{car} := 60\text{in} \]
\[ W_{car} := 48\text{in} \]
\[ \theta_{caster} := 2\text{deg} = 0.035\text{rad} \quad \text{(measured from vertical)} \]
\[ r_{shock} := 2 \quad \text{(shock motion ratio)} \]

Force Distributions
\[ Y_R := \frac{mg x_{cg} - ma_x y_{cg}}{L_{car}} = 397.56\text{N} \]
\[ Y_F := mg - Y_R = 2.049 \times 10^3 \text{N} \]
\[ \frac{Y_F}{Y_F + Y_R} \cdot 100 = 83.75\% \text{ on front tires} \]
\[ Y_O := \frac{Y_F}{2} + \frac{(ma_y y_{cg})}{2W_{car}} = 1.024 \times 10^3 \text{N} \quad = \text{Vertical force on outer tire} \]
\[ Y_I := Y_F - Y_O = 1.024 \times 10^3 \text{N} \quad = \text{Vertical force on inner tire} \]
Forces on outside tire

\[ F_{txO} := Y_O = 1.024 \times 10^3 \text{ N} \]
\[ F_{tyO} := \left( \frac{Y_O}{g} \right) a_y = 0 \]
\[ F_{txO} := -\left( \frac{Y_O}{g} \right) a_x = -1.537 \times 10^3 \text{ N} \]

Forces on inside tire

\[ F_{txI} := Y_I = 1.024 \times 10^3 \text{ N} \]
\[ F_{tyI} := \left( \frac{Y_I}{g} \right) a_y = 0 \]
\[ F_{txI} := -\left( \frac{Y_I}{g} \right) a_x = -1.537 \times 10^3 \text{ N} \]

Uprights

\[ r_{tire} := 10\text{ in} \quad d_{uppermount} := 4.91\text{ in} \quad d_{lowermount} := 4.54\text{ in} \]
\[ L_u := d_{uppermount} + r_{tire} = 0.379\text{ m} \]
\[ L_m := d_{uppermount} + d_{lowermount} = 0.24\text{ m} \]

Forces on outside upright

\[ F_{OLx} := \frac{F_{txO} L_u}{L_m} \left( 1 + \tan(\theta_{caster}) \right) = -2.509 \times 10^3 \text{ N} \]
\[ F_{OUx} := F_{txO} - F_{OLx} = 972.55\text{ N} \]
\[ F_{OLy} := \frac{F_{tyO} L_u}{L_m} = 0 \]
\[ F_{OUy} := F_{OLy} - F_{tyO} = 0 \]

Forces on inside upright

\[ F_{ILx} := \frac{F_{txI} L_u}{L_m} \left( 1 + \tan(\theta_{caster}) \right) = -2.509 \times 10^3 \text{ N} \]
\[ F_{IUx} := F_{txI} - F_{ILx} = 972.55\text{ N} \]
\[ F_{ILy} := \frac{F_{tyI} L_u}{L_m} = 0 \]
\[ F_{IUy} := F_{ILy} - F_{tyI} = 0 \]
Upper A-arms

\[ L_U := 12.42 \text{ in} \] = Y-length of A-arm, from spherical bearing to chassis mounts

\[ a_U := 9.5 \text{ in} \] = X-distance from front pick-up to spherical bearing

\[ b_U := 7 \text{ in} \] = X-distance from rear pick-up to spherical bearing

\[ k_U := \sqrt{a_U^2 + L_U^2} = 15.637 \text{ in} \] = Length of front a-arm tube

\[ m_U := \sqrt{b_U^2 + L_U^2} = 14.257 \text{ in} \] = Length of rear a-arm tube

**Inside**

\[ F_{mU} := m_U \left( \frac{F_{IUx} + \frac{a_U F_{IUy}}{L_U}}{a_U + b_U} \right) = 840.33 \text{ N} \]

\[ F_{kU} := k_U \left( \frac{F_{IUy}}{L_U} + \frac{F_{IUx} + \frac{a_U F_{IUy}}{L_U}}{a_U + b_U} \right) = 921.668 \text{ N} \]

**Outside**

\[ F_{mUO} := m_U \left( \frac{F_{OUx} + \frac{a_U F_{OUy}}{L_U}}{a_U + b_U} \right) = 840.33 \text{ N} \]

\[ F_{kUO} := k_U \left( \frac{F_{OUy}}{L_U} + \frac{F_{OUx} + \frac{a_U F_{OUy}}{L_U}}{a_U + b_U} \right) = 921.668 \text{ N} \]
Lower A-arms

\[ L_L := 14.03\text{in} \quad \text{= Y-length of A-arm, from spherical bearing to chassis mounts} \]

\[ a_L := 9.5\text{in} \quad \text{= X-distance from front pick-up to spherical bearing} \]

\[ b_L := 7\text{in} \quad \text{= X-distance from rear pick-up to spherical bearing} \]

\[ k_L := \sqrt{a_L^2 + L_L^2} = 16.944\text{in} \quad \text{= Length of front a-arm tube} \]

\[ m_L := \sqrt{b_L^2 + L_L^2} = 15.679\text{in} \quad \text{= Length of rear a-arm tube} \]

Inside

\[
F_{mLI} := m_L \left( \frac{F_{ILx} + \frac{a_L \cdot F_{ILy}}{L_L}}{a_L + b_L} \right) = -2.384 \times 10^3 \text{N}
\]

\[
F_{kLI} := k_L \left( \frac{F_{ILy}}{L_L} + \frac{F_{ILx} + \frac{a_L \cdot F_{ILy}}{L_L}}{a_L + b_L} \right) = -2.577 \times 10^3 \text{N}
\]

Outside

\[
F_{mLO} := m_L \left( \frac{F_{OLx} + \frac{a_L \cdot F_{OLy}}{L_L}}{a_L + b_L} \right) = -2.384 \times 10^3 \text{N}
\]

\[
F_{kLO} := k_L \left( \frac{F_{OLy}}{L_L} + \frac{F_{OLx} + \frac{a_L \cdot F_{OLy}}{L_L}}{a_L + b_L} \right) = -2.577 \times 10^3 \text{N}
\]
A-arm Mounts on Chassis

\[ F_{AxUI} := \frac{a_U}{k_U} (F_{kUI}) = 559.955 \text{N} \]

\[ F_{AyUI} := \frac{L_U}{k_U} (F_{kUI}) = 732.067 \text{N} \]

\[ F_{BxUI} := \frac{b_U}{m_U} (F_{mUI}) = 412.598 \text{N} \]

\[ F_{ByUI} := -\frac{L_U}{m_U} (F_{mUI}) = -732.067 \text{N} \]

\[ F_{AxUO} := \frac{a_U}{k_U} (F_{kUO}) = 559.955 \text{N} \]

\[ F_{AyUO} := \frac{L_U}{k_U} (F_{kUO}) = 732.067 \text{N} \]

\[ F_{BxUO} := \frac{b_U}{m_U} (F_{mUO}) = 412.598 \text{N} \]

\[ F_{ByUO} := -\frac{L_U}{m_U} (F_{mUO}) = -732.067 \text{N} \]

\[ F_{AxLI} := \frac{a_L}{k_L} (F_{kLI}) = -1.445 \times 10^3 \text{N} \]

\[ F_{AyLI} := \frac{L_L}{k_L} (F_{kLI}) = -2.134 \times 10^3 \text{N} \]

\[ F_{BxLI} := \frac{b_L}{m_L} (F_{mLI}) = -1.065 \times 10^3 \text{N} \]

\[ F_{ByLI} := -\frac{L_L}{m_L} (F_{mLI}) = 2.134 \times 10^3 \text{N} \]

\[ F_{AxLO} := \frac{a_L}{k_L} (F_{kLO}) = -1.445 \times 10^3 \text{N} \]

\[ F_{AyLO} := \frac{L_L}{k_L} (F_{kLO}) = -2.134 \times 10^3 \text{N} \]

\[ F_{BxLO} := \frac{b_L}{m_L} (F_{mLO}) = -1.065 \times 10^3 \text{N} \]

\[ F_{ByLO} := -\frac{L_L}{m_L} (F_{mLO}) = 2.134 \times 10^3 \text{N} \]
Forces on shock mounts

\[ F_{\text{innershock}} := F_{tzf_{\text{shock}}} = 2.049 \times 10^3 \text{ N} \]

\[ F_{\text{outershock}} := F_{tzO_{\text{shock}}} = 2.049 \times 10^3 \text{ N} \]
Appendix L: Impact Attenuator Bond Graph
-1.5 camber plate

Aluminum
Anti_Intrusion_Plate

Aluminum
Control Arm Bushing Half Tower

Dimensions:
- Diameter: 0.313
- Height: 0.600
- Width: 0.500
- Depth: 0.151
- Length: 0.626
Connecting plate

Aluminum
Lower Control Arm Mount Rear
steering shaft housing

Aluminum

Dimensions:
- Diameter: Ø 88
- Radius: R 35
- Radius: R 23
- Distance: 1.15
- Distance: 2.30
- Distance: 2.05
- Distance: 25
- Distance: 50
Upper control arm mount front w-slots
Upper Control Arm - Right side

1/2 inch OD
.049 Wall

make sure spherical housing is facing up
(wider opening of spherical upwards)
vertical bell crank mount
Appendix N: 2009 FSAE Rules

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2009 Formula SAE Rules

INTRODUCTION

This brief introduction will highlight a few of the items of interest that you'll find in the 2009 Formula SAE Rules. A 2009 Rules Change Summary covering some of the important changes to Part B "Technical Requirements" has been posted on the FSAE website.

Neither this Introduction nor the 2009 Rules Changes Summary is a substitute for thoroughly reading and understanding all the Rules.

New Format - The 2009 Formula SAE Rules have been reformatted to make them easier to use and easier to reference. There are now 4 Parts to the Rules:
Part A - Administrative Regulations - Objectives, Policies, Eligibility and Registration
Part B - Technical Requirements - Design and fabrication requirements and restrictions.
Part C - Static Event Regulations - Technical Inspection, Cost, Design and Presentation
Part D - Dynamic Event Regulations - Acceleration, Skid Pad, Autocross and Endurance

New Rule Numbers - Each Part of the Rules has its own set of numbers. Renumbering the Rules has allowed us to make individual rules easier to find while using shorter numbers. Cross references within a single Part of the Rules will only show the rule number, e.g. 3.8, references to a rule in a different Part will include the Part, e.g. B-10.2.

Illustrations - Many of the illustrations for "Part B - Technical Requirements" are now grouped together at the end of that Part.

Vehicle Design Objectives - The design objectives have been rephrased to make it clear that the goal is to develop a vehicle that complies with the FSAE Rules and is "… sufficiently durable to successfully complete all the events…".

Cost Event - The Cost Event Rules (Part C Article 3) have been completely revised. The 2009 changes include:
1. Standardized Prices - The prices for parts, materials and processes have been standardized and the prices in the official Cost Tables must be used. If you use a part or process that's not in the table there is a procedure for having it added. The standardized Cost Tables will be published through the FSAE website.
2. No Receipts - Since prices are standardized no receipts are required - except when requesting items be added to the table.
3. No Maximum Cost - You can spend as much as you like on your FSAE car with the understanding that your total cost is a significant factor in your Cost Event score.
4. Comprehensive BOM - You will need to develop a complete Bill of Materials covering everything that's on the car and all the processes used in the fabrication. There will be significant penalties for missing items or processes.

The 2009 revision is the first phase of a project to make the Cost Report web based.

Fuel Economy - The Fuel Economy scoring formula has been revised and maximum points increased from 50 to 100. Fuel Economy has not been completely decoupled from Endurance and 4 minute excess fuel burn has been abolished. However, excess fuel burn can result in a negative fuel economy score of up to -100 points. The maximum score for Endurance is now 300 points.
Mechanical Black Flags - Any time spent during a stop for inspection under a mechanical black flag will now be classified as official's time and will not be included in your total time.

Structural Equivalency Form - Every team must submit an SEF - even if you are not deviating from the baseline materials.

Reminder - Late Submission Penalties - Timely submission of the required reports and documents is essential to the smooth operation of FSAE. Late submission of the Cost Report, Impact Attenuator Data Report, Design Report, Design Spec Sheet, or Structural Equivalency Form will result in a penalty. Please submit everything by the specified deadline.
ARTICLE 1: FORMULA SAE OVERVIEW AND COMPETITION

1.1 Formula SAE Competition Objective
The Formula SAE ® Series competitions challenge teams of university undergraduate and graduate students to conceive, design, fabricate and compete with small, formula style, autocross racing cars.

1.1.1 To give teams the maximum design flexibility and the freedom to express their creativity and imaginations there are very few restrictions on the overall vehicle design. The challenge to teams is to develop a vehicle that can successfully compete in all the events described in the FSAE Rules. The competitions themselves give teams the chance to demonstrate and prove both their creativity and their engineering skills in comparison to teams from other universities around the world.

1.2 Vehicle Design Objectives
For the purpose of the Formula SAE competition, teams are to assume that they work for a design firm that is designing, fabricating, testing and demonstrating a prototype vehicle for the non-professional, weekend, competition racer market.

1.2.1 The vehicle should have very high performance in terms of acceleration, braking and handling and be sufficiently durable to successfully complete all the events described in the Formula SAE Rules and held at the Formula SAE competitions.

1.2.2 The vehicle must accommodate drivers whose stature ranges from 5th percentile female to 95th percentile male and must satisfy the requirements of the Formula SAE Rules.

1.2.3 Additional design factors to be considered include: aesthetics, cost, ergonomics, maintainability, manufacturability, and reliability.

1.2.4 Once the vehicle has been completed and tested, your design firm will attempt to "sell" the design to a "corporation" that is considering the production of a competition vehicle. The challenge to the design team is to develop a prototype car that best meets the FSAE vehicle design goals and which can be profitably marketed.

1.2.5 Each design will be judged and evaluated against other competing designs to determine the best overall car.

1.3 Good Engineering Practices
Vehicles entered into Formula SAE competitions are expected to be designed and fabricated in accordance with good engineering practices.

1.4 Judging Categories
The cars are judged in a series of static and dynamic events including: technical inspection, cost, presentation, and engineering design, solo performance trials, and high performance track endurance.
1.4.1 The dynamic events are scored to determine how well the car performs. Each dynamic event has specified minimum acceptable performance levels that are reflected in the scoring equations.

The following points are possible:

**Static Events:**
- Presentation: 75
- Engineering Design: 150
- Cost Analysis: 100

**Dynamic Events**
- Acceleration: 75
- Skid-Pad: 50
- Autocross: 150
- Fuel Economy: 100
- Endurance: 300

**Total Points:** 1,000

---

**ARTICLE 2: THE 2009 FORMULA SAE SERIES**

2.1 The 2009 Formula SAE Competitions series consists of the following seven (7) competitions:
1. Formula SAE Michigan held in Michigan, USA and organized by SAE
2. Formula SAE California held in California, USA and organized by SAE
3. Formula SAE Virginia held in Virginia, USA and sponsored by SAE
4. Formula SAE Australasia held in Australia and organized by SAE Australasia
5. Formula SAE Brazil held in Brazil and organized by SAE Brazil
6. Formula SAE Italy held in Italy and organized by ATA
7. Formula Student held in the United Kingdom and organized by IMechE

2.2 Open Registration
All Formula SAE competitions have open registration policies and accept registrations by student teams representing universities in any country.

2.3 Rule Variations
Formula SAE Australasia, Formula SAE Brasil, Formula SAE Italy and Formula Student may post some minor rule variations specific to the operation of the events in their countries, however, the vehicle design requirements and restrictions will remain unchanged. Any rule variations will be posted on the websites specific to those competitions.

2.4 Official Announcements and Competition Information
Teams are required to read the published announcements by SAE and the other organizing bodies and to be familiar with all official announcements concerning the competitions and rules interpretations released by the FSAE Rules Committee.

2.4.1 Formula SAE news is published online and can be found at:
http://students.sae.org/competitions/formulaseries/
2.5 **Official Languages**

The official language of the Formula SAE series is English. Document submissions, presentations and discussions in English are acceptable at all competitions in the series.

2.5.1 Team members, judges, and officials at FSAE Brazil and FSAE Italy may use their respective national languages for document submissions, presentations and discussions if all the parties involved agree to the use of that language.

2.5.2 The languages in use at the competitions of Formula SAE series are:

- Formula SAE Michigan - English
- Formula SAE California - English
- Formula SAE Virginia - English
- Formula SAE Australasia - English
- Formula SAE Brazil - Portuguese and English
- Formula SAE Italy - Italian and English
- Formula Student - English

2.6 **Competition Codes**

The competition codes that must be used as part of the file names of the various documents and data that are required to be submitted electronically are:

- Formula SAE Michigan - FSAEM
- Formula SAE California - FSAEC
- Formula SAE Virginia - FSAEV
- Formula SAE Australasia - FSAEA
- Formula SAE Brazil - FSAEB
- Formula SAE Italy - FSAEI
- Formula Student - FS

ARTICLE 3: FORMULA SAE RULES AND ORGANIZER AUTHORITY

3.1 **Rules Authority**

The Formula SAE Rules are the responsibility of the Formula SAE Rules Committee and are issued under the authority of the SAE University Programs Committee.

3.1.1 Official announcements from the Formula SAE Rules Committee, SAE or the other Formula SAE organizing bodies shall be considered part of, and shall have the same validity as, these rules.

3.1.2 Ambiguities or questions concerning the meaning or intent of these rules will be resolved by the Formula SAE Rules Committee, SAE or by the individual competition organizers as appropriate.

3.2 **Rules Validity**

The Formula SAE Rules posted on the SAE website and dated for the calendar year of the competition are the rules in effect for the competition.

3.2.1 Rule sets dated for other years are invalid.
3.3 **Rules Compliance**
By entering a Formula SAE competition the team, members of the team as individuals, faculty advisors and other personnel of the entering university agree to comply with, and be bound by, these rules and all rule interpretations or procedures issued or announced by SAE, the Formula SAE Rules Committee and the other organizing bodies.

3.3.1 All team members, faculty advisors and other university representatives are required to cooperate with, and follow all instructions from, competition organizers, officials and judges.

3.4 **Understanding the Rules**
Teams, team members as individuals and faculty advisors, are responsible for reading and understanding the rules in effect for the competition in which they are participating.

3.5 **Participating in the Competition**
Teams, team members as individuals, faculty advisors and other representatives of a registered university who are present on-site at a competition are considered to be "participating in the competition" from the time they arrive at the event site until they depart the site at the conclusion of the competition or earlier by withdrawing.

3.6 **Violations on Intent**
The violation of intent of a rule will be considered a violation of the rule itself.

3.6.1 Questions about the intent or meaning of a rule may be addressed to the Formula SAE Rules Committee or by the individual competition organizers as appropriate. (See Rule A-8)

3.7 **Right to Impound**
SAE and other competition organizing bodies reserve the right to impound any on-site registered vehicles at any time during a competition for inspection and examination by the organizers, officials and technical inspectors.

3.8 **Headings**
The article, section and paragraph headings in these rules are provided only to facilitate reading: they do not affect the paragraph contents.

3.9 **General Authority**
SAE and the competition organizing bodies reserve the right to revise the schedule of any competition and/or interpret or modify the competition rules at any time and in any manner that is, in their sole judgment, required for the efficient operation of the event or the Formula SAE series as a whole.

**ARTICLE 4: INDIVIDUAL PARTICIPATION REQUIREMENTS**

4.1 **Eligibility Limits**
Eligibility is limited to undergraduate and graduate students to insure that this is an engineering competition rather than a race.

4.2 **Student Status**
Team members must be enrolled as degree seeking undergraduate or graduate students in a college or university. Team members who have graduated during the seven (7) month period prior to the competition remain eligible to participate.
4.3 **Society Membership**
Team members must be members of at least one of the following societies: (1) SAE International, (2) SAE Australasia, (3) SAE Brazil, (4) ATA or (5) IMechE. Proof of membership, such as membership card, is required at the competition.

*Note:* Students can join SAE online at: www.sae.org/students

4.4 **Age**
Team members must be at least eighteen (18) years of age.

4.5 **Driver’s License**
Team members who will drive a competition vehicle at any time during a competition must hold a valid, government issued driver's license.

4.6 **Liability Waiver**
All on-site participants, including students, faculty and volunteers, are required to sign a liability waiver upon registering on-site.

4.7 **Medical Insurance**
Individual medical insurance coverage is required and is the sole responsibility of the participant.

4.8 **Individual Registration Requirements for North American Competitions - ACTION REQUIRED**

4.8.1 All students and faculty, both domestic and international, if you have an SAE International membership, make sure you are affiliated to your respective school/college/university on the SAE website under your “MySAE”.

4.8.2 If you are not a member of SAE International or other approved societies, you will need to join SAE International online at www.sae.org. Select the "Join SAE / Membership Renewal" link under "Quicklinks", and then select the "Join SAE" link under "Join SAE International". Students will need to select the "Student Membership" link and then follow the series of questions that are asked. Faculty that wishes to be SAE members should choose the "Professional Membership" link and proceed to the series of questions. Please note all student participants must be SAE International members to participate in the event. It is not mandatory for faculty to join.

4.8.3 All international student participants (or unaffiliated faculty advisors) who are not SAE International members are required to complete the International Student Registration form for the entire team found in the specific event registration webpage. Upon completion, email the form to CollegiateCompetitions@sae.org stating which event and university name.

4.8.4 **Online registration information is required!** Every participant, including advisors must affiliate themselves and complete the following information on under the team’s registration page on the SAE website:
- Medical insurance (provider, policy/ID number, telephone number)
- Driver's license (state/country, ID number)
- Emergency contact data (point of contact (parent/guardian, spouse), relationship, and phone number)

To do this you will need to go to "Registration" page under the specific event the team is registered and then click on the "Register Your Team / Update Team Information" link. At
this point, if you are properly affiliated to the school/college/university, a link will appear with your team name to select. Once you have selected the link, the registration page will appear. Selecting the “Add New Member” button will allow individuals to include themselves with the rest of the team. This can also be completed by team captain and faculty advisor for all team members.

PLEASE BRING YOUR OFFICIAL DRIVER’S LICENSE OR PASSPORT TO ONSITE REGISTRATION. ALSO PLEASE BRING YOUR MEDICAL INSURANCE CARD.

All students, both domestic and international, must affiliate themselves online or submit the International Student Registration form by March 2, 2009. For additional assistance, please contact CollegiateCompetitions@sae.org.

ARTICLE 5: FACULTY ADVISOR

5.1 Status
Each team is expected to have a Faculty Advisor appointed by the university. The Faculty Advisor is expected to accompany the team to the competition and will be considered by competition officials to be the official university representative.

5.2 Responsibilities
Faculty Advisors may advise their teams on general engineering and engineering project management theory.

5.3 Limitations
Faculty Advisors may not design any part of the vehicle nor directly participate in the development of any documentation or presentation.

Additionally, Faculty Advisors may not fabricate nor assemble any components nor assist in the preparation, maintenance, testing or operation of the vehicle.

In Brief - Faculty Advisors may not design, build or repair any part of the car.

ARTICLE 6: VEHICLE ELIGIBILITY

6.1 Student Developed Vehicle
Vehicles entered into Formula SAE competitions must be conceived, designed, fabricated and maintained by the student team members without direct involvement from professional engineers, automotive engineers, racers, machinists or related professionals.

6.2 Information Sources
The student team may use any literature or knowledge related to car design and information from professionals or from academics as long as the information is given as a discussion of alternatives with their pros and cons.

6.3 Professional Assistance
Professionals may not make design decisions or drawings and the Faculty Advisor may be required to sign a statement of compliance with this restriction.
6.4 **Student Fabrication**

It is the intent of the SAE Collegiate Design Series competitions to provide direct hands-on experience to the students. Therefore, students should perform all fabrication tasks whenever possible.

6.5 **The Formula SAE Competition Year - First Year Cars**

For the purpose of defining first, second and third year cars, a competition “year” is any consecutive run of the Series, i.e. Formula SAE Michigan, Formula SAE California, Formula SAE Virginia, Formula Student, Formula SAE Italy, Formula SAE Brasil, and Formula SAE Australasia held within a roughly 12 month period counting from the event in which a vehicle first competes. For example, a car that competes first in Formula SAE Australasia is classified as a “first year car” until the following year’s Formula SAE Australasia competition.

**Note:** Teams are reminded that their vehicles must comply with the rules in effect for each competition they enter.

6.6 **First Year Vehicles - North American Formula SAE Competitions**

6.6.1 Only first year vehicles may enter the Formula SAE Competitions in North America.

6.6.2 To be classified as a “first year vehicle” a car must, as a minimum, have a completely new frame. Photographic or other evidence will be used to determine if the frame is new.

6.6.3 If there is any question about whether or not the car is in fact a first year vehicle, it will be the sole responsibility of the team to produce such evidence as the organizers or judges may require.

6.7 **Second Year Vehicles - North American Formula SAE Competitions**

Vehicles that have competed during any previous Formula SAE year are prohibited from Formula SAE competitions held in North America.

6.8 **First Year Vehicles: FSAE-A, FSAE-B, FSAE-I and Formula Student**

6.8.1 To be classified as a “first year vehicle” a car must, as a minimum, have a completely new frame. Photographic or other evidence will be used to determine if the frame is new.

6.8.2 If there are any questions about whether or not the car is in fact a first year vehicle, it will be the sole responsibility of the team to produce such evidence as the organizers or judges may require.

6.9 **Second Year Vehicles: FSAE-A, FSAE-B, and Formula Student**

6.9.1 Vehicles that have competed during any one (1) previous Formula SAE year may compete provided that they have been substantially modified from their first appearance. Photographic and design documentation detailing the modifications are required along with a statement from the team’s Faculty Advisor.

6.9.2 Penalties for insufficient redesign or insufficient knowledge by the team will be applied during the Design Event. Refer to the Rule C - 5.15 "Penalties for Insufficient Redesign”.

6.10 **Third Year Vehicles - Prohibited**

6.10.1 Vehicles that have competed in any two (2) previous Formula SAE years are prohibited from participating in any Formula SAE competition.
6.10.2 Any team found to have entered a vehicle that contravenes this rule will be disqualified. Additionally, the team will be required to submit such documentation as the organizers may require in advance of the acceptance of any future registration.

ARTICLE 7: REGISTRATION

7.1 Registration - North American Formula SAE Competitions
Registration for Formula SAE competitions held in North America must be completed online. Online registration must be done by either (a) an SAE member or (b) the official faculty advisor connected with the registering university and recorded as such in the SAE record system.

Note: It typically takes at least 1 working day between the time you complete an on-line SAE membership application and our system recognizes you as eligible to register your team.

7.2 Entries per University - North American Formula SAE Competitions - One per Competition
Registration into Formula SAE competitions held in North America is limited to one (1) vehicle per university per competition depending on available space.

7.3 Registration Limits - North American Formula SAE Competitions
Registration into the North American Formula SAE competitions is limited as follows:

- Formula SAE Michigan: 120 teams
- Formula SAE California: 100 teams
- Formula SAE Virginia: 50 teams

Registration for each FSAE competitions closes as soon as the registration limit is reached. We strongly advise teams to register as soon as registration opens.

7.4 Registration Dates - North American Formula SAE Competitions
Registration for the North American Formula SAE competitions will open at 10:00 am EDT, Monday, October 6, 2008. For the first month of the registration period a team may enter either FSAE Michigan or FSAE California, but not both. During that period the team may also register for FSAE Virginia.

Specifically, from 10:00 am EDT, Monday, October 6, 2008 until 10:00 am Thursday, November 6, 2008, teams may register for any one of the following: (a) Formula SAE Michigan alone, (2) Formula SAE California alone, (c) Formula SAE Virginia alone, (d) Formula SAE Michigan and Formula SAE Virginia, or (e) Formula SAE California and Formula SAE Virginia.

After the first month of registration any untaken slots at any of the competitions will be available to any team on a first come, first serve basis.

Specifically from 10:00 am EST, Thursday, November 6, 2008, until the close of registration at 11:59 pm December 22, 2008 teams may register for any competition in which registration slots are available.
Registration for the North American Formula SAE competitions will close at 11:59 pm EST, December 22, 2008 or when all the registration slots have been taken, whichever occurs first.

There is no late registration and there are no exceptions to this registration policy.

7.5 **Formula SAE Australia, Formula SAE Brazil, Formula SAE Italy, and Formula Student**

*Note:* Check the individual competition websites for exact registration requirements, applicable to those events.

7.6 **Registration Fees**

7.6.1 Registration fees must be paid to the organizer by the deadline specified on the respective competition website.

7.6.2 Registration fees are not refundable.

7.7 **Withdrawals**

7.7.1 Registered teams that find that they will not be able to attend the competition are requested to officially withdraw by notifying the following no later than one (1) week before the event:

7.7.2 Formula SAE North American Event withdrawals: Kaley Zundel, kzundel@sae.org

7.7.3 For events outside North America, please visit the respective competition website for contact information.

7.8 **United States Visas**

Teams requiring visas to enter the United States are advised to apply at least sixty (60) days prior to the competition. Although most visa applications seem to go through without an unreasonable delay, occasionally teams have had difficulties and in several instances visas were not issued before the competition.

Don't wait - apply early for your visa.

Neither SAE staff nor any competition organizers are permitted to give advice on either visa or customs matters concerning the United States or any other country.

**ARTICLE 8: QUESTIONS ABOUT THE FORMULA SAE RULES**

8.1 **Frequently Asked Questions**

Before submitting a question, check the Frequently Asked Questions section of the Formula SAE Forum website.

8.2 **Question Format**

8.2.1 All rules questions must include (1) the full name and email address of the student submitting the question, (2) the name of the university - no abbreviations - and (3) the number of the applicable rule.
8.2.2 The following limits apply to questions submitted to the FSAE Rules Committee
(1) No photograph, drawing or other attachment may exceed 100 KB in size
(2) the total size of any question, with all attachments, must not exceed 1MB.

8.3 Response Time
8.3.1 Please allow a minimum of two (2) weeks for a response. The Rules Committee will respond as quickly as possible, however responses to questions presenting new issues, or of unusual complexity, may take more than two weeks.

8.3.2 Please do not resend questions.

8.4 Submission Addresses:
8.4.1 Teams entering Formula SAE competitions in North America
Send questions to: Kathleen McDonald, Formula SAE Consultant
Email: katklauz@aol.com

8.4.2 Teams entering only Formula SAE-Australasia:
Send questions to: SAE-A Organizers
Email: formulasae@saea.com.au

8.4.3 Teams entering only Formula SAE Brazil:
Send questions to: SAE Brazil Organizers
Email: formula.saebrasil@saebrasil.org.br

8.4.4 Teams entering only Formula SAE Italy:
Send questions to: Luciano Pera, Formula SAE Italy, ATA Managing Director
Email: luciano.pera@crf.it

8.4.5 Teams entering only Formula Student:
Send questions to: IMechE Organizers
Email: formulastudent@imeche.org.uk
ARTICLE 1: VEHICLE REQUIREMENTS & RESTRICTIONS

1.1 Technical Inspection
The following requirements and restrictions will be enforced through technical inspection. Noncompliance must be corrected and the car re-inspected before the car is allowed to operate under power.

1.2 Modifications and Repairs
1.2.1 Once the vehicle has been presented for judging in the Cost or Design Events, or submitted for Technical Inspection, and until the vehicle is approved to compete in the dynamic events, i.e. all the inspection stickers are awarded, the only modifications permitted to the vehicle are those directed by the Inspector(s) and noted on the Inspection Form.

1.2.2 Once the vehicle is approved to compete in the dynamic events, the ONLY modifications permitted to the vehicle are those listed below. They are also referenced in Part C of the Formula SAE Rules - Static Event Regulations.
   a) Adjustment of belts and chains
   b) Adjustment of brake bias
   c) Adjustment of the driver restraint system, head restraint, seat and pedal assembly
   d) Substitution of the head restraint or seat insert for different drivers
   e) Adjustment to engine operating parameters, e.g. fuel mixture and ignition timing
   f) Adjustment of mirrors
   g) Adjustment of the suspension where no part substitution is required, (except that springs, sway bars and shims may be changed)
   h) Adjustment of tire pressure
   i) Adjustment of wing angle
   j) Replenishment of fluids
   k) Replacement of worn tires or brake pads
   l) The changing of wheels and tires for "wet" or "damp" conditions as allowed in Part D of the FSAE Rules - Dynamic Event Regulations.

1.2.3 The vehicle must maintain all required specifications, e.g. ride height, suspension travel, braking capacity, sound level and wing location throughout the competition.

1.2.4 Once the vehicle is approved for competition, any damage to the vehicle that requires repair, e.g. crash damage, electrical or mechanical damage will void the Inspection Approval. Upon the completion of the repair and before re-entering into any dynamic competition, the vehicle MUST be re-submitted to Technical Inspection for re-approval.

ARTICLE 2: GENERAL DESIGN REQUIREMENTS

2.1 Vehicle Configuration
The vehicle must be open-wheeled and open-cockpit (a formula style body) with four (4) wheels that are not in a straight line.
2.2 **Bodywork**
There must be no openings through the bodywork into the driver compartment from the front of the vehicle back to the roll bar main hoop or firewall other than that required for the cockpit opening. Minimal openings around the front suspension components are allowed.

2.3 **Wheelbase**
The car must have a wheelbase of at least 1525 mm (60 inches). The wheelbase is measured from the center of ground contact of the front and rear tires with the wheels pointed straight ahead.

2.4 **Vehicle Track**
The smaller track of the vehicle (front or rear) must be no less than 75% of the larger track.

2.5 **Visible Access**
All items on the Inspection Form must be clearly visible to the technical inspectors without using instruments such as endoscopes or mirrors. Visible access can be provided by removing body panels or by providing removable access panels.

**ARTICLE 3: DRIVER'S CELL**

3.1 **General Requirements**
Among other requirements, the vehicle's structure must include two roll hoops that are braced, a front bulkhead with support system and Impact Attenuator, and side impact structures.

3.2 **Definitions**
The following definitions apply throughout the Rules document:
- **Main Hoop** - A roll bar located alongside or just behind the driver's torso.
- **Front Hoop** - A roll bar located above the driver's legs, in proximity to the steering wheel.
- **Roll Hoops** - Both the Front Hoop and the Main Hoop are classified as "Roll Hoops"
- **Frame Member** - A minimum representative single piece of uncut, continuous tubing.
- **Frame** - The "Frame" is the fabricated structural assembly that supports all functional vehicle systems. This assembly may be a single welded structure, multiple welded structures or a combination of composite and welded structures.
- **Primary Structure** - The Primary Structure is comprised of the following Frame components:
  1) Main Hoop, 2) Front Hoop, 3) Roll Hoop Braces, 4) Side Impact Structure, 5) Front Bulkhead, 6) Front Bulkhead Support System and 7) all Frame Members, guides and supports that transfer load from the Driver's Restraint System into items 1 through 6.
- **Major Structure of the Frame** - The portion of the Frame that lies within the envelope defined by the Primary Structure. The upper portion of the Main Hoop and the Main Hoop braces are not included in defining this envelope.
- **Front Bulkhead** - A planar structure that defines the forward plane of the Major Structure of the Frame and functions to provide protection for the driver's feet.
- **Impact Attenuator** - A deformable, energy absorbing device located forward of the Front Bulkhead.
### 3.3 Minimum Material Requirements

#### 3.3.1 Baseline Steel Material

The Primary Structure of the car must be constructed of:

- Either: Round, mild or alloy, steel tubing (minimum 0.1% carbon) of the minimum dimensions specified in the following table,
- Or: Approved alternatives per Rules 3.4, 3.5, 3.6 and 3.7.

<table>
<thead>
<tr>
<th>ITEM or APPLICATION</th>
<th>OUTSIDE DIAMETER X WALL THICKNESS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Main &amp; Front Hoops, Shoulder Harness Mounting Bar</td>
<td>1.0 inch (25.4 mm) x 0.095 inch (2.4 mm) or 25.0 mm x 2.50 mm metric</td>
</tr>
<tr>
<td>Side Impact Structure, Front Bulkhead, Roll Hoop Bracing, Driver’s Restraint Harness Attachment (except as noted above)</td>
<td>1.0 inch (25.4 mm) x 0.065 inch (1.65 mm) or 25.0 mm x 1.75 mm metric or 25.4 mm x 1.60 mm metric</td>
</tr>
<tr>
<td>Front Bulkhead Support</td>
<td>1.0 inch (25.4 mm) x 0.049 inch (1.25 mm) or 25.0 mm x 1.5 mm metric or 26.0 mm x 1.2 mm metric</td>
</tr>
</tbody>
</table>

**Note 1:** The use of alloy steel does not allow the wall thickness to be thinner than that used for mild steel.

**Note 2:** For a specific application, tubing of the specified outside diameter but with greater wall thickness, OR of the specified wall thickness and a greater outside diameter to those listed above, IS NOT a rules deviation requiring approval.

### 3.4 Alternative Tubing and Material - General

#### 3.4.1 Alternative tubing geometry and/or materials may be used except that the Main Roll Hoop and Main Roll Hoop Bracing must be made from steel, i.e. the use of aluminum or titanium tubing or composites for these components is prohibited.

#### 3.4.2 Titanium tubing on which welding has been utilized cannot be used for any tubing in the Primary Structure. This includes the attachment of brackets to the tubing or the attachment of the tubing to other components.

#### 3.4.3 If a team chooses to use alternative tubing and/or materials they must submit a "Structural Equivalency Form" per Rule 3.8. The teams must submit calculations for the material they have chosen, demonstrating equivalence to the minimum requirements found in Section 3.3.1 for yield and ultimate strengths in bending, buckling and tension, for buckling modulus and for energy dissipation. (The Buckling Modulus is defined as E\(I\), where, E = modulus of Elasticity, and I = area moment of inertia about the weakest axis.)

#### 3.4.4 Tubing cannot be of thinner wall thickness than listed in 3.5 or 3.6.
3.5 Alternative Steel Tubing

Minimum Wall Thickness Allowed:

<table>
<thead>
<tr>
<th>MATERIAL &amp; APPLICATION</th>
<th>MINIMUM WALL THICKNESS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Steel Tubing for Front and Main Roll Hoops</td>
<td>2.0 mm (0.079 inch)</td>
</tr>
<tr>
<td>Steel Tubing for Roll Hoop Bracing, Front Bulkhead &amp; Driver's Harness Attachment</td>
<td>1.6 mm (0.063 inch)</td>
</tr>
<tr>
<td>Steel Tubing for Side Impact Structure &amp; Front Bulkhead Support</td>
<td>1.2 mm (0.047 inch)</td>
</tr>
</tbody>
</table>

Note 1: All steel is treated equally - there is no allowance for alloy steel tubing, e.g. SAE 4130, to have a thinner wall thickness than that used with mild steel.

Note 2: To maintain EI with a thinner wall thickness than specified in 3.3.1, the outside diameter MUST be increased.

Note 3: To maintain the equivalent yield and ultimate tensile strength the same cross-sectional area of steel MUST be maintained.

3.6 Aluminum Tubing Requirements

3.6.1 Minimum Wall Thickness: Aluminum Tubing 3.0 mm (0.118 inch)

3.6.2 The equivalent yield strength must be considered in the "as-welded" condition. (Reference: WELDING ALUMINUM (latest Edition) by the Aluminum Association, or THE WELDING HANDBOOK, Vol. 4, 7th Ed., by The American Welding Society), unless the team demonstrates and shows proof that the frame has been properly solution heat treated and artificially aged.

3.6.3 Should aluminum tubing be solution heat-treated and age hardened to increase its strength after welding; the team must supply sufficient documentation as to how the process was performed. This includes, but is not limited to, the heat-treating facility used, the process applied, and the fixturing used.

3.7 Composite Materials

3.7.1 If any composite or other material is used, the team must present documentation of material type, e.g. purchase receipt, shipping document or letter of donation, and of the material properties. Details of the composite lay-up technique as well as the structural material used (cloth type, weight, resin type, number of layers, core material, and skin material if metal) must also be submitted. The team must submit calculations demonstrating equivalence of their composite structure to one of similar geometry made to the minimum requirements found in Section 3.3.1. Equivalency calculations must be submitted for energy dissipation, yield and ultimate strengths in bending, buckling, and tension. Submit the completed "Structural Equivalency Form" per Section 3.8.

3.7.2 Composite materials are not allowed for the Main Hoop or the Front Hoop.
3.8 Structural Equivalency and Structural Equivalency Form (SEF)

3.8.1 ALL TEAMS MUST SUBMIT A STRUCTURAL EQUIVALENCY FORM (SEF), even if they are NOT planning to use alternative materials or tubing sizes to those specified in 3.3.1 Baseline Steel Materials.

3.8.2 The use of alternative materials or tubing sizes to those specified in 3.3.1 “Baseline Steel Material,” is allowed, provided they have been judged by a technical review to have equal or superior properties to those specified in 3.3.1.

3.8.3 Approval of alternative material or tubing sizes will be based upon the engineering judgment and experience of the chief technical inspector or his appointee.

3.8.4 The technical review is initiated by completing the “Structural Equivalency Form” (SEF) using the format given in Appendix B-1.

3.8.5 Structural Equivalency Form - Submission
   a. Address - SEF's must be submitted to the officials at the competition you are entering at the address shown in the Appendix or indicated at the competition website.
   b. Due Date - SEF's must be submitted no later than the date given in the "Action Deadlines" indicated on the competition website. Teams that submit their Structural Equivalency Form after the due date for the competition will be penalized 10 points per day up to a maximum of 50 points, which will be taken off the team's Total Score.
   c. Acknowledgement - North America competitions - SEF’s submitted for vehicles entered into competitions held in North America will be acknowledged upon receipt.

Do Not Resubmit SEF's

3.8.6 Vehicles completed under an approved SEF must be fabricated in accordance with the materials and processes described in the SEF.

3.8.7 Teams must bring a copy of the approved SEF with them to Technical Inspection.

3.9 Main and Front Roll Hoops - General Requirements

3.9.1 The driver's head and hands must not contact the ground in any rollover attitude.

3.9.2 The Frame must include both a Main Hoop and a Front Hoop as shown in Figure 1.

3.9.3 When seated normally and restrained by the Driver's Restraint System, the helmet of a 95th percentile male (anthropometrical data) and all of the team's drivers must:
   a. Be a minimum of 50.8 mm (2 inches) from the straight line drawn from the top of the main hoop to the top of the front hoop. (Figure 1a)
   b. Be a minimum of 50.8 mm (2 inches) from the straight line drawn from the top of the main hoop to the lower end of the main hoop bracing if the bracing extends rearwards. (Figure 1b)
   c. Be no further rearwards than the rear surface of the main hoop if the main hoop bracing extends forwards. (Figure 1c)
95th Percentile Male Template Dimensions

A two dimensional template used to represent the 95th percentile male is made to the following dimensions:

- A circle of diameter 200 mm (7.87 inch) will represent the hips and buttocks.
- A circle of diameter 200 mm (7.87 inch) will represent the shoulder/cervical region.
- A circle of diameter 300 mm (11.81 inch) will represent the head (with helmet).
- A straight line measuring 490 mm (19.29 inch) will connect the centers of the two 200 mm circles.
- A straight line measuring 280 mm (11.02 inch) will connect the centers of the upper 200 mm circle and the 300 mm head circle.

3.9.4 The 95th percentile male template will be positioned as follows: (See Figure 2.)
- The seat will be adjusted to the rearmost position,
- The bottom 200 mm circle will be placed at the junction of the seat back and the seat bottom, tangential to both.
- The middle 200 mm circle, representing the shoulders, will be positioned on the seat back.
- The upper 300 mm circle will be positioned no more than 25.4 mm (1 inch) away from the head restraint (i.e. where the driver's helmet would normally be located while driving).

3.9.5 If the requirements of 3.9.3 are not met with the 95th percentile male template, the car will be allowed to compete. However, 35 points will be deducted from the team's Design Event score.

3.9.6 Drivers who do not meet the helmet clearance requirements of 3.9.3 will not be allowed to drive in the competition.

3.9.7 The minimum radius of any bend, measured at the tube centerline, must be at least three times the tube outside diameter. Bends must be smooth and continuous with no evidence of crimping or wall failure.

3.9.8 The Main Hoop and Front Hoop must be securely integrated into the Primary Structure using gussets and/or tube triangulation.

3.10 Main Hoop

3.10.1 The Main Hoop must be constructed of a single piece of uncut, continuous, closed section steel tubing per Rule 3.3.1.

3.10.2 The use of aluminum alloys, titanium alloys or composite materials for the Main Hoop is prohibited.

3.10.3 The Main Hoop must extend from the lowest Frame Member on one side of the Frame, up, over and down the lowest Frame Member on the other side of the Frame.

3.10.4 In the side view of the vehicle, the portion of the Main Roll Hoop that lies above its attachment point to the Major Structure of the Frame must be within 10 degrees (10°) of the vertical.
3.10.5 In the front view of the vehicle, the vertical members of the Main Hoop must be at least 380 mm (15 inch) apart (inside dimension) at the location where the Main Hoop is attached to the Major Structure of the Frame.

3.10.6 On vehicles where the Primary Structure is not made from steel tubes, the Main Hoop must be continuous and extend down to the bottom of the Frame. The Main Hoop must be securely attached to the monocoque structure using 8 mm Grade 8.8 (5/16 in Grade 5) bolts. Mounting plates welded to the Roll Hoop shall be at least 2.0 mm (0.080 inch) thick steel. Steel backup plates of equal thickness must be installed on the opposing side of the monocoque structure such that there is no evidence of crushing of the core. The attachment of the Main Hoop to the monocoque structure requires an approved Structural Equivalency Form per Section 3.8. The form must demonstrate that the design is equivalent to a welded Frame and must include justification for the number and placement of the bolts.

3.11 Front Hoop
3.11.1 The Front Hoop must be constructed of closed section metal tubing per Rule 3.3.1.

3.11.2 The use of composite materials for the Front Hoop is prohibited.

3.11.3 The Front Hoop must extend from the lowest Frame Member on one side of the Frame, up, over and down to the lowest Frame Member on the other side of the Frame.

3.11.4 With proper gusseting and/or triangulation, it is permissible to fabricate the Front Hoop from more than one piece of tubing.

3.11.5 The top-most surface of the Front Hoop must be no lower than the top of the steering wheel in any angular position.

3.11.6 The Front Hoop must be no more than 250 mms (9.8 inches) forward of the steering wheel. This distance shall be measured horizontally, on the vehicle centerline, from the rear surface of the Front Hoop to the forward most surface of the steering wheel rim with the steering in the straight-ahead position.

3.11.7 In side view, no part of the Front Hoop can be inclined at more than twenty degrees (20°) from the vertical.

3.12 Main Hoop Bracing
3.12.1 Main Hoop braces must be constructed of closed section steel tubing per Rule 3.3.1.

3.12.2 The use of aluminum alloys, titanium alloys or composite materials for the Main Hoop braces is prohibited.

3.12.3 The Main Hoop must be supported by two braces extending in the forward or rearward direction on both the left and right sides of the Main Hoop.

3.12.4 In the side view of the Frame, the Main Hoop and the Main Hoop braces must not lie on the same side of the vertical line through the top of the Main Hoop, i.e. if the Main Hoop leans forward, the braces must be forward of the Main Hoop, and if the Main Hoop leans rearward, the braces must be rearward of the Main Hoop.
3.12.5 The Main Hoop braces must be attached as near as possible to the top of the Main Hoop but not more than 160 mm (6.3 in) below the top-most surface of the Main Hoop. The included angle formed by the Main Hoop and the Main Hoop braces must be at least thirty degrees (30°). See Figure 3.

3.12.6 The Main Hoop braces must be straight, i.e. without any bends.

3.12.7 The attachment of the Main Hoop braces must not compromise the function of the bracing i.e. the attachment method and supporting structure must be capable of transmitting all loads from the Main Hoop into the Major Structure of the Frame without failing. The braces must transmit this load directly through a properly triangulated structure back to the bottom of the Main Hoop. Bracing loads must not be fed solely into the engine, transmission or differential, i.e. the bracing must terminate at a node where there is a load path back to the Main Hoop.

3.12.8 If any item which is outside the envelope of the Primary Structure is attached to the Main Hoop braces, then additional bracing must be added to prevent bending loads in the braces in any rollover attitude.

3.13 Front Hoop Bracing

3.13.1 Front Hoop braces must be constructed of material per Rule 3.3.1.

3.13.2 The Front Hoop must be supported by two braces extending in the forward direction on both the left and right sides of the Front Hoop.

3.13.3 The Front Hoop braces must be constructed such that they protect the driver's legs and should extend to the structure in front of the driver's feet.

3.13.4 The Front Hoop braces must be attached as near as possible to the top of the Front Hoop but not more than 50.8 mm (2 in) below the top-most surface of the Front Hoop. See Figure 3.

3.13.5 If the Front Hoop leans rearwards by more than 10 degrees (10°) from the vertical, it must be supported by additional bracing to the rear. This bracing must be constructed of material per Rule 3.3.1.

3.13.5 Monocoque construction used as Front Hoop bracing requires an approved Structural Equivalency Form per Section 3.8.

3.14 Other Bracing Requirements

3.14.1 Where the braces are not welded to steel Frame Members, the braces must be securely attached to the Frame using 8 mm Grade 8.8 (5/16 in Grade 5), or stronger, bolts. Mounting plates welded to the Roll Hoop braces must be at least 2.0 mm (0.080 in) thick steel.

3.14.2 Where Main Hoop braces are attached to a monocoque structure, backup plates, equivalent to the mounting plates, must be installed on the opposing side of the monocoque structure such that there is no evidence of crushing of the core.

3.14.3 The attachment of the Main Hoop braces to the monocoque structure requires an approved Structural Equivalency Form per Section 3.8. The form must demonstrate that the design is
equivalent to a welded frame and must include justification for the number and placement of the bolts.

3.15 Other Side Tube Requirements
If there is a Roll Hoop brace or other frame tube alongside the driver, at the height of the neck of any of the team's drivers, a metal tube or piece of sheet metal must be firmly attached to the Frame to prevent the drivers' shoulders from passing under the roll hoop brace or frame tube, and his/her neck contacting this brace or tube.

3.16 Mechanically Attached Roll Hoop Bracing
3.16.1 Roll Hoop bracing may be mechanically attached.

3.16.2 Any non-permanent joint at either end must be either a double-lug joint as shown in Figures 4 and 5, or a sleeved butt joint as shown in Figure 6.

3.16.3 The threaded fasteners used to secure non-permanent joints are considered critical fasteners and must comply with Article 14.

3.16.4 No spherical rod ends are allowed.

3.16.5 For double-lug joints, each lug must be at least 4.5 mm (0.177 in) thick steel, measure 25 mm (1.0 in) minimum perpendicular to the axis of the bracing and be as short as practical along the axis of the bracing.

3.16.6 All double-lug joints, whether fitted at the top or bottom of the tube, must include a capping arrangement (Figures 4 & 5).

3.16.7 In a double-lug joint the pin or bolt must be 10 mm Grade 9.8 (3/8 in. Grade 8) minimum. The attachment holes in the lugs and in the attached bracing must be a close fit with the pin or bolt.

3.16.8 For sleeved butt joints (Figure 6), the sleeve must have a minimum length of 76 mm (3 inch), 38 mm (1.5 inch) either side of the joint, and be a close-fit around the base tubes. The wall thickness of the sleeve must be at least that of the base tubes. The bolts must be 6 mm Grade 9.8 (1/4 inch Grade 8) minimum. The holes in the sleeves and tubes must be a close-fit with the bolts.

3.17 Frontal Impact Structure
3.17.1 The driver's feet must be completely contained within the Major Structure of the Frame. While the driver's feet are touching the pedals, in side and front views no part of the driver's feet can extend above or outside of the Major Structure of the Frame.

3.17.2 Forward of the Front Bulkhead must be an energy-absorbing Impact Attenuator.

3.18 Bulkhead
3.18.1 The Front Bulkhead must be constructed of closed section tubing per Rule 3.3.1.

3.18.2 The Front Bulkhead must be located forward of all non-crushable objects, e.g. batteries, master cylinders, hydraulic reservoirs.
3.18.3 The Front Bulkhead must be located such that the soles of the driver's feet, when touching but not applying the pedals, are rearward of the bulkhead plane. (This plane is defined by the forward-most surface of the tubing.) Adjustable pedals must be in the forward most position.

3.18.4 Monocoque construction requires an approved Structural Equivalency Form, per Section 3.8. The form must demonstrate that the design is equivalent to a welded Frame in terms of energy dissipation, yield and ultimate strengths in bending, buckling and tension.

3.19 Front Bulkhead Support
3.19.1 The Front Bulkhead must be securely integrated into the Frame.

3.19.2 The Front Bulkhead must be supported back to the Front Roll Hoop by a minimum of three (3) Frame Members on each side of the vehicle with one at the top (within 50.8 mm (2 inches) of its top-most surface), one (1) at the bottom, and one (1) as a diagonal brace to provide triangulation.

3.19.3 The triangulation must be node-to-node, with triangles being formed by the Front Bulkhead, the diagonal and one of the other two required Front Bulkhead Support Frame Members.

3.19.4 All the Frame Members of the Front Bulkhead Support system listed above must be constructed of closed section tubing per Section 3.3.1.

3.19.5 Monocoque construction requires an approved Structural Equivalency Form, per Section 3.8. The form must demonstrate that the design is equivalent to a welded Frame in terms of energy dissipation, yield and ultimate strengths in bending, buckling and tension.

3.20 Impact Attenuator
3.20.1 The Impact Attenuator must be:
   a. Installed forward of the Front Bulkhead.
   b. At least 200 mm (7.8 in) long, with its length oriented along the fore/aft axis of the Frame.
   c. At least 100 mm (3.9 in) high and 200 mm (7.8 in) wide for a minimum distance of 200 mm (7.8 in) forward of the Front Bulkhead.
   d. Such that it cannot penetrate the Front Bulkhead in the event of an impact.
   e. Attached securely and directly to the Front Bulkhead and not by being part of non-structural bodywork.

3.20.2 The attachment of the Impact Attenuator must be constructed to provide an adequate load path for transverse and vertical loads in the event of off-center and off-axis impacts.

3.20.3 The attachment of the Impact Attenuator to a monocoque structure requires an approved "Structural Equivalency Form" per Section 3.8.

3.20.4 If the Impact Attenuator is foam filled or honeycomb, a 1.5 mm (0.060 in) solid steel or 4.0 mm (0.157 in) solid aluminum "anti-intrusion plate" must be integrated into the Impact Attenuator. The metal plate must be the same size as the outside dimensions of the Front Bulkhead and be bolted or welded to the Front Bulkhead.

3.20.5 If the anti-intrusion is not integral with the frame, i.e. welded, a minimum of four (4) 8 mm Grade 8.8 (5/16 inch Grade 5) bolts must attach the Impact Attenuator to the Front Bulkhead.
3.20.6 Alternative designs of the anti-intrusion plate required by 3.20.4 that do not comply with the minimum specifications given above require an approved "Structural Equivalency Form" per Section 3.8.

3.21 Impact Attenuator Data Requirement
3.21.1 The team must submit test data to show that their Impact Attenuator, when mounted on the front of a vehicle with a total mass of 300 kgs (661 lbs) and run into a solid, non-yielding impact barrier with a velocity of impact of 7.0 metres/second (23.0 ft/sec), would give an average deceleration of the vehicle not to exceed 20 g's, with a peak deceleration less than or equal to 40 g's.

3.21.2 When using acceleration data, the average deceleration must be calculated based on the raw data. The peak deceleration can be assessed based on the raw data, and if peaks above the 40g limit are apparent in the data, it can then be filtered with a Channel Filter Class (CFC) 60 (100 Hz) filter per SAE Recommended Practice J211 "Instrumentation for Impact Test", or a 100 Hz, 3rd order, lowpass Butterworth (-3dB at 100 Hz) filter.

3.21.3 A schematic of the test method must be supplied along with photos of the attenuator before and after testing.

3.21.4 The test piece must be presented at technical inspection for comparison to the photographs and the attenuator fitted to the vehicle.

3.21.5 The test data and calculations must be submitted electronically in Adobe Acrobat ® format (*.pdf file) to the address and by the date provided in the Action Deadlines provided on the relevant competition website. This material must be a single file (text, drawings, data or whatever you are including).

3.21.6 The Impact Attenuator Data must be named as follows: 
carnumber_schoolname_competition code_IAD.pdf using the assigned car number, the complete school name and competition code  
[Example: 087_University of SAE_FSAEV_IAD.pdf]  
Competition Codes are listed in Rule A - 2.6

3.21.7 Teams that submit their Impact Attenuator Data Report after the due date will be penalized 10 points per day up to a maximum of 50 points, which will be taken off the team's Total Score.

3.21.8 Impact Attenuator Reports will be graded by the organizers and the grades will be passed to the Captain of the Design Event for consideration in that event.

3.22 Non-Crushable Objects
All non-crushable objects (e.g. batteries, master cylinders, hydraulic reservoirs) must be rearward of the bulkhead. No non-crushable objects are allowed in the impact attenuator zone.

3.23 Front Bodywork
3.23.1 Sharp edges on the forward facing bodywork or other protruding components are prohibited.
3.23.2 All forward facing edges on the bodywork that could impact people, e.g. the nose, must have forward facing radii of at least 38 mm (1.5 inches). This minimum radius must extend to at least 45 degrees (45°) relative to the forward direction, along the top, sides and bottom of all affected edges.

3.24 Side Impact Structure for Tube Frame Cars
The Side Impact Structure must meet the requirements listed below.

3.24.1 The Side Impact Structure for tube frame cars must be comprised of at least three (3) tubular members located on each side of the driver while seated in the normal driving position, as shown in Figure 7.

3.24.2 The three (3) required tubular members must be constructed of material per Section 3.3.1.

3.24.3 The locations for the three (3) required tubular members are as follows:
• The upper Side Impact Structural member must connect the Main Hoop and the Front Hoop at a height between 300 mm (11.8 inch) and 350 mm (13.8 inch) above the ground with a 77kg (170 pound) driver seated in the normal driving position. The upper frame rail may be used as this member if it meets the height, diameter and thickness requirements.
• The lower Side Impact Structural member must connect the bottom of the Main Hoop and the bottom of the Front Hoop. The lower frame rail/frame member may be this member if it meets the diameter and wall thickness requirements.
• The diagonal Side Impact Structural member must connect the upper and lower Side Impact Structural members forward of the Main Hoop and rearward of the Front Hoop.

3.24.4 With proper gusseting and/or triangulation, it is permissible to fabricate the Side Impact Structural members from more than one piece of tubing.

3.24.5 Alternative geometry that does not comply with the minimum requirements given above requires an approved "Structural Equivalency Form" per Rule 3.8.

3.25 Side Impact Systems for Composite Monocoques
3.25.1 The section properties of the sides of the vehicle meet or exceed the structural requirements for tube frame cars and must reflect impact considerations. Non-structural bodies or skins alone are not adequate.

3.25.2 Teams building composite monocoque bodies must submit the "Structural Equivalency Form" per Section 3.8. Submitted information should include: material type(s), cloth weights, resin type, fiber orientation, number or layers, core material, and lay-up technique.

3.26 Side Impact Systems for Metal Monocoques
3.26.1 These structures must meet the same requirements as tube frames and composite monocoque.

3.26.2 Teams building metal monocoque bodies must submit the "Structural Equivalency Form" per Section 3.8.

3.27 Inspection Holes
3.27.1 To allow the verification of tubing wall thicknesses, 4.5 mm (0.18 inch) inspection holes must be drilled in a non-critical location of both the Main Hoop and the Front Hoop.
3.27.2 In addition, the Technical Inspectors may check the compliance of other tubes that have minimum dimensions specified. This may be done by the use of ultrasonic testing or by the drilling of additional inspection holes at the inspector’s request.

3.27.3 Inspection holes must be located so that the outside diameter can be measured ACROSS the inspection hole with a vernier caliper, i.e. there must be access for the vernier caliper to the inspection hole and to the outside of the tube one hundred eighty degrees (180°) from the inspection hole.

ARTICLE 4: COCKPIT

4.1 Cockpit Opening
4.1.1 In order to ensure that the opening giving access to the cockpit is of adequate size, a template shown in Figure 8 will be inserted into the cockpit opening. It will be held horizontally and inserted vertically until it has passed below the top bar of the Side Impact Structure (or until it is 350 mm above the ground for monocoque cars).

4.1.2 During this test, the steering wheel, steering column, seat and all padding may be removed.

4.2 Cockpit Internal Cross Section:
4.2.1 A free vertical cross section, which allows the template shown in Figure 9 to be passed horizontally through the cockpit to a point 100 mm (4 inches) rearwards of the face of the rearmost pedal when in the inoperative position, must be maintained over its entire length.

4.2.2 The only things that may encroach on this area are the steering wheel, steering column and any padding that is required by Rule 5.7 "Driver’s Leg Protection".

4.2.3 For 2009, teams whose cars do not comply with 4.1 or 4.2 will have 35 points deducted from their Design Event score.

4.3 Driver’s Seat
The lowest point of the driver’s seat must be no lower than the bottom surface of the lower frame rails or by having a longitudinal tube (or tubes) that meets the requirements for Side Impact tubing, passing underneath the lowest point of the seat.

4.4 Floor Close-out
All vehicles must have a floor closeout made of one or more panels, which separate the driver from the pavement. If multiple panels are used, gaps between panels are not to exceed 3 mm (1/8 inch). The closeout must extend from the foot area to the firewall and prevent track debris from entering the car. The panels must be made of a solid, non-brittle material.

4.5 Firewall
4.5.1 A firewall must separate the driver compartment from all components of the fuel supply, the engine oil and the liquid cooling systems. It must protect the neck of the tallest driver. It must extend sufficiently far upwards and/or rearwards such that any point less than 100 mm (4 ins.) above the bottom of the helmet of the tallest driver shall not be in direct line of sight with any part of the fuel system, the cooling system or the engine oil system.

4.5.2 The firewall must be a non-permeable surface made from a fire resistant material.
4.5.3 Pass-throughs for wiring, cables, etc. are allowable if grommets are used to seal the pass-throughs. Also, multiple panels may be used to form the firewall but must be sealed at the joints.

4.6 Accessibility of Controls
All vehicle controls, including the shifter, must be operated from inside the cockpit without any part of the driver, e.g. hands, arms or elbows, being outside the planes of the Side Impact Structure defined in Rule 3.24, 3.25, and 3.26.

4.7 Driver Visibility
4.7.1 General Requirement
The driver must have adequate visibility to the front and sides of the car. With the driver seated in a normal driving position he/she must have a minimum field of vision of 200 degrees (200°) (a minimum 100 (100°) degrees to either side of the driver). The required visibility may be obtained by the driver turning his/her head and/or the use of mirrors.

4.7.2 Mirrors
If mirrors are required to meet Rule 4.7.1, they must remain in place and adjusted to enable the required visibility throughout all dynamic events.

4.8 Driver Egress
All drivers must be able to exit to the side of the vehicle in no more than 5 seconds. Egress time begins with the driver in the fully seated position, hands in driving position on the connected steering wheel and wearing the required driver equipment. Egress time will stop when the driver has both feet on the pavement.

ARTICLE 5: DRIVERS EQUIPMENT (BELTS AND COCKPIT PADDING)

5.1 Belts - General
5.1.1 All drivers must use a 5, 6 or 7 point restraint harness meeting the following specifications.
      The restraint system installation is subject to approval of the Chief Technical Inspector. The restraint system must be worn as tightly as possible at all times.
      a) Material Requirements
         The material of all straps must be Nylon or Dacron polyester and in new or perfect condition. There must be a single release common to the lap belt and shoulder harness using a metal-to-metal quick-release type latch. All driver restraint systems must meet either SFI Specification 16.1, or FIA specification 8853/98. The belts must bear the appropriate dated labels.
      b) Harness Replacement
         SFI spec harnesses must be replaced following December 31st of the 2nd year after the date of manufacture as indicated by the label. FIA spec harnesses must be replaced following December 31st of the year marked on the label. (Note: FIA belts are normally certified for five (5) years from the date of manufacture.)

5.1.2 A 5-point system consists of a 76 mm (3 inch) wide lap belt, approximately 76 mm (3 inch) wide shoulder straps and a single approximately 51 mm (2 inch) wide anti-submarine strap.

      The single anti-submarine strap must have a metal-to-metal connection with the single release common to the lap belt and shoulder harness.
5.1.3 A 6-point system consists of a 76 mm (3 inch) wide lap belt, approximately 76 mm (3 inch) wide shoulder straps and two approximately 51 mm (2 inch) wide leg or anti-submarine straps.

5.1.4 A 7 point system is the same as the 6-point except it has three (3) antisubmarine straps, two (2) from the 6-point system and one (1) from the 5-point system. 6 and 7-point harnesses to FIA specification 8853/98 with approximately 51 mm (2 inch) lap belts are acceptable.

5.1.5 The double leg straps of the 6 or 7-point system may be attached to the Primary Structure, or be attached to the lap belt so that the driver sits on them, passing them up between his or her legs and attaching to the single release common to the lap belt and shoulder harness. The leg straps may also be secured at a point common with the lap belt attachment to Primary Structure, passing them under the driver and up between his or her legs to the harness release.

5.2 Belt and Strap Mounting - General
5.2.1 The lap belt, shoulder harness and anti-submarine strap(s) must be securely mounted to the Primary Structure. Such structure and any guide or support for the belts must meet the minimum requirements of 3.3.1.

5.2.2 The attachment of the Driver's Restraint System to a monocoque structure requires an approved Structural Equivalency Form per Rule 3.8.

5.3 Lap Belt Mounting
5.3.1 The lap belt must pass around the pelvic area below the Anterior Superior Iliac Spines (the hip bones). Under no condition may the lap belt be worn over the area of the intestines or abdomen.

5.3.2 The lap belts should come through the seat at the bottom of the sides of the seat to maximize the wrap of the pelvic surface and continue in a straight line to the anchorage point.

5.3.3 In side view, the lap belt must be at an angle of between 45 degrees (45°) and 65 degrees (65°) to the horizontal. This means that the centerline of the lap belt at the seat bottom should be between 0 - 76 mm (0 - 3 inches) forward of the seat back to seat bottom junction. (See Figure 10).

5.3.4 To fit drivers of differing statures correctly, in side view, the lap belt must be capable of pivoting freely by using either a shouldered bolt or an eye bolt attachment, i.e. mounting lap belts by wrapping them around frame tubes is no longer acceptable.

5.3.5 The lap belts should not be routed over the sides of the seat. The seat must be rolled or grommeted to prevent chafing of the belts.

5.4 Shoulder Harness
5.4.1 The shoulder harness must be the over-the-shoulder type. Only separate shoulder straps are permitted (i.e. "Y"-type shoulder straps are not allowed). The "H"-type configuration is allowed.
5.4.2 It is mandatory that the shoulder harness, where it passes over the shoulders, be 76 mm (3 inch) wide, except as noted below. The shoulder harness straps must be threaded through the three bar adjusters in accordance with manufacturers instructions.

5.4.3 When the HANS device is used by the driver, FIA certified 51 mm (2 inch) wide shoulder harnesses are allowed. Should a driver, at anytime not utilize the HANS device, then 76 mm (3 inch) wide shoulder harnesses are required.

5.4.4 The shoulder harness must be mounted behind the driver to structure that meets the requirements of 3.3.1. However, it cannot be mounted to the Main Roll Hoop Bracing or attendant structure without additional bracing to prevent loads being transferred into the Main Hoop Bracing.

5.4.5 If the harness is mounted to a tube that is not straight, the joints between this tube and the structure to which it is mounted must be reinforced in side view by gussets or triangulation tubes to prevent torsional rotation of the harness mounting tube.

5.4.6 The shoulder harness mounting points must be between 178 mm (7 inches) and 229 mm (9 inches) apart. (See Figure 11).

5.4.7 From the driver's shoulders rearwards to the mounting point or structural guide, the shoulder harness must be between 10 degrees (10°) above the horizontal and 20 degrees (20°) below the horizontal. (See Figure 12).

5.5 Head Restraint
5.5.1 A head restraint must be provided on the car to limit the rearward motion of the driver's head.

5.5.2 The restraint must:
- Have a minimum area of 232 sq. cm (36 sq. inches),
- Be vertical or near vertical in side view.
- Be padded with an energy absorbing material such as Ethafoam® or Ensolite® with a minimum thickness of 38 mm (1.5 inches).
- Be located so that:
  - It is no more than 25 mm (1 inch) away from the back of the driver's helmet in the uncompressed state.
  - The contact point of the back of the driver's helmet on the head restraint is no less than 50 mm (2 inch) from any edge of the head restraint.

5.5.3 The restraint, its attachment and mounting must be strong enough to withstand a force of 890 Newtons (200 lbs. force) applied in a rearward direction.

Notes: (1) The head restraint must meet the above requirements for all drivers. (2) Head restraints may be changed to accommodate different drivers (see 1.2.2.d)

5.6 Roll Bar Padding
Any portion of the roll bar, roll bar bracing or frame which might be contacted by the driver's helmet must be covered with a minimum thickness of 12 mm (0.5 inch) of padding which meets SFI spec 45.1 or FIA 8857-2001.
5.7 Driver's Leg Protection
5.7.1 To keep the driver's legs away from moving or sharp components, all moving suspension and steering components, and other sharp edges inside the cockpit between the front roll hoop and a vertical plane 100 mm (4 inches) rearward of the pedals, must be shielded with a shield made of a solid material. Moving components include, but are not limited to springs, shock absorbers, rocker arms, anti-roll/sway bars, steering racks and steering column CV joints.

5.7.2 Covers over suspension and steering components must be removable to allow inspection of the mounting points.

ARTICLE 6: GENERAL CHASSIS RULES

6.1 Suspension
6.1.1 The car must be equipped with a fully operational suspension system with shock absorbers, front and rear, with usable wheel travel of at least 50.8 mm (2 inches), 25.4 mm (1 inch) jounce and 25.4 mm (1 inch) rebound, with driver seated. The judges reserve the right to disqualify cars which do not represent a serious attempt at an operational suspension system or which demonstrate handling inappropriate for an autocross circuit.

6.1.2 All suspension mounting points must be visible at Technical Inspection, either by direct view or by removing any covers.

6.2 Ground Clearance
The ground clearance must be sufficient to prevent any portion of the car (other than tires) from touching the ground during track events, and with the driver aboard there must be a minimum of 25.4 mm (1 inch) of static ground clearance under the complete car at all times.

6.3 Wheels
6.3.1 The wheels of the car must be 203.2 mm (8.0 inches) or more in diameter.

6.3.2 Any wheel mounting system that uses a single retaining nut must incorporate a device to retain the nut and the wheel in the event that the nut loosens.

6.4 Tires
6.4.1 Vehicles may have two types of tires as follows:
- Dry Tires - The tires on the vehicle when it is presented for technical inspection are defined as its "Dry Tires". The dry tires may be any size or type. They may be slicks or treaded.
- Rain Tires - Rain tires may be any size or type of treaded or grooved tire provided:
  1) The tread pattern or grooves were molded in by the tire manufacturer, or were cut by the tire manufacturer or his appointed agent. Any grooves that have been cut must have documentary proof that it was done in accordance with these rules.
  2) There is a minimum tread depth of 2.4 mms (3/32 inch).

Note: Hand cutting, grooving or modification of the tires by the teams is specifically prohibited.
6.4.2 Within each tire set, the tire compound or size, or wheel type or size may not be changed after static judging has begun. Tire warmers are not allowed. No traction enhancers may be applied to the tires after the static judging has begun.

6.5 **Steering**

6.5.1 The steering system must affect at least two (2) wheels.

6.5.2 The steering system must have positive steering stops that prevent the steering linkages from locking up (the inversion of a four-bar linkage at one of the pivots). The stops may be placed on the uprights or on the rack and must prevent the tires from contacting suspension, body, or frame members during the track events.

6.5.3 Allowable steering system free play is limited to 7 degrees total measured at the steering wheel.

6.5.4 Rear wheel steering is permitted only if mechanical stops limit the turn angle of the rear wheels to ± 3 degrees from the straight ahead position.

6.5.5 The steering wheel must be mechanically connected to the front wheels, i.e. "steer-by-wire" of the front wheels is prohibited.

6.5.6 The steering wheel must be attached to the column with a quick disconnect. The driver must be able to operate the quick disconnect while in the normal driving position with gloves on.

6.5.7 The steering wheel must have a continuous perimeter that is near circular or near oval, i.e. the outer perimeter profile can have some straight sections, but no concave sections. "H", "Figure 8", or cutout wheels are not allowed.

6.6 **Jacking Point**

6.6.1 A jacking point, which is capable of supporting the car's weight and of engaging the organizers' "quick jacks", must be provided at the very rear of the car.

6.6.2 The jacking point is required to be:

- Visible to a person standing 1 metre (3 feet) behind the car.
- Painted orange.
- Oriented horizontally and perpendicular to the centerline of the car
- Made from round, 25 - 29 mm (1 - 1 1/8 inch) O.D. aluminum or steel tube
- A minimum of 300 mm (12 inches) long
- Exposed around the lower 180 degrees of its circumference over a minimum length of 280 mm (11 in)
- The height of the tube is required to be such that:
  - There is a minimum of 75 mm (3 in) clearance from the bottom of the tube to the ground measured at tech inspection.
  - With the bottom of the tube 200 mm (7.9 in) above ground, the wheels do not touch the ground when they are in full rebound.

6.7 **Rollover Stability**

6.7.1 The track and center of gravity of the car must combine to provide adequate rollover stability.
6.7.2 Rollover stability will be evaluated on a tilt table using a pass/fail test. The vehicle must not roll when tilted at an angle of 60 degrees (60°) to the horizontal in either direction, corresponding to 1.7 G's. The tilt test will be conducted with the tallest driver in the normal driving position.

ARTICLE 7: BRAKE SYSTEM

7.1 Brake System - General
The car must be equipped with a braking system that acts on all four wheels and is operated by a single control.

7.1.1 It must have two independent hydraulic circuits such that in the case of a leak or failure at any point in the system, effective braking power is maintained on at least two wheels. Each hydraulic circuit must have its own fluid reserve, either by the use of separate reservoirs or by the use of a dammed, OEM-style reservoir.

7.1.2 A single brake acting on a limited-slip differential is acceptable.

7.1.3 The brake system must be capable of locking all four (4) wheels during the test specified below.

7.1.4 "Brake-by-wire" systems are prohibited.

7.1.5 Unarmored plastic brake lines are prohibited.

7.1.6 The braking systems must be protected with scatter shields from failure of the drive train (see 8.13) or from minor collisions.

7.1.7 In side view no portion of the brake system that is mounted on the sprung part of the car can project below the lower surface of the frame or the monocoque, whichever is applicable.

7.2 Brake Test
The brake system will be dynamically tested and must demonstrate the capability of locking all four (4) wheels and stopping the vehicle in a straight line at the end of an acceleration run specified by the brake inspectors.

7.3 Brake Over-Travel Switch
7.3.1 A brake pedal over-travel switch must be installed on the car. This switch must be installed so that in the event of brake system failure such that the brake pedal over travels, the switch will be activated and will stop the engine from running. This switch must kill the ignition and cut the power to any electrical fuel pumps.

7.3.2 Repeated actuation of the switch must not restore power to these components, and it must be designed so that the driver cannot reset it.

7.3.3 The switch must be implemented with analog components, and not through recourse to programmable logic controllers, engine control units, or similar functioning digital controllers.
7.4 Brake Light
7.4.1 The car must be equipped with a red brake light of at least 15 watts, or equivalent, clearly visible from the rear. If an LED brake light is used, it must be clearly visible in very bright sunlight.

7.4.2 This light must be mounted between the wheel centerline and driver's shoulder level vertically and approximately on vehicle centerline laterally.

ARTICLE 8: POWERTRAIN

8.1 Engine Limitation
8.1.1 The engine(s) used to power the car must be four-stroke piston engine(s) with a displacement not exceeding 610 cc per cycle.

8.1.2 The engine can be modified within the restrictions of the rules.

8.1.3 If more than one engine is used, the total displacement can not exceed 610 cc and the air for all engines must pass through a single air intake restrictor (see 8.6, "Intake System Restrictor.")

8.1.4 Hybrid powertrains utilizing on-board energy storage are not allowed.

8.2 Engine Inspection
The organizer will measure or tear down a substantial number of engines to confirm conformance to the rules. The initial measurement will be made externally with a measurement accuracy of one (1) percent. When installed to and coaxially with spark plug hole, the measurement tool has dimensions of 381 mm (15 inches) long and 30 mm (1.2 inches) diameter. Teams may choose to design in access space for this tool above each spark plug hole to reduce time should their vehicle be inspected.

8.3 Starter
Each car must be equipped with an on-board starter, and be able to start without any outside assistance at any time during the competition.

8.4 Air Intake System
8.4.1 Air Intake System Location
All parts of the engine air and fuel control systems (including the throttle or carburetor, and the complete air intake system, including the air cleaner and any air boxes) must lie within the surface defined by the top of the roll bar and the outside edge of the four tires. (See Figure 13).

8.4.2 Any portion of the air intake system that is less than 350 mm (13.8 inches) above the ground must be shielded from side or rear impact collisions by structure built to Rule 3.24, 3.25, or 3.26 as applicable.

8.5 Throttle and Throttle Actuation
8.5.1 Carburetor/Throttle Body
The car must be equipped with a carburetor or throttle body. The carburetor or throttle body may be of any size or design.
8.5.2 Throttle Actuation
The throttle must be actuated mechanically, i.e. via a cable or a rod system. The use of electronic throttle control (ETC) or "drive-by-wire" is prohibited.

8.5.3 The throttle cable or rod must have smooth operation, and must not have the possibility of binding or sticking.

8.5.4 The throttle actuation system must use at least two (2) return springs located at the throttle body, so that the failure of any component of the throttle system will not prevent the throttle returning to the closed position.

Note: Throttle Position Sensors (TPS) are NOT acceptable as return springs.

8.5.5 Throttle cables must be at least 50.8 mm (2 inches) from any exhaust system component and out of the exhaust stream.

8.5.6 A positive pedal stop must be incorporated on the throttle pedal to prevent over stressing the throttle cable or actuation system.

8.6 Intake System Restrictor
8.6.1 In order to limit the power capability from the engine, a single circular restrictor must be placed in the intake system between the throttle and the engine and all engine airflow must pass through the restrictor.

8.6.2 Any device that has the ability to throttle the engine downstream of the restrictor is prohibited.

8.6.3 The maximum restrictor diameters are:
- Gasoline fueled cars - 20.0 mm (0.7874 inch)
- E-85 fueled cars - 19.0 mm (0.7480 inch)

8.6.4 The restrictor must be located to facilitate measurement during the inspection process.

8.6.5 The circular restricting cross section may NOT be movable or flexible in any way, e.g. the restrictor may not be part of the movable portion of a barrel throttle body.

8.6.6 If more than one engine is used, the intake air for all engines must pass through the one restrictor.

8.7 Turbochargers & Superchargers
8.7.1 Turbochargers or superchargers are allowed if the competition team designs the application. Engines that have been designed for and originally come equipped with a turbocharger are not allowed to compete with the turbo installed.

8.7.2 The restrictor must be placed upstream of the compressor but after the carburetor or throttle valve. Thus, the only sequence allowed is throttle, restrictor, compressor, engine.

8.7.3 The intake air may be cooled with an intercooler (a charge air cooler). Only ambient air may be used to remove heat from the intercooler system. Air-to-air and water-to-air intercoolers are permitted. The coolant of a water-to-air intercooler system must comply with Rule 8.10.
8.8 Fuel Lines
8.8.1 Plastic fuel lines between the fuel tank and the engine (supply and return) are prohibited.

8.8.2 If rubber fuel line or hose is used, the components over which the hose is clamped must have annular bulb or barbed fittings to retain the hose. Also, clamps specifically designed for fuel lines must be used. These clamps have three (3) important features, (i) a full 360 degree (360°) wrap, (ii) a nut and bolt system for tightening, and (iii) rolled edges to prevent the clamp cutting into the hose. Worm-gear type hose clamps are not approved for use on any fuel line.

8.8.3 Fuel lines must be securely attached to the vehicle and/or engine.

8.8.4 All fuel lines must be shielded from possible rotating equipment failure or collision damage.

8.9 Fuel Injection System Requirements
The following requirements apply to fuel injection systems.

8.9.1 Fuel Lines - Flexible fuel lines must be either (i) metal braided hose with either crimped-on or reusable, threaded fittings, or (ii) reinforced rubber hose with some form of abrasion resistant protection with fuel line clamps per 8.8.2. Note: Hose clamps over metal braided hose will not be accepted.

8.9.2 Fuel Rail - The fuel rail must be securely attached to the engine cylinder block, cylinder head, or intake manifold with brackets and mechanical fasteners. This precludes the use of hose clamps, plastic ties, or safety wire.

8.9.3 Intake Manifold - The intake manifold must be securely attached to the engine block or cylinder head with brackets and mechanical fasteners. This precludes the use of hose clamps, plastic ties, or safety wires. The use of rubber bushings or hose is acceptable for creating and sealing air passages, but is not considered a structural attachment.

8.10 Coolant Fluid Limitations
Water-cooled engines must only use plain water, or water with cooling system rust and corrosion inhibitor at no more than 0.015 liters per liter of plain water. Glycol-based antifreeze or water pump lubricants of any kind are strictly prohibited.

8.11 System Sealing
8.11.1 The engine and transmission must be sealed to prevent leakage.

8.11.2 Separate catch cans must be employed to retain fluids from any vents for the coolant system or the crankcase or engine lubrication system. Each catch-can must have a minimum volume of ten (10) percent of the fluid being contained or 0.9 liter (one U.S. quart) whichever is greater.

8.11.3 Catch cans must be capable of containing boiling water without deformation, and be located rearwards of the firewall below driver's shoulder level. They must have a vent with a minimum diameter of 3 mm (1/8 inch) with the vent pointing away from the driver.

8.11.4 Any crankcase or engine lubrication vent lines routed to the intake system must be connected upstream of the intake system restrictor.
8.12 Transmission and Drive
Any transmission and drivetrain may be used.

8.13 Drive Train Shields and Guards
8.13.1 Exposed high-speed equipment, such as torque converters, clutches, belt drives and clutch drives, must be fitted with scatter shields in case of failure.

8.13.2 Scatter shields for chains or belts must not be made of perforated material.

8.13.3 Chain drive - Scatter shields for chains must be made of at least 2.66 mm (0.105 inch) steel (no alternatives are allowed), and have a minimum width equal to three (3) times the width of the chain.

8.13.4 Belt drive - Scatter shields for belts must be made from at least 3.0 mm (0.120 inch) Aluminum Alloy 6061-T6, and have a minimum width that is equal to the belt width plus 35% on each side of the belt (1.7 times the width of the belt).

8.13.5 Attachment Fasteners - All fasteners attaching scatter shields and guards must be a minimum 6mm grade M8.8 (1/4 inch SAE grade 5).

8.13.6 Attached shields and guards must be mounted so that they remain laterally aligned with the chain or belt under all conditions.

8.13.7 Finger Guards - Finger guards may be made of lighter material.

ARTICLE 9: FUEL AND FUEL SYSTEM

9.1 Fuel
The basic fuel available at competitions in the Formula SAE Series is unleaded gasoline with an octane rating of 93 (R+M)/2 (approximately 98 RON). Other fuels may be available at the discretion of the organizing body.

9.1.1 Unless otherwise announced by the individual organizing body, the fuel at competitions in the Formula SAE Series will be provided by the organizer.

9.1.2 During all performance events the cars must be operated with the fuels provided by the organizer at the competition.

9.1.3 Nothing may be added to the provided fuels. This prohibition includes nitrous oxide or any other oxidizing agent.

Note: Teams are advised that the fuel supplied in the United States is subject to various federal and state regulations and may contain up to ten percent (10%) ethanol. The exact chemical composition and physical characteristics of the available fuel may not be known prior to the competition.

Consult the individual competition websites for fuel types and other information.
9.2 Fuel Additives - Prohibited
9.2.1 No agents other than fuel (gasoline or E85), and air may be induced into the combustion chamber. Non-adherence to this rule will be reason for disqualification.

9.2.2 Officials have the right to inspect the oil.

9.3 Fuel Temperature Changes - Prohibited
The temperature of fuel introduced into the fuel system may not be changed with the intent to improve calculated fuel economy.

9.4 Fuel Tanks
9.4.1 The fuel tank is defined as that part of the fuel containment device that is in contact with the fuel. It may be made of a rigid material or a flexible material.

9.4.2 Fuel tanks made of a rigid material cannot be used to carry structural loads, e.g. from roll hoops, suspension, engine or gearbox mounts, and must be securely attached to the vehicle structure with mountings that allow some flexibility such that chassis flex cannot unintentionally load the fuel tank.

9.4.3 Any fuel tank that is made from a flexible material, for example a bladder fuel cell or a bag tank, must be enclosed within a rigid fuel tank container which is securely attached to the vehicle structure. Fuel tank containers (containing a bladder fuel cell or bag tank) may be load carrying.

9.4.4 Any size fuel tank may be used.

9.4.5 The fuel system must have a provision for emptying the fuel tank if required.

9.5 Fuel System Location Requirements
9.5.1 All parts of the fuel storage and supply system must lie within the surface defined by the top of the roll bar and the outside edge of the four tires. (See Figure 13).

9.5.2 All fuel tanks must be shielded from side or rear impact collisions. Any fuel tank which is located outside the Side Impact Structure required by 3.24, 3.25, or 3.26 must be shielded by structure built to 3.24, 3.26, or 3.26.

9.5.3 A firewall must be incorporated to separate the fuel tank from the driver, per Rule 4.5.

9.6 Fuel Tank Filler Neck & Sight Tube
9.6.1 All fuel tanks must have a filler neck:
   (a) at least 38 mm (1.5 inches) diameter,
   (b) at least 125 mm (4.9 inches) vertical height and
   (c) angled at no more than 45 degrees (45°) from the vertical.

9.6.2 The 125 mm of vertical height must be above the top level of the tank, and must be accompanied by a clear fuel resistant sight tube for reading the fuel level. (Figure 14).

9.6.3 The sight tube must have at least 75 mm (3 inches) of vertical height and a minimum inside diameter of 6 mm (0.25 inches).

9.6.4 The sight tube must not run below the top surface of the fuel tank.
9.6.5 A clear filler tube may be used as a sight tube, subject to approval by the Rules Committee or technical inspectors at the event.

9.6.6 A permanent, non-moveable fuel level line must be located between 12.7 mm and 25.4 mm (0.5 inch and 1 inch) below the top of the sight tube. This line will be used as the fill line for the Tilt Test (Rule 9.9), and before and after the Endurance Test to measure the amount of fuel used during the Endurance Event.

9.6.7 The sight tube and fuel level line must be clearly visible to an individual filling the tank.

9.7 Tank Filling Requirement
9.7.1 The tank must be capable of being filled to capacity without manipulating the tank or vehicle in any way (shaking vehicle, etc.).

9.7.2 The fuel system must be designed such that the spillage during refueling cannot contact the driver position, exhaust system, hot engine parts, or the ignition system.

9.7.3 Belly pans must be vented to prevent accumulation of fuel.

9.8 Venting Systems
9.8.1 The fuel tank and carburetor venting systems must be designed such that fuel cannot spill during hard cornering or acceleration. This is a concern since motorcycle carburetors normally are not designed for lateral accelerations.

9.8.2 All fuel vent lines must be equipped with a check valve to prevent fuel leakage when the tank is inverted. All fuel vent lines must exit outside the bodywork.

9.9 Fuel System Integrity - Tilt Test
9.9.1 Tilt Test - Fuel and Fluids
   During technical inspection, the car must be capable of being tilted to a 45 degree (45°) angle without leaking fuel or fluid of any type.

9.9.2 The tilt test will be conducted with the vehicle containing the maximum amount of fluids it will carry during any test or event.

ARTICLE 10: EXHAUST SYSTEM AND NOISE CONTROL

10.1 Exhaust System General
   The car must be equipped with a muffler in the exhaust system to reduce the noise to an acceptable level.

10.1.1 Exhaust Outlet
   The exhaust must be routed so that the driver is not subjected to fumes at any speed considering the draft of the car.

10.1.2 The exhaust outlet(s) must not extend more than 60 cm (23.6 inches) behind the centerline of the rear axle, and shall be no more than 60 cm (23.6 inches) above the ground.
10.1.3 Any exhaust components (headers, mufflers, etc.) that protrude from the side of the body in front of the main roll hoop must be shielded to prevent contact by persons approaching the car or a driver exiting the car.

10.2 Noise Measuring Procedure
10.2.1 The sound level will be measured during a static test. Measurements will be made with a free-field microphone placed free from obstructions at the exhaust outlet level, 0.5 m (19.68 inches) from the end of the exhaust outlet, at an angle of 45 degrees (45°) with the outlet in the horizontal plane. The test will be run with the gearbox in neutral at the engine speed defined below. Where more than one exhaust outlet is present, the test will be repeated for each exhaust and the highest reading will be used.

10.2.2 The car must be compliant at all engine speeds up to the test speed defined below.

10.2.3 If the exhaust has any form of movable tuning or throttling device or system, it must be compliant with the device or system in all positions. The position of the device must be visible to the officials for the noise test and must be manually operable by the officials during the noise test.

10.2.4 Test Speeds
   The test speed for a given engine will be the engine speed that corresponds to an average piston speed of 914.4 m/min (3,000 ft/min) for automotive or motorcycle engines, and 731.5 m/min (2,400 ft/min) for "industrial engines". The calculated speed will be rounded to the nearest 500 rpm. The test speeds for typical engines will be published by the organizers.

   An "industrial engine" is defined as an engine which, according to the manufacturers specifications and without the required restrictor, is not capable of producing more than 5 hp per 100cc. To have an engine classified as "an industrial engine", approval must be obtained from organizers prior to the Competition.

10.3 Maximum Sound Level
   The maximum permitted sound level is 110 dBA, fast weighting.

10.4 Noise Level Re-testing
   At the option of the officials, noise can be measured at any time during the competition. If a car fails the noise test, it will be withheld from the competition until it has been modified and re-passes the noise test.

ARTICLE 11: ELECTRICAL SYSTEM

11.1 Master Switches
11.1.1 The vehicle must be equipped with two (2) master switches. Actuating either switch must stop the engine.

11.1.2 The international electrical symbol consisting of a red spark on a white-edged blue triangle must be affixed in close proximity to each switch.

  Note: Teams are reminded that any alternator field wire must also be disabled by each master switch to prevent any possible feedback through the field coil circuit.
11.2 Primary Master Switch

11.2.1 The primary master switch must:
   a. Be located on the (driver's) right side of the vehicle, in proximity to the Main Hoop, at
      shoulder height and be easily actuated from outside the car.
   b. Disable power to ALL electrical circuits, including the battery, alternator, lights, fuel
      pump(s), ignition and electrical controls.
   c. All battery current must flow through this switch.
   d. Be of a rotary type and must be direct acting, i.e. it cannot act through a relay.

   An example of a typical switch that meets these requirements is shown below.

11.2.2 The "OFF" position of the primary master switch must be clearly marked.

11.3 Cockpit-mounted Master Switch

11.3.1 The cockpit-mounted master switch:
   a. Must be located to provide easy actuation by the driver in an emergency or panic
      situation.
   b. Must be located within easy reach of the belted-in driver, alongside the steering wheel,
      and unobstructed by the steering wheel or any other part of the car. It is suggested that
      it be placed on the same side of the steering wheel as the shifter mechanism.
   c. Must be a push/pull Emergency switch. The switch must be installed such that:
      i. From the ON position, pushing on the switch will disable power to the ignition and all
         fuel pumps, and
      ii. From the OFF position, pulling on the switch will enable power to the ignition and
          fuel pump(s). Switches that require a twist or twist and pull to enable power are
          acceptable.
   d. May act through a relay.

   Examples of typical switches that meet these requirements are shown below.
11.4 Batteries
11.4.1 All batteries, i.e. on-board power supplies, must be attached securely to the frame.

11.4.2 Any wet-cell battery located in the driver compartment must be enclosed in a nonconductive marine-type container or equivalent.

11.4.3 The hot terminal must be insulated on all cars.

ARTICLE 12: AERODYNAMIC DEVICES

12.1 Aero Dynamics and Ground Effects - General
All aerodynamic devices must satisfy the following requirements:

12.2 Location
12.2.1 In plan view, no part of any aerodynamic device, wing, under tray or splitter can be:
   a. Further forward than 460 mm (18 inches) forward of the fronts of the front tires
   b. No further rearward than the rear of the rear tires.
   c. No wider than the outside of the front tires measured at the height of the front hubs.

12.3 Minimum Radii of Edges of Aerodynamic Devices
12.3.1 All wing leading edges must have a minimum radius 12.7 mm (0.5 inch). Wing leading edges must be as blunt or blunter than the required radii for an arc of plus or minus 45 degrees (± 45°) centered on a plane parallel to the ground or similar reference plane for all incidence angles which lie within the range of adjustment of the wing or wing element. If leading edge slats or slots are used, both the fronts of the slats or slots and of the main body of the wings must meet the minimum radius rules.

12.3.2 Other Edge Radii Limitations - All wing edges, end plates, Gurney flaps, wicker bills, splitters undertrays and any other wing accessories must have minimum edge radii of at least 3 mm (1/8 inch) i.e., this means at least a 6 mm (1/4 inch) thick edge.

12.3.3 Wing Edge Restrictions - No small radius edges may be included anywhere on the wings in such a way that would violate the intent of these rules (e.g. vortex generators with thin edges, sharp square corners on end plates, etc.).

12.4 Ground Effect Devices - No power device may be used to move or remove air from under the vehicle except fans designed exclusively for cooling. Power ground effects are prohibited.

12.5 Driver Egress Requirements
12.5.1 Egress from the vehicle within the time set in Rule 4.8 "Driver Egress," must not require any movement of the wing or wings or their mountings.

12.5.2 The wing or wings must be mounted in such positions, and sturdily enough, that any accident is unlikely to deform the wings or their mountings in such a way to block the driver’s egress.
ARTICLE 13: COMPRESSED GAS SYSTEMS AND HIGH PRESSURE HYDRAULICS

13.1 Compressed Gas Cylinders and Lines
Any system on the vehicle that uses a compressed gas as an actuating medium must comply with the following requirements:

a. Working Gas- The working gas must be nonflammable, e.g. air, nitrogen, carbon dioxide.

b. Cylinder Certification- The gas cylinder/tank must be of proprietary manufacture, designed and built for the pressure being used, certified by an accredited testing laboratory in the country of its origin, and labeled or stamped appropriately.

c. Pressure Regulation- The pressure regulator must be mounted directly onto the gas cylinder/tank.

d. Cylinder Location- The gas cylinder/tank and the pressure regulator must be located within the structural portion of the Frame, but not in the cockpit or in a non-structural side pod.

e. Cylinder Mounting- The gas cylinder/tank must be securely mounted to the Frame, engine or transmission.

f. Cylinder Axis- The axis of the gas cylinder/tank must not point at the driver.

g. Insulation- The gas cylinder/tank must be insulated from any heat sources, e.g. the exhaust system.

h. Lines and Fittings- The gas lines and fittings must be appropriate for the maximum possible operating pressure of the system.

i. Protection- The gas cylinder/tank and lines must be protected from damage resulting from the failure of rotating equipment.

13.2 High Pressure Hydraulic Pumps and Lines
The driver and anyone standing outside the car must be shielded from any hydraulic pumps and lines (other than brake lines) by steel or aluminum shields with a minimum thickness of 1 mm (0.039 inch).

ARTICLE 14: FASTENERS

14.1 Fastener Grade Requirements
All threaded fasteners utilized in the steering, braking, driver's harness and suspension systems must meet or exceed, SAE Grade 5, Metric Grade 8.8 and/or AN/MS specifications.

14.2 Securing Fasteners
14.2.1 All critical bolt, nuts, and other fasteners on the steering, braking, driver's harness, and suspension must be secured from unintentional loosening by the use of positive locking mechanisms. Positive locking mechanisms include:

• Correctly installed safety wiring
• Cotter pins
• Nylon lock nuts
• Prevailing torque lock nuts

Note: Lock washers and thread locking compounds, e.g. Loctite®, DO NOT meet the positive locking requirement.

14.2.2 There must be a minimum of two (2) full threads projecting from any lock nut.
14.2.3 All spherical rod ends and spherical bearings on the steering or suspension must be in
double shear or captured by having a screw/bolt head or washer with an O.D. that is larger
than spherical bearing housing I.D.

14.2.4 Adjustable tie-rod ends must be constrained with a jam nut to prevent loosening.

ARTICLE 15: TRANSPONDERS

15.1 Transponders - North American FSAE Competitions
15.1.1 Transponders will be used as part of the timing system for the dynamic events at the North
American FSAE competitions

15.1.2 Each team is responsible for having a functional, properly mounted transponder of the
specified type on their vehicle. Vehicles without a specified transponder will not be allowed
to compete in any event for which a transponder is used for timing and scoring.

15.1.3 All vehicles must be equipped with at least one AMB TranX260 Rechargeable or AMB
TranX260 Direct Power transponder.

15.2 Transponders - Events outside North America
Transponders may be used for timing and scoring at FSAE Australasia, FSAE Brazil, FSAE
Italy and Formula Student and may be provided by the competition organizers. The
transponders specified in 15.1 above for the North American FSAE competitions may or
may not be compatible with the systems used for other events. Teams should check the
individual competition websites for further details.

15.3 Transponder Mounting - All Events
The transponder mounting requirements are:
a. Orientation - The transponder must be mounted vertically and orientated so the number
   can be read "right-side up".
b. Location - The transponder must be mounted on the driver's right side of the car
   forward of the front roll hoop. The transponder must be no more than 60 cm (24 in)
   above the track.
c. Obstructions - There must be an open, unobstructed line between the antenna on the
   bottom of the transponder and the ground. Metal and carbon fiber may interrupt the
   transponder signal. The signal will normally transmit through fiberglass and plastic. If
   the signal will be obstructed by metal or carbon fiber, a 10.2 cm (4 in) diameter opening
can be cut, the transponder mounted flush with the opening, and the opening covered with a material transparent to the signal.
d. Protection - Mount the transponder where it will be protected from obstacles.

ARTICLE 16: VEHICLE IDENTIFICATION

16.1 Car Number
16.1.1 Each car will be assigned a number at the time of its entry into a competition.

16.1.2 Car numbers must appear on the vehicle as follows:
   a. Locations: In three (3) locations: the front and both sides;
   b. Height: At least 15.24 cm (6 inch) high;
   c. Font: Block numbers (i.e. sans-serif characters). Italic, outline, serif, shadow, or cursive numbers are prohibited.
   d. Stroke Width and Spacing between Numbers: At least 2.0 cm (3/4 inch).
   e. Color: Either white numbers on a black background or black numbers on a white background. No other color combinations will be approved.
   f. Background shape: The number background must be one of the following: round, oval, square or rectangular. There must be at least 2.5 cm (1 inch) between the edge of the numbers and the edge of the background.
   g. Clear: The numbers must not be obscured by parts of the car, e.g. wheels, side pods, exhaust system, etc.

16.1.3 Car numbers for teams registered for North American FSAE competitions can be found on the “Registered Teams” section of the relevant Formula SAE website.

Comment: Car numbers must be quickly read by course marshals when your car is moving at speed. Make your numbers easy to see and easy to read.

Example:

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16.2 School Name
16.2.1 Each car must clearly display the school name (or initials - if unique and generally recognized) in roman characters at least 5.08cm, (2 inch) high on both sides of the vehicle. The characters must be placed on a high contrast background in an easily visible location.

16.2.2 The school name may also appear in non-roman characters, but the roman character version must be uppermost on the sides.

16.3 SAE Logo
   The SAE logo must be displayed on the front and/or both sides of the vehicle in a prominent location. SAE logo stickers will be provided to the teams on site.
16.4 Technical Inspection Sticker Space

16.4.1 Technical inspection stickers will be placed on the upper nose of the vehicle. Cars must have a clear and unobstructed area at least 25.4 cm wide x 20.3 cm high (10" x 8") on the upper front surface of the nose along the vehicle centerline.

16.4.2 Vehicles that are being entered into multiple competitions in the FSAE series must allow sufficient space along the nose centerline for all inspection stickers.

ARTICLE 17: EQUIPMENT REQUIREMENTS

17.1 Driver’s Equipment

The following equipment must be worn by the driver anytime he or she is in the cockpit with the engine running:

a. Helmet - A well-fitting, closed face helmet that meets one of the following certifications and is labeled as such:

- SFI 31.2A, SFI 31.1/2005
- FIA 8860-2204
- British Standards Institution BS 6658-85 types A or A/FR rating (Type B is not accepted)

Open faced helmets are not approved. All helmets to be used in the competition must be presented during Technical Inspection where approved helmets will be stickered. The organizer reserves the right to impound all non-approved helmets until the end of the competition.

b. Suit - A fire resistant suit that covers the body from the neck down to the ankles and the wrists. The suit must be in good condition, i.e. it must have no tears or open seams, or oil stains that could compromise its fire resistant capability. The suit must be certified to one of the following standards and be labeled as such:

- SFI 3-2A/1 (or higher)

- FIA Standard 1986

- FIA Standard 8856-2000
c. Gloves - Fire resistant gloves which are free of any holes. Leather gloves are not acceptable.
d. Eye Protection - Goggles or face shield, made of impact resistant materials.
e. Shoes - Shoes of durable fire resistant material and which are free from any holes.
f. Arm restraints - Certified and labeled to SFI standard 3.3, or a commercially manufactured equivalent, and worn such that the driver can release them and exit the vehicle unassisted regardless of the vehicle's position.
g. Hair Covering - A head, hair and neck covering (balaclava) of accepted fire resistant material, e.g. a Nomex balaclava, or a full helmet skirt of accepted fire resistant material. Note: This applies to ALL drivers.
h. Socks - Socks made from an accepted fire resistant material, e.g. Nomex that cover the bare skin between the driver's suit and the boots or shoes. Socks made from wool or cotton is acceptable. Socks of nylon or polyester are not acceptable.

17.2 Fire Extinguishers

17.2.1 Each team must have at least two (2) 0.9 kg (2 lb.) dry chemical/dry powder or 1.75 litres Aqueous Film Forming Foam (AFFF), fire extinguishers.

17.2.2 The following are the minimum ratings, any of which are acceptable at any Formula SAE Series event:

- USA, Canada & Brazil: 10BC or 1A 10BC
- UK, Italy & Europe: 34B or 5A 34B
- Australia: 20BE or 1A 10BE

Extinguishers of larger capacity (higher numerical ratings) are acceptable.

17.2.3 All extinguishers must be equipped with a manufacturer installed pressure/charge gauge.

17.2.4 Except for the initial inspection, one extinguisher must readily be available in the team's paddock area, and the second must accompany the vehicle wherever the vehicle is moved. Both extinguishers must be presented with the vehicle at Technical Inspection.

17.2.5 As a team option, commercially available on-board fire systems are encouraged as an alternative to the extinguisher that accompanies the vehicle.

17.2.6 Hand held fire extinguishers are not permitted to be mounted on or in the car.

Note: Halon extinguishers and systems are prohibited.
ARTICLE 18: POSSIBLE FUTURE RULES CHANGES

NOTICE OF POSSIBLE RULE CHANGES FOR THE 2010 FORMULA SAE SERIES

This section is intended to provide teams with advance notice of possible changes to the Formula SAE Rules that are being considered by the Formula SAE Rules Committee. Only changes that may have a significant influence on a team's engineering design and manufacturing decisions are listed. This section is provided only for information and is not intended to be the final text of the rules under consideration.

For 2010, the Rules Committee is planning to:

- Restructure the rules covering space frames. This will not change the essential requirements of these rules, but will make them easier to understand.
- List the expectations for composite monocoques and any chassis made with carbon fibre tubes.
- For drivers whose helmet is under the Main Hoop, require a minimum clearance to the underside of the Main Hoop. The proposed additional wording is:
  - "In addition, either the driver's shoulders must be forward of the Main Hoop, or there must be a minimum of 100 mm (4 inches) vertical distance between the top of the helmet of all the team's drivers and of a 95th percentile male and the underside of the Main Hoop or any padding on the underside of the Main Hoop."

For 2010 or 2011, to improve the effectiveness of the driver's restraint systems, the Committee is considering following the recommendations of the FIA Institute for Motor Sport Safety to limit the angle of the seat back to 30 degrees from the vertical. The proposed wording would be:

"The seat back must not be inclined at more than 30 degrees to the vertical. This angle will be measured along the line joining the centers of the two 200 mm diameter circles of the template of the 95th percentile male as defined in 3.9.3 of the FSAE Technical Regulations. The template will be located as defined in 3.9.4 of the FSAE Technical Regulations."
2009 Formula SAE Rules

TECHNICAL DRAWINGS

The figures referenced in Part B "Technical Requirements" follow this page.
50 mm (2 inch) Minimum to ALL drivers and 95th percentile template

FIGURE 1a

50 mm (2 inch) Minimum to ALL drivers and 95th percentile template

FIGURE 1b

Helmet must not be rearwards of this line when only forward main hoop bracing used

FIGURE 1c
"Percy" - 95th Percentile Male with Helmet

Circle A = Head with helmet - 300 mm diameter
Circle B = Shoulders - 200 mm diameter
Circle C = Hips and buttocks - 200 mm diameter

Line A-B = 280 mm from centerpoint to centerpoint
Line B-C = 490 mm from centerpoint to centerpoint

FIGURE 2
Front Roll Hoop no lower than top of steering wheel

Bracing 50 mm (2 inch) Max.

Front Roll Hoop and Braces must be integrated into frame and surrounding structure

Bracing 16 cm (6.3 inch) Max.

Main Roll Hoop Braces fore or aft on right and left sides. Minimum of 30° included angle with Roll Hoop

30° Min.

30° Min.

FIGURE 3

Capping Plate

25 mm (1 inch) Minimum

Capping Plate

3/8 in pin

Capping Plate

3/16 in min

3/8 in I.D. Tubing welded into ends of stay

FIGURE 4

FIGURE 5

6 mm (1/4 in)

FIGURE 6
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77 Kg (170 pounds)
driver seated in normal
driving position

In this example:
Upper Frame Member
not considered part of
Side Impact Structure

Upper Side Impact Member
Diagonal Side Impact Member
Lower Side Impact Member

300 - 350 mm
(11.8 - 13.8 inch)

FIGURE 7
Typical 50 mm Flap or slot for steering column clearance only

FIGURE 9
FIGURE 10
Lap Belt Angle

FIGURE 11
Shoulder Harness Mounting Points

FIGURE 12
Shoulder Harness Angle
FIGURE 13
FIGURE 14
### APPENDIX B-1

**FSAE™ STRUCTURAL EQUIVALENCY FORM**

This form must be completed and submitted by all teams no later than the date specified in the Action Deadlines on specific event website. The FSAE Technical Committee will review all submissions which deviate from the FSAE® rules and reply with a decision about the requested deviation. All requests will have a confirmation of receipt sent to the team. Structural Equivalency Forms (SEF) and supporting calculations must be submitted electronically in Adobe Acrobat Format (*.pdf). The submissions must be named as follows: schoolname_sef.pdf using the complete school name. Please submit to the person indicated in the Action Deadlines for each event.

University Name______________________________
Car Number(s) & Event(s)______________________________
Team Contact__________________________E-mail Address______________________________
Faculty Advisor__________________________E-mail Address______________________________

Is proof of equivalency for your design required for any of the rules?

[ ] Yes. Rule(s) deviated (indicate which below)  [ ] No. Chassis did not deviate from baseline requirements

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</tbody>
</table>

**Attachment Checklist** (make sure all are included in your report)

- Receipt, letter of donation or proof for non-steel materials (composite, honeycomb, resin, etc).
- Properties for all non-steel materials
- Holes drilled in any regulated tubing require a deviation, include area and moment of inertia

**ATTACH PROOF OF EQUIVALENCY**

Please see "Structural Equivalency Guide" on SAE website for more information about the proof of equivalency.

**TECHNICAL COMMITTEE DECISION/COMMENTS**

Approved by__________________________ Date__________________________

**NOTE: THIS FORM AND THE APPROVED COPY OF THE SUBMISSION MUST BE PRESENTED AT TECHNICAL INSPECTION AT EVERY FORMULA SAE EVENT ENTERED**
ARTICLE 1:  STATIC EVENTS AND MAXIMUM SCORES

The maximum possible scores in the static events are:

<table>
<thead>
<tr>
<th>Event</th>
<th>Points</th>
</tr>
</thead>
<tbody>
<tr>
<td>Technical Inspection</td>
<td>No</td>
</tr>
<tr>
<td>Cost and Manufacturing</td>
<td>100</td>
</tr>
<tr>
<td>Presentation</td>
<td>75</td>
</tr>
<tr>
<td>Design</td>
<td>150</td>
</tr>
<tr>
<td>Total</td>
<td>325</td>
</tr>
</tbody>
</table>

ARTICLE 2:  TECHNICAL INSPECTION

2.1 Objective of Technical Inspection
The objective of technical inspection is to determine if the vehicle meets the FSAE Rules requirements and restrictions and if, considered as a whole, it satisfies the intent of the Rules.

2.1.1 For purposes of interpretation and inspection the violation of the intent of a rule is considered a violation of the rule itself. (see Rule A - 3.6)

2.1.2 Technical inspection is a non-scored activity.

2.2 Inspection & Testing Requirement
Each vehicle must pass all parts of technical inspection and testing, and bear the inspection stickers, before it is permitted to participate in any dynamic event or to run on the practice track.

2.2.1 All items on the Inspection Form must be clearly visible to the technical inspectors.

2.2.2 Visible access can be provided by removing body panels or by providing removable access panels.

2.3 Team Responsibility
Teams are responsible for confirming that their vehicle, and the required equipment, satisfies the requirements and restrictions of the FSAE Rules before presenting it for Technical Inspection.

2.3.1 Presenting a vehicle for Technical Inspection constitutes a declaration by the team that they have determined by self inspection that the vehicle complies with the Rules.

2.4 Items to be Inspected
The following items must be brought to Technical Inspection:

- Vehicle
- Dry and wet tires
- Driver's equipment including helmets, suits, gloves, eye protection, hair protection equipment, socks, shoes for all drivers.
• Fire extinguishers
• Push bar
• Structural Equivalency Form copies
• Technical Inspection Form
• All drivers must be present at inspection.

2.5 Technical Inspection Procedure
Technical inspection will examine all items included on the Inspection Form found on the SAE website plus any other items the inspectors may wish to examine to ensure conformance with the Rules. The exact procedures and instruments employed for inspection and testing are entirely at the discretion of the Chief Technical Inspector.

2.5.1 Decisions of the inspectors and the Chief Technical Inspector concerning vehicle compliance are final and are not permitted to be appealed.

2.6 Inspection Condition
Vehicles must be presented for technical inspection in finished condition, i.e. fully assembled, complete and ready-to-run. Technical inspectors will not inspect any vehicle presented for inspection in an unfinished state.

Note: Cars may be presented for technical inspection even if final tuning and set-up has not been finished.

2.7 Inspection Process
Vehicle inspection will consist of three separate parts as follows:

2.7.1 Part 1 - Scrutineering
Each vehicle will be inspected to determine if it complies with the requirements of the rules. This inspection will include examination of the driver’s equipment (Rule B - 17.1) and a test of the driver egress time (Rule B - 4.8).

Part 1 must be passed before a vehicle may apply for Part 2 and Part 3 inspection.

2.7.2 Part 2 - Tilt Table Tests
Each vehicle will be tested to insure it satisfies both the 45 degree (45°) fuel and fluid tilt requirement (Rule B - 9.9) and the 60 degree (60°) tilt table requirement (Rule B - 6.7).

Parts 1 and 2 must both be passed before a vehicle may apply for Part 3 inspection.

2.7.3 Part 3 - Noise, Master Switch, and Brake Tests
Noise will be tested by the specified method (Rule B - 10.2). If the vehicle passes the noise test then its master switches will be tested (see Rule B - 11.1). If the vehicle passes both the noise and master switch tests then its brakes will be tested by the specified method (see Rule B - 7.2).

2.8 Correction and Re-inspection
2.8.1 If any part of a vehicle does not comply with the Rules, or is otherwise deemed to be a concern, then the team must correct the problem and have the car re-inspected.

2.8.2 The judges and inspectors have the right to re-inspect any vehicle at any time during the competition and require correction of non-compliance.
2.9  **Inspection Stickers**

Inspection stickers issued following the completion of any part of Technical Inspection will be placed on the upper nose of the vehicle as specified in Rule B - 16.4 "Technical Inspection Sticker Space".

2.9.1 Inspection stickers are issued contingent on the vehicle remaining in the required condition throughout the competition.

2.9.2 Inspection stickers may be removed from vehicles that are not in compliance with the Rules or are required to be re-inspected.

2.10  **"As-Approved Condition"**

Once a vehicle has passed inspection, except as specifically allowed under Rule B -1.2 "Modification and Repairs", it must remain in the "As-approved" condition throughout the competition and must not be modified.

2.11  **Inspection Validity**

Technical approval is valid only for the duration of the specific Formula SAE competition during which the inspection is conducted.

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**ARTICLE 3: COST AND MANUFACTURING EVENT**

3.1  **Event Objective**

The objectives of the Cost and Manufacturing Event are:

A. To teach the participants that cost and budget are significant factors that must be considered in any engineering exercise.

B. For teams to make trade off decisions between content and cost based on the performance advantage of each part and assembly.

C. To gain experience with creating and maintaining a Bill of Material (BOM).

D. For the participants to learn and understand the principles of Design for Manufacture and Assembly, lean manufacturing and Minimum Constraint Design.

3.2  **Rules Objective**

The objectives of the Cost and Manufacturing Event rules are:

A. To provide a logical, simple and time efficient rule set enabling students to achieve the event's objectives.

B. To improve fairness by providing consistent pricing guidelines independent of team geographical location by using standardized Cost Tables.

C. To require the minimal burden of supporting documentation such as receipts or catalog pages. However, in order to convey design information to cost judges engineering documentation (drawings, process descriptions, etc) are required.

3.3  **Event Requirements**

This event is comprised of three (3) parts

3.3.1  The preparation and submission of a report (the "Cost Report"), which is to be sent to the Cost Judges prior to the competition. See 3.8.
3.3.2 A discussion at the Competition with the Cost Judges around the team’s vehicle. See Section 3.21. This evaluates not only the cost of the car, but also the team’s ability to prepare accurate engineering and manufacturing cost estimates.

3.3.3 A “real case” scenario where students will have to respond to a challenge related to cost or manufacturing of the student vehicle.

3.4 Formula SAE Michigan, Formula SAE Virginia & Formula SAE California Reports
Teams that are entering more than one North American competition may submit one (1) Cost Report covering all the competitions entered providing that (a) the report properly identifies the competition names and car numbers and (b) any addenda necessary to cover changes or modifications made to the vehicle between events is properly completed and submitted.

3.5 Definitions
The following definitions will apply throughout the Cost Event rules:

3.5.1 Adjusted Cost - The final cost for the vehicle including penalties

3.5.2 Amended Cost - The cost of the vehicle after modification by the competition addendum

3.5.3 Bill of Material - A hierarchical list of all parts of the vehicle. A BOM lists every item that is on the vehicle but also shows the relationships between these items, for example showing the parts that make up an assembly. A Costed Bill of Material (CBOM) is a standard BOM that includes cost information including cost of purchased parts, raw materials and processes that go into manufacturing the vehicle.

3.5.4 Category - Each table has numerous entries which describe a classification of entry. For example there are several types of hose clamps, and all have various costs. The category of hose clamp may be worm drive, constant tension, etc.

3.5.5 Cost - The cost for each item from the materials table is simply the quantity multiplied by the unit cost.

3.5.6 Cost Report - All materials, including electronic and hard copy, submitted for judging

3.5.7 Cost Score - Refers to the total number of points out of 100 earned in the Cost Event

3.5.8 Cost Tables - All tables that list costs for objects and processes

3.5.9 Design for Manufacture and Assembly (DFMA) - The process where parts are designed for ease of manufacture and assembly, resulting in lower cost.

3.5.10 Fasteners Table - A Cost Table that consists of not only traditional fasteners such as bolts, nuts and rivets but also adhesives, hose clamps and retaining rings.

3.5.11 Fixed Cost - Costs associated with production that are independent of volume produced. Fixed cost items, such as tooling, are converted to variable costs when included in the Cost Report.

3.5.12 Initial Cost - The cost of the vehicle submitted for initial judging in the Cost Report.
3.5.13 Lean Manufacture - A methodology for producing goods that emphasizes the elimination of waste and improvement in process flow with the goal of optimizing the cost and quality of goods.

3.5.14 Materials Table - Lists the costs for raw materials used to manufacture parts built by the teams and also of finished parts purchased by the teams.

3.5.15 Minimum Constraint Design (MCD) - A design methodology emphasizing elimination of redundant constraints in the attachment of parts. Each part requires constraint in six degrees of freedom and additional constraints can make assembly difficult, force tight tolerances and increase the cost of manufactured goods.

3.5.16 Parameters - Used to create an equation describing the cost of an object as a function of some characteristic of that object. For example the cost of steel is proportional to the mass (or volume) of steel. In this case steel has been parameterized by mass. Rubber hose could be parameterized by diameter. The equations can be linear or non-linear and both 1st and 2nd order equations are used as necessary to build the Cost Tables.

3.5.17 Process Multipliers - Modify the standard costs of different operations to account for material and geometric differences in the part.

3.5.18 Purchased Parts - Also called bought parts; these items are listed in the Cost Tables in a near as-installed condition. For example wheels, engines and turbochargers are purchased parts. In some cases purchased parts may still require additional processing before they can be assembled to the car. Wheels, for example, do not include the machined features for mounting to the hub. Purchased parts do not include fasteners unless specifically noted in the Cost Tables.

3.5.19 Quantity - The amount of the item

3.5.20 Raw Materials - Materials used for manufacturing parts, such as aluminum, steel and rubber hose.

3.5.21 Tools - Tools refer to hand or power tools used to assemble the vehicle. The costs of these tools are not included in the Cost Report. The effect of the tools used for assembly are captured in the process tables for labor as different costs are given based on the tools used for assembly.

3.5.22 Tooling - Is the production tooling associated with processes that are specific to the part geometry. The costs of tooling must be included in the Cost Report. For example the dies to stamp out a chassis bracket are tooling. The press used to stamp the bracket is not, and is considered production equipment which is not part of the Cost Event.

3.5.23 Unit - Is the measurement system used to define the quantity of a parameter. For example millimeters and kilograms are units. The hose clamp diameter unit is mm. When calculating the cost of the clamp the unit of measurement used by the team must match the Unit specified in the tables. For example a US team mistakenly calculates the hose clamp cost by using the expression with a diameter of 1, because their radiator hose is 1 inch in diameter. They should have used 25.4mm for the diameter and their cost is wrong because of it. For the penalties associated with this type of error see 3.18
3.5.24 Unit Cost - Is the cost for something assuming a numerical value of one (1) of the unit used to measure the item. The cost is the quantity of an item multiplied by the unit cost.

3.5.25 Variable Cost - Is a cost associated with production that is proportional to the vehicle volume produced. All costs submitted with the Cost Report will be variable costs.

3.6 General Requirements

3.6.1 The Cost Report must:
   A. Use the standardized Cost Tables. The tables are designed to reflect a hypothetical car built for production at the annual volume of 1000 units per year.
   B. List and cost every part on the prototype vehicle. This includes any equipment fitted on the vehicle at any time during the competition. The only exceptions are that, per 3.22 "Cost Report Exempt Items" of the Rules, the cost of any finish, on-board fire suppression system, rain tires, or "stand-alone" data acquisition, video or radio system, does not need to be included in the Cost Report.
   C. Be based on the estimated costs of materials, fabrication, purchased parts, and assembly of the car. The costs shall be calculated as defined in these rules.
   D. Be based on the actual manufacturing technique used on the prototype, e.g. cast parts on the prototype must be cost as cast, and fabricated parts as fabricated, etc.
   E. Include tooling (e.g. welding jigs, molds, patterns and dies) for processes requiring it.
   F. Exclude R & D and capital expenditures (e.g. plant, machinery, hand tools and power tools).

   Note: There is no maximum cost. Receipts are not required for any items.

3.6.2 The Cost Tables have been designed to:
   A. Be verifiable at the event. Differentiating between different types of materials (for example different alloys of steel) is not possible so no differentiation is made in the table cost.
   B. Minimize influence on safety equipment content. For example driver harnesses are cost independent of the style chosen.
   C. Higher costs of some goods must reflect actually higher value of those goods. However, the costs must still allow for team innovation and vehicle content, with some reduction in cost score.
3.7 Scoring

The points for the Cost and Manufacturing Event will be broken down as follows:

<table>
<thead>
<tr>
<th>Formula</th>
<th>Points</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>$40x[(P_{max})/(P_{our})-1]$</td>
<td>40</td>
<td>Lowest cost - each of the participating schools will be ranked by total adjusted cost from the BOM and given 0-40 points based on the formula on the left.</td>
</tr>
<tr>
<td>$(P_{max})/(P_{min})-1$</td>
<td>20</td>
<td>Accuracy, Clarity &amp; Event Day/Visual Inspection - The cars will be reviewed for part content, manufacturing feasibility and accuracy of the cost information. Supporting documentation will be assessed based on its quality, accuracy and thoroughness. The range for the score is 0-40 points.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Event Day/Manufacturing Processes - The teams must be prepared to discuss in detail the “real case” scenario distributed prior to the competition. The materials will include more specifics about the goal and scoring of the scenario. The range for the score is 0-20 points.</td>
</tr>
<tr>
<td></td>
<td>100</td>
<td>Total</td>
</tr>
</tbody>
</table>

Where:

$P_{our}$ is the adjusted cost of your car (with penalties) in dollars.

$P_{min}$ is the adjusted cost of the lowest cost car in dollars.

$P_{max}$ is the cost of the highest cost car in dollars.

3.8 Cost Report

3.8.1 The Cost Report consists of a full vehicle BOM with cost data derived from the Cost Tables and supporting documentation. The Cost Report must be submitted in two (2) forms:

A. Electronic Version - The electronic version must be identified as follows:
   Carnumber_schoolname_competitioncode_CR.pdf using the assigned car number, the complete school name and the competition code.
   Example: 087_University of FSAE_FSAEV_CR.pdf

   Competition Codes are listed in Rule A - 2.6

B. Hard Copy - The hard copy Cost Report must be in a ring binder with 8.5" x 11" or A4 pages.

3.8.2 Cost Report Identification

The cover of the Cost Report must include the following:

(a) university name, (b) competition name, and (c) vehicle number.

Note: Teams that are submitting a single Cost Report covering more than one North American competition must identify their report as follows:

University Name (full name)
Formula SAE Michigan, Car # XXX and Formula SAE California, Car #YYY

3.8.3 The Cost Report must consist of the following:

- A Cover sheet
- A Table of Contents
- A Cost Summary page listing each section's cost, and the total vehicle cost
3.9 Bill of Materials (BOM)
The BOM is a parts list for every vehicle part. It also shows the relationships between the items.

3.9.1 The following terminology will be used when referring to the BOM.
- The overall vehicle is broken down into eight (8) Systems which are defined in Appendix C-3.
- Systems are made up of Assemblies.
- Assemblies are made up of Parts.
- Parts consist of materials, processes and fasteners.
- Tooling is associated with each process that requires production tooling.

3.9.2 An example BOM structure is shown below:
- Engine & Drivetrain........................................System
  o Engine........................................Assembly
  o Differential........................................ Assembly
    f Housing.........................................Part
    f Aluminum.................................Material
    f Needle Bearing.........................Material
    f Sand cast.................................Process
    o Die & Core Package #4........Tooling
    f Machining-Turn.........................Process
    f Weld.................................Process
    f M6x1.25 Grade 8.8...............Fastener
    f Internals.................................Part
    f End Cap................................. Part

The BOM must follow the format given above. There must be no other BOM levels added or any removed. Deviations from the structure published will be penalized per Section 3.17.

3.9.3 All assemblies, parts and fasteners in the BOM must use a standard numbering convention explained in Appendix C-2.

3.10 The Cost Tables
3.10.1 All costs in the Cost Report come from the standardized Cost Tables. These tables have been compiled to represent the cost of parts and processes that a manufacturing company could be expected to pay for manufacturing a vehicle at 1000 units per year. Generally, the tabulated value represents ½ of the Manufacturer's Suggested Retail Price (MSRP) for finished parts. Raw materials, commodities and fasteners also intended to represent the production volume of a company rather than the purchase price of the University teams.

3.10.2 Requests to alter the cost of goods in the tables because of changing world markets or individual team purchase price will not be approved. The tables are intended to provide a fair, unchanging (within a given competition year) cost for parts and to reduce regional variations in price that may help or hurt certain teams. All teams must use the costs given...
in the tables. If a team wishes to use any parts, processes or materials not included in the tables an "Add Item Request" must be submitted as per Section 3.13.

3.10.3 The tables represent cost based on specific parameters. For example the cost of steel is given per unit of volume (or mass). Likewise, engine costs are listed by displacement and specific power output.

3.10.4 The following Cost Tables are used
- Materials
- Processes
- Fasteners
- Process Multipliers

3.10.5 In general, most items have a cost expressed as a function of one parameter. In cases where more than one parameter is necessary additional categories are listed. For example the power output of the engine has three Categories and for each Category a different expression calculates the cost as a function of the engine displacement, which is the Parameter. The Unit would be cubic centimeters in this case.

3.10.6 Process Multipliers are used to modify the standard costs of different operations to account for material and geometric differences in the part. For every process included in the Cost Report the list of process multipliers must be checked to determine if any apply, and if they do their effect on the cost must be included.

3.10.7 When adding items from tables to the BOM the comments section should be reviewed thoroughly to understand what is included in the table entry. For example is the spring included in the damper cost? Do the spark plugs come with the engine or are they a separate line item? In cases where the explanation is not clear please contact the Rules Committee for clarification.

3.11 Cost Models & Costing Methodology
The cost models are the underlying methodology and equations that relate the final cost of a part or process to the different operations and goods used in that part. The detailed explanation of the Cost Models and Costing Methodology is included in Appendix C-1 and should be referenced for understanding the use of the Cost Tables.

3.12 Make Versus Buy
Every part on an individual car can be classified as "made" or "bought". This designation does not necessarily refer to whether a team actually purchased or fabricated a part but is a reflection of how the part must be cost from the Cost Tables.
A. Made (or manufactured) parts must be cost as if the company manufacturing the vehicle was going to make the part internally. That is by purchasing raw materials and processing them into a finished product.
B. Bought parts must be cost as if the company manufacturing the vehicle was going to outsource the fabrication of that part. These parts would be received by the vehicle manufacturer in a relatively finished state (see the particular table entry comments field for specific information).

3.12.1 The Cost Tables have been constructed as a tradeoff between complexity for the organizers and fairness for the teams. The make versus buy designation enables certain parts to be simplified to a relatively few number of entries. For example some teams may
purchase axles but the majority of teams manufacture them. Axles are designated "make" parts so teams that purchase axles must cost them as if they had made them starting with the raw materials, in this case probably steel tubing. Made parts can be distinguished because they do not appear explicitly in the Cost Tables.

3.12.2 If a team genuinely makes a part listed on the table as a bought part they may alternatively cost it as a made part if and only if a place holder entry is listed in the tables enabling them to do so. For example, in the category of dampers a "team built" entry is included. This line item must be included in the BOM (it has zero cost). Then they must proceed to cost the damper they actually designed and built.

3.12.3 A table summary of options is given below:

<table>
<thead>
<tr>
<th>How Table Lists Part</th>
<th>Team Made</th>
<th>Team Bought</th>
</tr>
</thead>
<tbody>
<tr>
<td>Table Lists Part as &quot;Made&quot;, or Part is not Listed in the Tables</td>
<td>Cost as &quot;Made&quot;</td>
<td>Cost as &quot;Made&quot;</td>
</tr>
<tr>
<td>Table Lists Part as &quot;Bought&quot;</td>
<td>Team made option NOT in table cost as &quot;Bought&quot;. If team made option in table team can choose either &quot;Bought&quot; or &quot;Made&quot;</td>
<td>Cost as &quot;Bought&quot;</td>
</tr>
</tbody>
</table>

3.12.4 For example a snap ring does not have a "team made" entry in the Cost Tables. A team who made their own would still have to use the table cost based on diameter, even if they could cost it less expensively by buying steel and processing it.

3.12.5 Any part which is normally purchased that is optionally shown as a made part must have supporting documentation submitted to prove team manufacture. This might include engineering drawings, pictures of machining, etc. Teams found costing bought parts as made parts will be penalized appropriately.

3.13 Add Item Request

3.13.1 The costs tables are intended to include all materials, processes and fasteners needed by the teams to accurately reflect the content, manufacture and assembly of their vehicle. However, it will be necessary to add items to the tables to suit individual team requirements. To do this an "Add Item Request" must be submitted to the Rules Committee. After review the item will be added to the tables with the next table update with a cost appropriate to the overall Cost Table framework and spirit of the competition.

The tables will be updated throughout the competition year as required.
3.13.2 The form should be completely filled out and contains the necessary instructions. Some supporting documentation will be required such as receipts or website links. The Add Item request is the only time receipts will be needed for the Cost Event.

**Note:** Since all teams work off the same tables once a team requests an item be added to the tables all teams will see the addition. Any team using the newly added item will use the same cost. The identity of the school that made the request will not be published.

3.14 Report Submission and Deadline
A. The Cost Report must be submitted in the designated format for each event.
B. For some events, a printed copy of the report must also be submitted and must be on 8 1/2 inch x 11 inch or A4 size paper, using a 10-point font size or larger.
C. Submission Address and Deadline - The submission requirements, address and deadline will be published in the appendix or released on the website of the specific competition.

3.15 Late Submission of Cost Report
It is imperative that the cost judges have the Cost Reports in enough time for proper evaluation. Teams that submit reports late will be penalized 10 points per day late, with a maximum penalty of 80 points. Teams that do not submit a Cost Report will receive negative 100 points for the Cost & Manufacturing Analysis score. Penalties will be applied based on official upload date and time for electronic submission and by post mark for printed submissions.

3.16 Addenda
3.16.1 An addendum that reflects any changes or corrections made after the submission of the Cost Report must be submitted at Registration when the Team registers on-site at the Event. It will not be accepted at any other time or place. The addendum document must follow the template format specified in Appendix C-5. No other format will be accepted.

3.16.2 A separate addendum is permitted for every competition a vehicle attends.

3.16.3 Any items added to the Cost Report through addenda will be cost at 1.25 times the table cost. Any items removed through addenda will only be credited 0.75 times the table cost.

**Note:** Late changes to designs impact costs in the real world. Contracts need to be altered, commodity costs can change, cancellation fees may be incurred and information needs to be transmitted to suppliers. The scaling factors for the addenda capture this as well as encourage teams to submit full and accurate information with the initial Cost Report.

3.17 Cost Report Judging and Penalties Process
3.17.1 The following procedure will be used in determining penalties:
1. Penalty A will be calculated first using procedure 3.18
2. Penalty B will then be calculated using alternative procedure 3.19
3. The greater of the two penalties will be applied against the cost score
   a. Penalty A expressed in points will be deducted from the Accuracy score
   b. Penalty B expressed in dollars will be added to the Adjusted Cost of the vehicle
4. If no additional points remain to be deducted from the Accuracy score the penalty will be applied using method B against the Adjusted Cost
3.17.2 If the alternative penalty is used because no additional accuracy points remain then the highest of the A type penalties will be converted to B type penalties. In effect, the order the penalties are calculated and applied against the team does not matter.

3.17.3 Any error that results in a team over reporting a cost in their Cost Report will not be further penalized. For example, when the Cost Report is prepared the thickness of the brake rotors has not yet been determined. The team conservatively costs the rotors as 10mm thick. The final thickness is 8mm and no change is made in the addendum. The team rotor price is higher than necessary but no penalty is applied.

**Note:** The penalty system is intended to reward accuracy and minimize workload at the competition for students and judges. In most cases the standard points deductions will be made to the accuracy score.

**Note:** Any instance where a team's score benefits by an intentional or unintentional error on the part of the students will be corrected on a case by case basis.

3.18 **Penalty Method A - Fixed Point Deductions**

3.18.1 From the Bill of Material, the cost judges will determine if all parts and processes have been included in the analysis. In the case of any omission or error the judges will add a penalty proportional to the BOM level of the error. The following standard points deductions will apply:

- Missing/inaccurate material, process, fastener .....................1 pt.
- Missing/inaccurate part .................................................. 3 pt.
- Missing/inaccurate assembly .........................................5 pt.

**Note:** Each of the penalties listed above supersedes the previous penalty. If a 5 point deduction is given for a missing assembly the missing parts are ignored for Method A. Method B would include the cost of the missing parts in the calculation.

3.18.2 Differences other than those listed above will be deducted at the discretion of the cost judges.

Examples of errors leading to points deductions:

- Five M6 fasteners listed, six used - 1 pt.
- Three kilograms of steel listed, 4.4 used - 1 pt.
- Bearing carrier face machined, mill operation not included - 1 pt.
- Installation labor for steering wheel missing - 1 pt.
- Upright cost as cast but actual part billet machined - 3 pt.
- Pneumatic shifter not included on BOM - 5 pt.

The penalties above will be deducted from the points awarded for Accuracy of the Cost Report.

3.19 **Penalty Method B - Adjusted Cost Deductions**

The alternative penalty will be calculated using the following equation:

\[
\text{Penalty} = 2 \times (\text{Table Cost} - \text{Team Reported Cost})
\]
The table cost will be calculated from the standard Cost Tables. The penalty calculation will result in a dollar value equal to twice the difference between the team cost and the correct cost for all items in error.

This penalty, if applied, will be made to the Adjusted Cost of the vehicle.

**Note:** The table costs of all items in error are included in the calculation. A missing assembly would include the price of all parts, materials, processes and fasteners making up the assembly.

### 3.20 Penalty Calculation Example

For example the pneumatic shifter was inadvertently left off the Cost Report. As this is an assembly the standard error is 5 points. The cost of all air shifter parts and processes from the Cost Tables is $500. This means the total penalty cost is $1000. To see which is greater, 5 points or $1000, the dollar penalty needs to be converted to points by reference to the Cost Points formula:

\[
\text{Points} = 40 \times \frac{(P_{\text{max}})/(P_{\text{your}})-1}{((P_{\text{max}})/(P_{\text{min}})-1)}
\]

Substitute the cost of the vehicle (\(P_{\text{your}}\)) with $15,000 while the minimum vehicle cost (\(P_{\text{min}}\)) was $10,000. The maximum vehicle cost (\(P_{\text{max}}\)) was $50,000. Calculating the points equivalent for this dollar amount yields 2.5 points. This is less than the standard penalty. In this case the 5 points would be deducted from the Accuracy score.

If the team had made many small errors and had no more accuracy points available then the $1000 would be added to the team’s adjusted cost.

### 3.21 Discussion at the Competition

3.21.1 At this discussion, the Cost Judges will:

A. Review whether the specification of the vehicle in the Cost Report accurately reflects the vehicle brought to the Competition
B. Review the manufacturing feasibility of the vehicle
C. Assess penalties for missing or incorrect information in the Cost Report compared to the vehicle presented at inspection.

3.21.2 The team must present their vehicle at the designated time to the Cost Judges for review of the Cost Report. Teams that miss their cost appointment will potentially lose all cost points for that day. The schedule for these appointments will be in the registration packets and/or posted on the website.

### 3.22 Cost Report Exempt Items

#### 3.22.1 Finishes

The car will be considered to be shipped as primed or gel coated and a cost recorded. Any finishes (paint, polish, etc.) that are only used to beautify need not be costed. Preservative finishes intended to protect the appearance or function of a part for an extended period of time must be costed (labor and material included).
3.22.2 Fire Extinguisher and Suppression System
Hand held fire extinguishers are not allowed on the vehicle (See Rule B-17.2 "Fire Extinguishers"), but if the car has an on-board fire suppression system, it is not required to be costed.

3.22.3 Tires and Wheels
Only one set of tires and wheels needs to be included in the Cost Report. The tires and wheels that are declared as dry tires per rule B-6.4 "Tires" must be the tires included in the Cost Report, and must be the tires on the car during the Cost Event judging. Other tires that will be potentially used at the competition (i.e. rain tires) do not need to be included in the Cost Report.

3.22.4 Transponders, Data Acquisition, Video and Radio Systems
Transponders, "stand-alone" data acquisition, video and radio systems, and their associated sensors, need not be included in the Cost Report. A "stand-alone" system is one that can be removed from the vehicle without affecting the vehicle's ability to perform. Teams that claim to be using a "stand-alone" system may be required to remove the system to substantiate their claim.

3.23 Exchange Rates & Unit Systems
The currency of the Cost Report will be referred to as dollars. Since all items have a cost from the Cost Tables the actual currency unit is irrelevant.

3.23.1 All Cost Tables are presented using metric units. The tables do not differentiate between parts designed in metric and US systems of measure. For example a ¼ bolt is simply input as a 6.35mm bolt. Tubing with a wall thickness of 0.035 inches is input as 0.889mm tubing. All sizes are assumed to be standard for the part being cost and no surcharge applies for any size, even if the size is non-standard. For example a team makes a custom 6.112mm bolt which took several hours of student time. However, this bolt is chosen from the Cost Tables and is less than one dollar. The assumption is in high volume production these bolts would be purchased in bulk.

3.23.2 The comment section for each material, process or fastener may, at the student's discretion, refer to the specific part by actual local designation. For example a 6.35mm bolt is cost but the comments would say "¼ inch A-arm bolt".

3.23.3 Because the Cost Report reflects a production cost for 1000 units per year all material and commodity sizes are assumed to be available for the necessary volume without cost penalty.

3.24 Examples
Examples will be posted to the SAE website

ARTICLE 4: PRESENTATION EVENT

4.1 Presentation Event Objective - Business Case
4.1.1 The objective of the presentation event is to evaluate the team's ability to develop and deliver a comprehensive business case that will convince the executives of a corporation that the team's design best meets the demands of the amateur, weekend competition
racing market, including Sports Car Club of America (SCCA) Solo II, and that it can be profitably manufactured and marketed. (See also A - 1.2)

4.1.2 The judges should be treated as if they were executives of a corporation.

4.1.3 Teams should assume that the "executives" represent different areas of a corporate organization, including engineering, production, marketing and finance, and thus may not all be engineers.

4.1.4 Presentations will be evaluated on the contents, organization and visual aids as well as the presenters' delivery and the team's response to questions.

4.1.5 The presentation must relate to the car entered into the competition although the actual quality of the prototype itself will not be considered as part of the presentation judging.

4.2 Presentation Schedule
4.2.1 Presentations will be made on the static events day. Presentation times will be scheduled by the organizers and either, or both, posted in advance on the competition website or released during on-site registration.

4.2.2 Teams that fail to make their presentation during their assigned time period will receive zero (0) points for the event.

4.3 Presentation Format
4.3.1 One or more team members will give the presentation to the judges.

4.3.2 All team members who will give any part of the presentation, or who will respond to the judges' questions, must be in the podium area when the presentation starts and must be introduced to the judges. Team members who are part of this "presentation group" may answer the judge's questions even if they did not speak during the presentation itself.

4.3.3 Presentations are limited to a maximum of ten (10) minutes. The judges will stop any presentation exceeding ten minutes.

4.3.4 The presentation itself will not be interrupted by questions. Immediately following the presentation there will be a question and answer session of up to five (5) minutes.

4.3.5 Only judges may ask questions. Only team members who are part of the "presentation group" may answer the judges' questions.

4.4 Data Projection Equipment
4.4.1 Projection equipment is not provided by the organizers.

4.4.2 Teams planning to use data projectors, or any type of projectors, as part of their presentation are responsible for bringing, or otherwise arranging for, their own projection equipment.

4.5 Evaluation Criteria
4.5.1 Presentations will be evaluated on content, organization, visual aids, delivery and the team's response to the judges' questions. The scoring criteria are detailed in Appendix C-6 "Presentation Judging".
4.5.2 The criteria are applied only to the team's presentation itself. The team that makes the best presentation, regardless of the quality of their car, will win the event.

4.6 Scoring Formula
4.6.1 The Presentation Events score is based on the average of the judges' scores.

4.6.2 There is a maximum of fifty (50) points from the Presentation Judging Form.

\[
P_{\text{PRESENTATION}} = 75 \times \frac{P_{\text{your}}}{P_{\text{max}}}
\]

Where:
- \(P_{\text{max}}\) is the highest score awarded to any team
- \(P_{\text{your}}\) is the score awarded to your team

4.6.3 It is intended that the scores will range from near zero (0) to seventy-five (75) to provide good separation.

4.6.4 The Presentation Event Captain may at his/her discretion; normalize the scores of different judging teams.

ARTICLE 5: DESIGN EVENT

5.1 Design Event Objective
5.1.1 The concept of the design event is to evaluate the engineering effort that went into the design of the car and how the engineering meets the intent of the market.

5.1.2 The car that illustrates the best use of engineering to meet the design goals and the best understanding of the design by the team members will win the design event.

Comment: Teams are reminded that FSAE is an engineering design competition and that in the Design Event; teams are evaluated on their design. Components and systems that are incorporated into the design as finished items are not evaluated as a student designed unit, but are only assessed on the team's selection and application of that unit. For example, teams that design and fabricate their own shocks are evaluated on the shock design itself as well as the shock’s application within the suspension system. Teams using commercially available shocks are evaluated only on selection and application within the suspension system.

5.2 Design Report - Submission Requirements
5.2.1 Design Report - Judging will start with a Design Review before the event. The principal document submitted for the Design Review is a Design Report.

5.2.2 The Design Report must not exceed eight (8) pages, consisting of not more than four (4) pages of text, three (3) pages of drawings (see 5.4, "Vehicle Drawings") and one (1) optional page containing content to be defined by the team (photo's, graphs, etc...).

5.2.3 The document should contain a brief description of the vehicle with a discussion of any important design features and vehicle concepts. Include a list of different analysis and testing techniques (FEA, dynamometer testing, etc.). Evidence of this analysis and back-up
data should be brought to the competition and be available, on request, for review by the judges.

5.2.4 These documents will be used by the judges to sort teams into the appropriate design groups based on the quality of their review.

Comment: Consider your Design Report to be the "resume of your car".

5.3 Design Spec Sheet - Submission Requirements
5.3.1 Design Spec Sheet - A completed FSAE Design Spec Sheet must be submitted.

5.3.2 The FSAE Design Spec Sheet template can be found on the FSAE website at: http://www.sae.org/students/fsae-designspecs.xls. Do not alter or re-format the template prior to submission.

5.3.3 The design judges realize that final design refinements and vehicle development may cause the submitted figures to diverge slightly from those of the completed vehicle. For specifications that are subject to tuning, an anticipated range of values may be appropriate.

5.3.4 The Design Report and the Design Spec Sheet, while related documents, should stand alone and be considered two (2) separate submissions. Two separate file submissions are required.

5.4 Vehicle Drawings
5.4.1 The Design Report must include one set of 3 view drawings showing the vehicle, from the front, top, and side.

5.4.2 Each drawing shall appear on a separate page. The drawings can be manual or computer generated.

5.4.3 Photos should be placed on the optional page and will not be counted as drawings.

5.5 Design Report and Design Spec Sheet Formats
5.5.1 The Design Report must be submitted electronically in Adobe Acrobat® Format (*.pdf file). This document must be a single file (text, drawings, and optional content all inclusive).

5.5.2 The Design Report file must be named as follows: carnumber_schoolname.pdf using the FSAE assigned car number and the complete school name, e.g. 001_University of SAE.pdf

5.5.3 Design Spec Sheets must be submitted electronically in Microsoft Excel® Format (*.xls file). The format of the Spec Sheet MUST NOT be altered.
5.5.4 Similar to the Design Report, the Design Spec Sheet file must be named as follows: carenumber_schoolname_specs.xls using the FS AE assigned car number and the complete school name, e.g. 001_University of SAE_spec.xls

5.6 **Excess Size Design Reports**

If a team submits a Design Report that exceeds four (4) pages of text, three (3) pages of drawing and one (1) optional page, then only the first four pages of text, three pages of drawings and first optional page will be read and evaluated by the judges. Note: If included, cover sheets and tables of contents will count as text pages.

5.7 **Submission Deadlines**

5.7.1 The Design Report and the Design Spec Sheets must arrive at the specified e-mail address by the date shown in the Action Deadlines for the competition your team is entering. E-mail the Design Report and Design Spec Sheets to the address provided in the appendix.

5.7.2 The two files must be e-mailed as separate files.

5.7.3 Teams will receive confirmation of receipt via email and/or the event website once report is reviewed for accuracy. Teams should have a printed copy of this reply available at the competition as proof of submission in the event of discrepancy.

5.8 **Penalty for Late Submission or Non-submission**

Teams that do not submit a Design Report and a Design Spec Sheet by the specified deadline will not compete in the design event, and will receive zero (0) points for design.

5.9 **Penalty for Unsatisfactory Submissions**

At the discretion of the judges, teams that submit a Design Report or a Design Spec Sheet which is deemed to be unsatisfactory, will also not compete in the design event, but may receive between five (5) and twenty (20) pts. for their efforts.

5.10 **Design Event - Vehicle Condition**

5.10.1 Cars must be presented for design judging in finished condition, i.e. fully assembled, complete and ready-to-run.

5.10.2 The judges will not evaluate any car that is presented at the design event in what they consider to be an unfinished state.

5.10.3 Unfinished cars that are refused judging will receive zero (0) points for design.

5.10.4 Point penalties may be assessed for cars with obvious preparation issues, e.g. notably loose or missing fasteners.

Note: Cars can be presented for design judging without having passed technical inspection, and even if final tuning and setup is in progress.
5.11 Judging Criteria

5.11.1 The design judges will evaluate the engineering effort based upon the team's Design Report, Spec Sheet, responses to questions and an inspection of the car.

5.11.2 The design judges will inspect the car to determine if the design concepts are adequate and appropriate for the application (relative to the objectives set forth in the rules).

5.11.3 It is the responsibility of the judges to deduct points on the design judging form, as given in Appendix C-7, if the team cannot adequately explain the engineering and construction of the car.

5.12 Judging Sequence

5.12.1 The actual format of the design event may change from competition to competition and year to year as determined by the organizing body.

5.12.2 All Formula SAE organizing bodies reserve the right to organize Design Judging into one, two or three steps at their sole discretion.

5.12.3 Three step Design Judging is typically organized as follows:
   1. Initial judging of all vehicles
   2. Semi-final judging of the top 10 to 20 vehicles
   3. Final judging ranking the top 4 to 8 vehicles.

5.13 Scoring

5.13.1 Scoring may range from 0 to 150 pts. at the judges discretion.

5.13.2 The judges may at their discretion award the highest placing team less than 150 points.

5.14 Support Material

Teams may bring with them to the Design Event any photographs, drawings, plans, charts, example components or other materials that they believe are needed to support the presentation of the vehicle and the discussion of their development process.

5.15 Second Year Cars - Penalties for Insufficient Redesign

5.15.1 Penalties for insufficient redesign are in effect at Formula SAE Australasia, Formula SAE Brazil, Formula SAE Italy, and Formula Student.

5.12.2 The judges will deduct fifty (50) points from the final design score for cars without a new frame. (see Rule A-6.9) An additional thirty (30) points may be deducted if the photographic and other supporting documentation fails to show that the remaining parts of the vehicle have been significantly changed (e.g. the intake manifold is obviously the same or it is obvious that the old suspension was simply bolted to a new frame, or none of the team members show an understanding of the design of various components).

5.15.3 If the new frame is similar to last years, it is advisable to bring along evidence of the change (bringing along the old frame is not a bad idea).

5.15.4 Second year cars are prohibited at the North American FSAE competitions. (see Rule A-6.7)
APPENDIX C - 1
COST MODELS AND COST METHODOLOGY
Please see SAE Website for Appendix C-1

APPENDIX C - 2
STANDARD PART NUMBERING
Please see SAE Website for Appendix C-2

APPENDIX C - 3
ORGANIZED LIST OF SYSTEMS & ASSEMBLIES
Please see SAE Website for Appendix C-3

APPENDIX C - 4
POWER TOOL PACKAGE ENVELOPES
Please see SAE Website for Appendix C-4
## APPENDIX C - 5
### 2009 FSAE COST EVENT ADDENDUM

School: ___________________________ Car Number: ________

(Please indicate decreases using bracketed numbers.)

<table>
<thead>
<tr>
<th>Section</th>
<th>Original Reported Total</th>
<th>New Reported Total</th>
<th>Difference</th>
<th>Cost Judge Initials</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td></td>
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<td></td>
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<td>8</td>
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</tbody>
</table>

**TOTAL VEHICLE**

Summary of differences listed above. Fully detailed Costed Bill of Material for changes.

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</table>
|   |   |   | Attach


Addendums will be accepted only at the time of registration on-site at the competition!

These forms will then be forwarded to the cost judges the morning of the cost event.

Accepted by:  
Entered by:  
Date: _______  Date/Time: _______
APPENDIX C - 6
PRESENTATION JUDGING

SCHOOL

Score the following categories on the basis of 0-10 points each according to the following scale (any number or fraction along this scale may be used).

0.0 = inadequate or no attempt
2.5 = attempted but below expectation
5 = average or expected
7.5 = above average but still lacking
10 = excellent, perfectly meets intent

CONTENT: Were the concepts presented appropriate and adequate to explain how the car meets the intent of the customer? Were enough technical details presented without being boring?

ORGANIZATION: Were the concepts presented in a logical order progressing from basic concept and showing how the engineering accomplished the concept? Was it clear to the audience what was to be presented and what was coming next? Were distinct introduction and overviews as well as summary and conclusions given?

VISUAL AIDS: Were visual aids used or clear visual references made to the car? Were the illustrations visible for all of the audience?

DELIVERY: Did the presenter speak in a clear voice? Did the presenter show enthusiasm and promote confidence in the technical aspects? Did he maintain eye contact?

QUESTIONS: Did the answer illustrate that the team fully understood the question? Is there doubt that the team understood the answer? Did the team promote complete confidence in their response to the questions?

TOTAL = PRESENTATION POINTS (50 points maximum)

COMMENTS:
<table>
<thead>
<tr>
<th>Category</th>
<th>Points</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>AESTHETICS (0-5)</td>
<td></td>
<td>Does the vehicle look attractive? Does it have a high performance appearance?</td>
</tr>
<tr>
<td>MECHANICAL DESIGN (0-20)</td>
<td></td>
<td>Do components appear to have been sized properly for the load? Does form follow function? Do brackets serve more than one purpose?</td>
</tr>
<tr>
<td>CHASSIS DESIGN (0-30)</td>
<td></td>
<td>Does the suspension design consider kinematics, roll center placement or load transfer? How was vehicle handling designed for and developed? How was brake system designed? Was weight distribution and C.G. height optimized?</td>
</tr>
<tr>
<td>MANUFACTURABILITY (0-10)</td>
<td></td>
<td>Can 1000 units per year be economically produced? Was manufacturing and ease of assembly a major consideration?</td>
</tr>
<tr>
<td>SERVICEABILITY (0-15)</td>
<td></td>
<td>Is the engine easy to service or remove? Is the suspension easy to adjust?</td>
</tr>
<tr>
<td>INNOVATIVENESS (0-15)</td>
<td></td>
<td>Are any of the components or systems unique? Do the innovations add to the product's functions?</td>
</tr>
<tr>
<td>ERGONOMICS/INTERIORS/SAFETY (0-20)</td>
<td></td>
<td>Is the vehicle designed to accommodate &amp; function with a wide variety of body sizes? Are controls and instruments easy to use? Does the design consider occupant safety beyond the requirements?</td>
</tr>
<tr>
<td>POWERTRAIN (0-30)</td>
<td></td>
<td>Does the engine have significant modifications with respect to fuel injection, turbocharging, intake or exhaust? Was the drivetrain well done? Were throttle, drive controls designed well?</td>
</tr>
<tr>
<td>BUILD QUALITY (0-5)</td>
<td></td>
<td>Fit and finish, quality of materials, detail work, quality appearance.</td>
</tr>
<tr>
<td>MISCELLANEOUS (0 to -50)</td>
<td></td>
<td>If (a) this entry is a second year car and did not undergo significant improvements (not applicable in North America) or (b) if the team does not exhibit a good understanding of the car, then a penalty may be applied.</td>
</tr>
<tr>
<td>TOTAL = DESIGN POINTS (150 points maximum)</td>
<td></td>
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</tbody>
</table>

COMMENTS:
ARTICLE 1: DYNAMIC EVENTS AND MAXIMUM SCORES

The maximum scores in the dynamic events are:

- Acceleration: 75 points
- Skid Pad: 50 points
- Autocross: 150 points
- Fuel Economy: 100 points
- Endurance: 300 points

Total: 675 points

1.1 Vehicle Integrity and Disqualification

1.1.1 During the Dynamic Events, the mechanical integrity of the vehicle must be maintained.

1.1.2 Any vehicle condition that could compromise vehicle integrity, or could compromise the track surface or could pose a potential hazard to participants, e.g. damaged suspension, brakes or steering components, fluid leaks, dragging bodywork, or lost or loose body panels, will be a valid reason for exclusion by the official until the problem is rectified.

Note: If this happens during the Endurance Event, it means disqualification from the heat.

ARTICLE 2: WEATHER CONDITIONS

The organizer reserves the right to alter the conduct and scoring of the competition based on weather conditions.

ARTICLE 3: RUNNING IN RAIN

3.1 Operating Conditions

The following operating conditions will be recognized at Formula SAE:

3.1.1 Dry - Overall the track surface is dry.

3.1.2 Damp - Significant sections of the track surface are damp.

3.1.3 Wet - The entire track surface is wet and there may be puddles of water.

3.1.4 Weather Delay/Cancellation - Any situation in which all, or part, of an event is delayed, rescheduled or canceled in response to weather conditions.

3.2 Decision on Operating Conditions

The operating condition in effect at any time during the competition will be decided by the competition officials.
3.3 Notification
If the competition officials declare the track(s) to be "Damp" or "Wet",
i. This decision will be announced over the public address system, and
ii. A sign with either "Damp" or "Wet" will be prominently displayed at both the
starting line(s) or the start-finish line of the event(s), and the entry gate to the
"hot" area.

3.5 Tire Requirements
The operating conditions will determine the type of tires a car may run as follows:

3.5.1 Dry - Cars must run their Dry Tires, except as covered in Rule 3.9.2.

3.5.2 Damp - Cars may run either their Dry Tires or Rain Tires, at each team's option.

3.5.3 Wet - Cars must run their Rain Tires.

3.6 Event Rules
All event rules remain in effect.

3.7 Penalties
All penalties remain in effect.

3.8 Scoring
No adjustments will be made to teams' times for running in "Damp" or "Wet" conditions. The
minimum performance levels to score points may be adjusted if deemed appropriate by the
officials.

3.9 Tire Changing
3.9.1 During the Acceleration, Skid-Pad or Autocross Events:
Within the provisions of Rule 3.5 above, teams may change from Dry Tires to Rain Tires
or vice versa at any time during those events at their own discretion.

3.9.2 During the Endurance Event:
Teams may change from Dry to Rain Tires or vice versa at any time while their car is in the
staging area inside the "hot" area.

All tire changes after a car has received the "green flag" to start the Endurance Event shall
take place in the Driver Change Area.

(a) If the track was "Dry" and is declared "Damp":
• Teams may start on either Dry or Rain Tires at their option.
• Teams that are on the track when it is declared "Damp", may elect, at
their option, to pit in the Driver Change Area and change to Rain Tires
under the terms spelled out below in "Tire Changes in the Driver Change
Area".

(b) If the track is declared "Wet":
• A Red Flag will be shown at the Start/Finish Line and all cars will enter
the Driver Change Area.
• Those cars that are already fitted with "Rain" tires will be allowed re-start
without delay subject to the discretion of the Event Captain/Chief
• Those cars without "Rain" tires will be required to fit them under the
terms spelled out below in "Tire Changes in the Driver Change Area".
They will then be allowed to re-start at the discretion of the Event
Captain/Chief Marshall.

(c) If the track is declared "Dry" after being "Damp" or "Wet":
• The teams will NOT be required to change back to "Dry" tires.

(d) Tire Changes at Team's Option:
• Within the provisions of Rule 3.5 above and Rule 3.9.2(b) above, a team
will be permitted to change tires at their option.
• If a team elects to change from "Dry" to "Rain" tires, the time to make the
change will NOT be included in the team's total time.
• If a team elects to change from "Rain" tires back to "Dry" tires, the time
taken to make the change WILL be included in the team's total time for
the event, i.e. it will not be subtracted from the total elapsed time.
However, a change from "Rain" tires back to "Dry" tires will not be
permitted during the driver change.
• To make such a change, the following procedure must be followed:
  o Team makes the decision,
  o Team has tires and equipment ready near Driver Change Area,
  o The team informs the Event Captain/Chief Marshall they wish
    their car to be brought in for a tire change,
  o Officials inform the driver by means of a sign or flag at the
    checker flag station,
  o Driver exits the track and enters the Driver Change Area in the
    normal manner.

(e) Tire Changes in the Driver Change Area:
• Per Rule 8.11.2, no more than three people for each team may be
  present in the Driver Change Area during any tire change, e.g. a driver
  and two crew or two drivers and one crew member.
• No other work may be performed on the cars during a tire change.
• Teams changing from "Dry" to "Rain" tires will be allowed a maximum of
ten (10) minutes to make the change.
• If a team elects to change from "Dry" to "Rain" tires during their
  scheduled driver change, they may do so, and the total allowed time in
  the Driver Change Area will be thirteen (13) minutes.
• The time spent in the driver change area of less than 10 minutes without
  driver change, or 13 minutes with driver change, will not be counted in
  the team's total time for the event. Any time in excess of these times will
  be counted in the team's total time for the event.

ARTICLE 4: DRIVER LIMITATIONS

4.1 Three Event Limit
An individual team member may not drive in more than three (3) events.

4.1.1 The Fuel Economy Event is considered a separate event although it is conducted
simultaneously with the Endurance Event.
4.2 Single Heat Limit
An individual may not drive in both heats of any event. It is the team's option to participate in any event.

4.2.1 The team may forfeit their second heat in any performance event.

Note: At competitions where Endurance and Fuel Economy is run with one (1) heat a minimum of four (4) drivers are required to participate in all heats of the dynamic events. At competitions where Endurance and Fuel Economy is run with two (2) heats a minimum of five (5) drivers are required to participate in all heats of the dynamic events.

ARTICLE 5: ACCELERATION EVENT

5.1 Acceleration Objective
The acceleration event evaluates the car's acceleration in a straight line on flat pavement.

5.2 Acceleration Procedure
The cars will accelerate from a standing start over a distance of 75 m (82 yards) on a flat surface.

5.2.1 The foremost part of the car will be staged at 0.30 m (11.8 inches) behind the starting line.

5.2.2 A green flag will be used to indicate the approval to begin, however, time starts only after the vehicle crosses the start line.

5.2.3 A driver has the option to take a second run immediately after the first.

5.3 Acceleration Heats
5.3.1 There will be two (2) heats. Each heat must have a different driver and each driver can have two (2) runs.

5.3.2 Starting order will be based upon time of arrival to the staging area.

5.3.3 Heat one (1) and heat two (2) will not be run sequentially, but simultaneously. Heat 1 drivers will have starting priority over heat 2 drivers.

5.4 Tire Traction - Limitations
Special agents that increase traction may not be added to the tires or track surface and "burnouts" are not allowed.

5.5 Acceleration Scoring
The acceleration score is based upon the corrected elapsed time. Elapsed time will be measured from the time the car crosses the starting line until it crosses the finish line.

5.6 Acceleration Penalties
5.6.1 Cones Down Or Out (DOO)
A two (2) second penalty will be added for each DOO (including entry and exit gate cones) that occurred on that particular run to give the corrected elapsed time.
5.6.2 Off Course
An Off Course (OC) will result in a DNF for that run.

5.7 Did Not Attempt
Cars that have not run by the end of the event (determined by the organizer) will receive a Did Not Finish (DNF).

5.8 Acceleration Scoring Formula

5.8.1 The score for the acceleration event is spread between zero (0) and seventy-five (75) based upon the elapsed time.

5.8.2 The following equation is used to determine the scores for the event:

\[
\text{ACCELERATION SCORE} = 71.5 \times \frac{(5.8/T_{\text{your}}) - 1}{(5.8/T_{\text{min}}) - 1} + 3.5
\]

Where:
- \( T_{\text{your}} \) is the best corrected elapsed time for the team including penalties.
- \( T_{\text{min}} \) is the elapsed time of the fastest car.

5.8.3 In the above equation, the first term on the right hand side is "performance" points, while the second term represents "completion points," or the minimum score for having successfully completed the event.
- DNF = zero (0) points

5.8.4 The maximum acceptable acceleration time is 5.8 seconds corresponding to an average speed of 46.55 km/hr.

5.8.5 Negative "performance" points will not be given. However, 3.5 points will be given for a car that completes a run, even if \( T_{\text{your}} \) exceeds 5.8 seconds.

ARTICLE 6: SKID-PAD EVENT

6.1 Skid-Pad Objective
The objective of the skid-pad event is to measure the car's cornering ability on a flat surface while making a constant-radius turn.

6.2 Skid-Pad Heats
6.2.1 Each car may compete in two heats. Each heats must have a different driver, and each driver may have two (2) runs.

6.2.2 Two separate skid-pad locations may exist. If there are two (2) skid-pads, one driver must make both his runs on one skid-pad (Skid-Pad 1) and the other driver must make both his runs on the other skid-pad (Skid-Pad 2).

6.2.3 If there is only one skid-pad location then both Heat one (1) and Heat two (2) will be run on the same skid-pad.
6.3  **Skid-Pad Heat Priority**
There will be no distinction between Heat one (1) and Heat two (2) and there will be no particular starting order. Heat one (1) drivers will have a starting priority over Heat two (2) drivers. Cars which have not run by the event closing (determined by the organizer) will receive a DNF for the event.

6.4  **Skid-Pad Layout**
There will be two (2) pairs of concentric circles in a figure of eight pattern. The centers of these circles will be 18.25 m (59.88 feet) apart. The inner circles will be 15.25 m (50.03 feet) in diameter, and the outer circles will be 21.25 m (69.72 feet) in diameter. The driving path will be the 3.0 m (9.84 feet) path between the inner and outer circles. The cars will enter and exit through gates on a 3.0 m wide path that is tangential to the circles where they meet.

The line between the centers of the circles defines the start/stop line. A lap is defined as traveling around one (1) of the circles from the start/stop line and returning to the start/stop line.
6.5 **Skid-Pad Layout - Marking**

6.5.1 Sixteen (16) pylons will be placed around the inside of each inner circle and sixteen (16) pylons around the outside of each outer circle.

6.5.2 Each circle will be marked with a chalk line, inside the inner circle and outside the outer circle, i.e. not on the driving path.

6.5.3 Additional pylons will establish the required entry and exit gates. Also, a cone will be placed in the middle of the exit gate to prevent unintended exits until the finish lap.

Note: The diagram in section 6.4 shows the circles for cone placement, not for course marking. Chalk lines are marked on the opposite side of the cones, i.e. not in the driving path.

6.6 **Skid-Pad Procedure**

The cars will enter perpendicular to the figure eight and will take one full lap on the right circle to establish the turn. The next lap will be on the right circle and will be timed. Immediately following the second lap, the car will enter the left circle for the third lap. The fourth lap will be on the left circle and will be timed. Immediately upon finishing the fourth lap, the car will exit the track. The car will exit at the intersection moving in the same direction as entered. A driver has the option to take a second run immediately after the first.

6.7 **Skid-Pad Penalties**

The elapsed time for the right and left circle will be averaged together after the following penalties have been assessed.

6.7.1 Cones Down Or Out (DOO)

A penalty of 0.25 seconds will be added to the time for every cone that is knocked "down or out" (including gate cones).

6.7.2 Off Course

Cars that spin-out can continue as long as they have not gone off course. Cars going off course will be classified as DNF.

6.7.3 Incorrect Laps

Cars that do not follow 6.6 above, i.e. run an incorrect number of laps or run the laps in the wrong sequence will be classified as DNF.

6.8 **Skid-Pad Scoring**

6.8.1 The skid-pad score is computed based upon the lateral acceleration capability. Lateral acceleration (typically referred to as G's) is computed from 2.012 diameter/t². A diameter of 17.10 m will be assumed in computing lateral G's.

6.8.2 If there are two separate skid-pad locations, then the score will be based on the best run from either skid-pad.
6.8.3 The following equation is used to determine the scores for the skid-pad event:

\[
\text{SKID PAD SCORE} = 47.5 \times (6.184/T_{\text{your}})^2 - 1 + 2.5
\]

Where:
- \(T_{\text{your}}\) is the average of the left and the right timed laps on your best run including penalties.
- \(T_{\text{min}}\) is the elapsed time of the fastest car.

6.8.4 The first term on the right-hand side of the equation represents "performance points," while the second term represents "completion points," or the minimum score for having successfully completed the event.

6.8.5 The minimum acceptable lateral acceleration to earn "performance" points is 0.90 G's corresponding to 6.184 seconds per circle. Negative "performance" points will not be given. However, 2.5 points will be given if a car that completes a run that exceeds 6.184 seconds per circle AND is not classified as a DNF.

ARTICLE 7: AUTOCROSS EVENT

7.1 Autocross Objective
The objective of the autocross event is to evaluate the car's maneuverability and handling qualities on a tight course without the hindrance of competing cars. The autocross course will combine the performance features of acceleration, braking, and cornering into one event.

7.2 Autocross Course Specifications & Speeds
7.2.1 The following standard specifications will suggest the maximum speeds that will be encountered on the course. Average speeds should be 40 km/hr (25 mph) to 48 km/hr (30 mph).

- **Straights:** No longer than 60 m (200 feet) with hairpins at both ends (or) no longer than 45 m (150 feet) with wide turns on the ends.
- **Constant Turns:** 23 m (75 feet) to 45 m (148 feet) diameter.
- **Hairpin Turns:** Minimum of 9 m (29.5 feet) outside diameter (of the turn).
- **Slaloms:** Cones in a straight line with 7.62 m (25 feet) to 12.19 m (40 feet) spacing.
- **Miscellaneous:** Chicanes, multiple turns, decreasing radius turns, etc. The minimum track width will be 3.5 m (11.5 feet).

7.2.2 The length of each run will be approximately 0.805 km (1/2 mile) and the driver will complete a specified number of runs.

7.2.3 The organizers reserve the right to run the Autocross Event on courses of different length.

7.2.4 The organizers reserve the right to deviate from the standard specifications when they determine it is appropriate given the characteristics of a particular competition site.
7.3 **Autocross Procedure**

7.3.1 There will be two (2) Autocross-style heats, with each heat having a different driver. Two (2) timed laps will be run (weather and time permitting) by each driver and the best lap time will stand as the time for that heat.

7.3.2 The car will be staged such that the front wheels are 6 m (19.7 feet) behind the starting line. The timer starts only after the car crosses the start line.

7.3.3 There will be no particular order of the cars to run each heat but a driver has the option to take a second run immediately after the first.

7.3.4 The organizer will determine the allowable windows for each heat and retains the right to adjust for weather or technical delays. Cars that have not run by the end of the heat will be disqualified for that heat.

7.4 **Autocross Penalties**

The cars are judged on elapsed time plus penalties. The following penalties will be added to the elapsed time:

7.4.1 Cone Down or Out (DOO)
Two (2) seconds per cone, including any after the finish line.

7.4.2 Off Course

a) Driver must re-enter the track at or prior to the missed gate or a twenty (20) second penalty will be assessed.

b) Penalties will not be assessed for accident avoidance or other reasons deemed sufficient by the track officials.

c) If a paved road edged by grass or dirt is being used as the track, e.g. a go kart track, four (4) wheels off the paved surface will count as an "off course". Two (2) wheels off will not incur an immediate penalty; however, consistent driving of this type may be penalized at the discretion of the event officials.

7.4.3 Missed Slalom

Missing one or more gates of a given slalom will be counted as one "off-course" per occurrence. Each occurrence will incur a twenty (20) second penalty.

7.5 **Stalled & Disabled Vehicles**

7.5.1 If a car stalls and cannot restart without external assistance, the car will be deemed disabled.

7.5.2 Disabled cars are scored DNF for that attempt.

7.5.3 Disabled cars will be cleared from the track by the track workers. At the direction of the track officials team members may be instructed to retrieve the vehicle. Vehicle recovery may only be done under the control of the track officials.

7.6 **Corrected Elapsed Time**

7.6.1 The elapsed time plus any penalties from that specific run will be used as the corrected elapsed time.
7.6.2 Cars that are unable to complete the course with an average speed of 80% of the fastest car will not be awarded "performance" points. This means that any autocross time in excess of 125% of the fastest time will receive no "performance" points.

7.7 Best Run Scored
The time required to complete each run will be recorded and the team's best corrected elapsed time will be used to determine the score.

7.8 Autocross Scoring Formula
7.8.1 The following equation is used to determine the autocross score:

\[
\text{AUTOCROSSSCORE} = 142.5 \cdot \left( \frac{T_{\text{max}}}{T_{\text{your}}} - 1 \right) - 1 \left( \frac{T_{\text{min}}}{T_{\text{max}}} - 1 \right) + 7.5
\]

Where:
- \( T_{\text{min}} \) is the lowest corrected elapsed time recorded for any competitor in either heat
- \( T_{\text{max}} \) is 125% of \( T_{\text{min}} \)
- \( T_{\text{your}} \) is the lowest corrected elapsed time in either heat for the team being scored.

7.8.2 In the equation above, the first term on the right hand side represents "performance" points, while the second term, or "completion" points represents the minimum score for having successfully completed the event.

7.8.3 Negative "performance" points will not be given. However, 7.5 points will be given for a car that completes a run, even if \( T_{\text{your}} \) exceeds 125% of the fastest time (\( T_{\text{min}} \)).

ARTICLE 8: ENDURANCE AND FUEL ECONOMY

8.1 At Formula SAE competitions in North America the Endurance & Fuel Economy event will consist of a single heat. For competitions outside North America please check the event website.

8.2 Driver Eligibility - The Endurance and Fuel Economy are separate events even though they are run simultaneously. Therefore anyone driving in a heat of Endurance and Fuel Economy uses two (2) driving eligibilities. (See Article 4 "Driver Limitations")

8.3 Right to Change Procedure
Article 8 contains the general guidelines for conducting the Endurance and Fuel Economy event, however, the organizers reserve the right to establish procedures specific to the conduct of the event at the site. All such procedures will be made known to the teams through email or the specific FSAE competition news page website.

8.4 Endurance Objective—300 points
The Endurance Event is designed to evaluate the overall performance of the car and to test the car's durability and reliability.

8.5 Fuel Economy—100 points
The car's fuel economy will be measured in conjunction with the Endurance Event. The fuel economy under racing conditions is important in most forms of racing and also shows how well the car has been tuned for the competition. This is a compromise event because the
fuel economy score and endurance score will be calculated from the same heat. No refueling will be allowed during an endurance heat.

8.6 **Endurance Course Specifications & Speeds**

8.6.1 Course speeds can be estimated by the following standard course specifications. Average speed should be 48 km/hr (29.8 mph) to 57 km/hr (35.4 mph) with top speeds of approximately 105 km/hr (65.2 mph).

8.6.2 The standard specifications for the FSAE Endurance Course are:

- **Straights**: No longer than 77.0 m (252.6 feet) with hairpins at both ends (or) no longer than 61.0 m (200.1 feet) with wide turns on the ends. There will be passing zones at several locations.

- **Constant Turns**: 30.0 m (98.4 feet) to 54.0 m (177.2 feet) diameter.

- **Hairpin Turns**: Minimum of 9.0 m (29.5 feet) outside diameter (of the turn).

- **Slaloms**: Cones in a straight line with 9.0 m (29.5 feet) to 15.0 m (49.2 feet) spacing.

- **Miscellaneous**: Chicanes, multiple turns, decreasing radius turns, etc. The standard minimum track width is 4.5 m (14.76 feet).

8.6.3 The organizers reserve the right to deviate from the standard specifications when they determine it is appropriate given the characteristics of a particular competition site.

8.7 **Endurance General Procedure**

8.7.1 The event will be run as a single heat approximately 22 km (13.66 miles) long.

8.7.2 Teams are not allowed to work on their vehicles during the heat.

8.7.3 A driver change must be made during a three (3) minute period at the mid point of the heat.

8.7.4 Wheel-to-wheel racing is prohibited.

8.7.5 Passing another vehicle may only be done in an established passing zone or under control of a course marshal.

8.7.6 Elapsed time will begin when Driver A enters the course and crosses the timing line.

8.8 **Endurance Run Order**

8.8.1 The run order for endurance will be based primarily on the finish order for the autocross event with the fastest team first followed by the second fastest etc. For teams without an autocross score, the finish order for the acceleration event may be substituted. For teams without a score in either autocross or acceleration, the finish order for skid pad may be substituted. Teams without a score in the event used to determine the run order may run at the end of the heat.
Based on the results of all dynamic events, and considering the operating conditions under which they were run, the endurance event captain may, at his sole discretion, move teams to different positions within the starting order.

Teams are required to keep track of the run order and have their cars fueled, in line and prepared to start when their turn to run arrives.

Teams that are not ready-to-run when their turn arrives will be penalized two (2) minutes and permitted to run at the end of the heat (time permitting) or at the discretion of the event captain.

Before entering the event each vehicle's fuel tank must be filled to the fuel level line (see Rule B - 9.6.6, "Fuel Level Line") at the fueling station. During fueling, once filled to the scribe line, no shaking or tilting of the tank or fuel system (incl. entire vehicle) is allowed.

The vehicle must be capable of starting / restarting without external assistance at all times once the vehicle has begun the heat.

If a vehicle stalls out on the track, it will be allowed one (1) lap by the car that is following it (approximately one (1) minute) to restart.

If a vehicle has a restart problem at the end of Driver Change, it will be allowed a further two (2) minutes to restart the engine.

If restarts are not accomplished within the above times, the car will be deemed disabled and scored DNF for the heat.

Three (3) minutes are allowed for the team to change drivers.

Only three (3) team members, including the driver or drivers, will be allowed in the driver change area, and only the tools necessary adjust the car to accommodate the second driver and/or change tires will be carried into this area (no tool chests etc.). Extra people entering the driver change area will result in a twenty point (20 pt) penalty to the final endurance score for each extra person entering the area.

Driver A will drive for 11 km (6.83 miles), then be signaled into the driver change area.

Driver A will exit the vehicle and any necessary adjustments will be made to the vehicle to fit Driver B (seat cushions, head restraint, pedal position, etc.). Driver B will then be secured in the vehicle.

Driver B will drive for 11 km (6.83 miles) and elapsed time will stop when the car completes the total 22 km (13.66 miles) distance.

Driver B will proceed directly to the fueling station. The tank will be filled to refill mark and the amount will be recorded.
8.11.7 The driver change area will be placed such that the timing system will see the driver change as an extra long lap. Unless this driver change takes longer than three minutes, this extra long lap will not count. If the driver change takes longer than three minutes, the extra time will be counted into the final time.

8.12 Entering the Track
8.12.1 Cars will be allowed to enter the track based upon the level of traffic on the course.

8.12.2 The number of vehicles simultaneously on the course depends on the track length and design as well as the operating conditions. In dry conditions, there are typically 5 to 7 vehicles allowed per kilometer of track. This includes cars in the driver change area.

8.12.3 Because repairs are not allowed during the heat, and there will be no refueling during the heat, there will not be a restart queue of any kind.

8.13 Breakdowns & Stalls
8.13.1 If a vehicle breaks down it will be removed from the course and will not be allowed to re-enter the course.

8.13.2 If a vehicle stalls, or ingests a cone, etc., it will be allowed to restart (See 8.10 "Endurance Vehicle Starting/Restarting") and re-enter the course where it went off, but no work may be performed on the vehicle.

8.13.3 If a car stalls and cannot be restarted without external assistance, the track workers will push the car clear of the track. At the discretion of event officials, two (2) team members may retrieve the car under direction of the track workers.

8.14 Endurance Minimum Speed Requirement
8.14.1 If a car is unable to maintain lap times within 133% of the fastest lap time for the course, then it must exit immediately.

8.14.2 Disqualification for failure to maintain the minimum speed will be made at the discretion of the Chief Marshall/Director of Operations.

8.15 Post Event Refueling
Vehicles must power down after leaving the course and be pushed to the fueling area.

Fuel pumps will be turned on and fuel valves will be opened to insure complete refueling.

8.16 Endurance Lap Timing
Each lap of the endurance event will be individually timed either by electronic means, or by hand. The time for an individual heat will be determined by subtracting the extra long lap for the driver change, and the time taken for any stops under a mechanical black flag, from the total time and adding any penalty points.

8.17 Endurance Penalties
8.17.1 Penalties will not be assessed for accident avoidance or other reason deemed sufficient by the track official.

8.17.2 The penalties in effect during the Endurance Event are listed below.
8.17.3 Cones
Cone down or out (DOO) - two (2) seconds per cone. This includes cones before the start line and after the finish line.

8.17.4 Off Course (OC)
   a) For an OC, the driver must re-enter the track at or prior to the missed gate or a twenty (20) second penalty will be assessed.
   b) If a paved road edged by grass or dirt is being used as the track, e.g. a go kart track, four (4) wheels off the paved surface shall count as an "off course".
   c) Two (2) wheels off will not incur an immediate penalty. However, consistent driving of this type may be penalized at the discretion of the event officials.

8.17.5 Missed Slalom
Missing one or more gates of a given slalom will incur a twenty (20) second penalty.

8.17.6 Penalties for Moving Violations
The following are penalties and assessed times or disqualifications for moving violations:
   a) Failure to obey a flag: 1 minute
   b) Over Driving (After a closed black flag): 1 Minute
   c) Vehicle to Vehicle contact: 2 Minutes up to disqualification depending on the nature of the incident.

8.17.7 Out of Order
Running out of order - two (2) minute penalty.

8.17.8 Mechanical Problem
No time penalty. The time taken for mechanical inspection under a "mechanical black flag" is considered officials' time and is not included in the teams' total time. However, if the inspection reveals a mechanical integrity problem the vehicle may be disqualified under Rule 1.1.

8.17.9 Reckless or Aggressive Driving
Any reckless or aggressive driving behavior (such as forcing another car off the track, refusal to allow passing, or close driving that would cause the likelihood of car contact) will result in a black flag for that driver. When a driver receives a black flag signal, he must proceed to the penalty box to listen to a reprimand for his driving behavior. The amount of time spent in the penalty box will vary from one (1) to four (4) minutes depending upon the severity of the offense.

   If it is impossible to impose a penalty by a stop under a black flag, e.g. not enough laps left, the event officials may add an appropriate time penalty to the team's elapsed time.

8.17.10 Vehicle Control Issues
The Chief Marshall/Director of Operations may disqualify a vehicle if, for any reason including driver inexperience and mechanical problems, it is too slow or being driven in a manner that, in the sole opinion of the event officials demonstrates an inability to properly control the car. Disqualification for a vehicle control issue is scored as DNF.
8.18 Endurance Scoring
8.18.1 The score for the Endurance Event is the sum of the Endurance Time Score and the Endurance Finish Score.

8.18.2 The Endurance Time Score is based on the team's time for the event, including penalties, compared to the fastest team.

8.18.3 A car will also receive an Endurance Finish Score of fifty (50) points if the team's time for the event, including penalties, is less than or equal to the maximum allotted time.

8.19 Endurance Scoring Formula
8.19.1 The times for the endurance event will be based upon the sum of the times of each driver in the heat plus penalties.

8.19.2 The following equation is used to determine the time scores for the event:

If $T_{your} \leq T_{max}$:

$$\text{ENDURANCE SCORE} = 250 \times \frac{(T_{max}/T_{your}) - 1}{(T_{max}/T_{min}) - 1} + 50$$

If $T_{your} > T_{max}$: ENDURANCE SCORE = 0 (ZERO)

$T_{min}$ will be the lowest corrected time of the fastest team of the event.

$T_{your}$ will be the combined corrected times of both of your team's drivers in the heat.

$T_{max}$ will be 1.333 times $T_{min}$.

8.19.3 If, in the opinion of the officials, course conditions change significantly during the running of the event then they may, at their sole discretion, set $T_{max}$ to a higher value.

8.20 Fuel Economy
The Fuel Economy score is based on the average liters per kilometer fuel economy obtained during the endurance heat.

Teams are advised that the fuel economy score is based only on the distance cars run on the course during the endurance event. Although the starting line, exit line and the driver change zone increase the actual distance a car must drive during the event, those distances are not factored into the fuel economy calculations. Additionally fuel consumption adjustments will not be made for engine running in the entry/exit lines, during driver change, in the penalty box or for any on-course incidents.

8.21 E85 Correction Factor
The volume of E85 fuel will be divided by a 1.40 correction factor to determine the gasoline equivalent volume. This correction factor is equal to the ratio of energy (lower heating value) per unit volume of gasoline to E85.
8.22 Fuel Economy Scoring Formula

8.22.1 If $V_{your}$ is less than $V_{max}$ then the following equation will be used to determine the fuel economy score:

$$\text{FUEL ECONOMY SCORE} = 100 \cdot \left( \frac{(V_{max}/V_{your} - 1)}{(V_{max}/V_{min} - 1)} \right)$$

If $V_{your}$ is greater than $V_{max}$ then the following equation will be used to determine a negative fuel economy score:

$$\text{FUEL ECONOMY SCORE} = -100 \cdot \left( \frac{(V_{your}/V_{max} - 1)}{0.33} \right)$$

Where:
- $V_{max}$ is the volume of fuel that produces a fuel consumption of 26 liters/100 km.
- Note: For an Endurance Event distance of exactly 22 km, $V_{max}$ is 5.72 liters (1.51 US gallons).
- $V_{min}$ is the smallest volume of fuel used by any competitor
- $V_{your}$ is the volume of fuel used by the team being scored

8.22.2 Vehicles using a fuel volume which exceeds $V_{max}$ by 33% will score negative one hundred (-100) points.

8.22.3 Vehicles whose corrected time exceeds 1.333 times the corrected time of the fastest team, will receive zero (0) points for fuel economy.

8.22.4 For shortened courses, $V_{min}$ will be the low value per heat.

8.22.5 Fuel economy scores can range from negative one hundred (-100) to positive one hundred (100) points.

8.22.6 The minimum combined score for the endurance and fuel economy event will be zero (0) points.

8.23 Endurance and Fuel Economy Scoring with Two Heats

If the Endurance and Fuel Economy is run with two (2) heats, the following procedure will apply:

a) $T_{min}$ will be the lowest corrected time of the fastest team of the event in either heat.

b) $V_{min}$ will be the smallest volume of fuel used by any team in either heat; provided that team's Corrected Time from that heat does not exceed $T_{max}$. Note: $T_{min}$ and $V_{min}$ do not have to be from the same heat.

c) The score for a team will be taken from the heat that gives the higher total Endurance & Fuel Economy Score for that team, i.e. $T_{your}$ and $V_{your}$ will be from the same heat.

8.24 Post Event Engine Check

The organizer reserves the right to impound any vehicle immediately after the event to check engine displacement (method to be determined by the organizer) and restrictor size.
8.25  **Endurance Event - Driving**

8.25.1 During Endurance when multiple cars are running on the course it is paramount that the drivers strictly follow all of the rules and driving requirements.

8.25.2 Aggressive driving, failing to obey signals, not yielding for passing, etc will result in a black flag and a discussion in the penalty box with course officials. The amount of time spent in the penalty box is at the discretion of the officials and is included in the run time. Penalty box time serves as a reprimand as well as informing the driver of what he/she did wrong. Drivers should be aware that contact between open wheel racers is especially dangerous because tires touching can throw one car into the air.

Endurance is a timed event in which drivers compete only against the clock not against other cars. Aggressive driving is unnecessary.

8.26  **Endurance Event - Passing**

8.26.1 Passing during Endurance may only be done in the designated passing zones and under the control of the track officials.

8.26.2 Passing zones have two parallel lanes - a slow lane for the cars that are being passed and a fast lane for the cars that are making a pass. On approaching a passing zone a slower leading car will be blue flagged and must shift into the slow lane and decelerate. The following faster car will continue in the fast lane and make the pass. The car that had been passed may reenter traffic only under the control of the passing zone exit flagman.

8.26.3 Passing, i.e. slow, lanes may be either to the left or right of the fast lane depending on the design of the specific course.

8.26.4 These passing rules do not apply to cars that are passing disabled cars on the course or cars that have spun out and are not moving. When passing a disabled or off-track car it is critical to slow down, drive cautiously and be aware of all the vehicles and track workers in the area.

8.26.5 Under normal driving conditions when not being passed all cars use the fast lane.

8.27  **Endurance Event - Driver's Course Walk**

The endurance course will be available for walk by drivers prior to the event. All endurance drivers are required to walk the course before the event starts.

**ARTICLE 9:  FLAGS**

9.1  **Flag Effect**

Flag signals are commands that must be obeyed immediately and without question.

9.2  **Flag Types**

There are two kinds of flags for the competition: Command flags and Informational flags.

9.2.1  Command flags are just that, flags that send a message to the competitor that the competitor must obey without question.
9.2.2 Informational flags, on the other hand, require no action from the driver, but should be used as added information to help him or her to maximize performance.

9.3 Command Flags
The following is a brief description of the flags used at the competitions in North America and what each flag means.

Note: Not all of these flags are used at all competitions and some alternate designs are occasionally displayed. Any variations from this list will be explained at the drivers meetings.

9.3.1 BLACK FLAG - Pull into the penalty box for discussion with the Chief Marshall/Director of Operations or other official concerning an incident. A time penalty may be assessed for such incident.

9.3.2 BLACK FLAG - With Orange Dot - Pull into the penalty box for a mechanical inspection of your car, something has been observed that needs closer inspection.

9.3.3 BLUE FLAG - Pull into the designated passing zone to be passed by a faster competitor. Obey the corner workers hand signals at the end of the passing zone to merge into competition.

9.3.4 CHECKER FLAG - Your session has been completed. Exit the course at the first opportunity.

9.3.5 GREEN FLAG - Your session has started, enter the course under direction of the starter. (NOTE: If you stall the vehicle, please restart and await another green flag as the opening in traffic may have closed.)

9.3.6 RED FLAG - Come to an immediate safe controlled stop on the course. Pull to the side of the course as much as possible to keep the course open. Follow corner worker directions.

9.3.7 YELLOW FLAG (Stationary) - Danger, SLOW DOWN, be prepared to take evasive action, something has happened beyond the flag station. NO PASSING unless directed by the corner workers.

9.3.8 YELLOW FLAG (Waved) - Great Danger, SLOW DOWN, evasive action is most likely required, BE PREPARED TO STOP, something has happened beyond the flag station, NO PASSING unless directed by the corner workers.

9.4 Informational Flags
9.4.1 RED AND YELLOW STRIPED FLAG - Something is on the racing surface that should not be there. Be prepared for evasive maneuvers to avoid the situation. (Corner workers may be able to point out what and where it is located, but do not expect it.)

9.4.2 WHITE FLAG - There is a slow moving vehicle on the course that is much slower than you are. Be prepared to approach it at a cautious rate.
ARTICLE 10: RULES OF CONDUCT

10.1 Competition Objective - A Reminder
The Formula SAE® event is a design engineering competition that requires performance demonstration of vehicles and is NOT a race. Engineering ethics will apply. It is recognized that hundreds of hours of labor have gone into fielding an entry into Formula SAE. It is also recognized that this event is an "engineering educational experience" but that it often times becomes confused with a high stakes race. In the heat of competition, emotions peak and disputes arise. Our officials are trained volunteers and maximum human effort will be made to settle problems in an equitable, professional manner.

10.2 Unsportsmanlike Conduct
In the event of unsportsmanlike conduct, the team will receive a warning from an official. A second violation will result in expulsion of the team from the competition.

10.3 Official Instructions
Failure of a team member to follow an instruction or command directed specifically to that team or team member will result in a twenty five (25) point penalty.

Note: This penalty can be individually applied to all members of a team.

10.4 Arguments with Officials
Argument with, or disobedience to, any official may result in the team being eliminated from the competition. All members of the team may be immediately escorted from the grounds.

10.5 Alcohol and Illegal Material
10.5.1 Alcohol, illegal drugs, weapons or other illegal material are prohibited on the event site during the competition. This rule will be in effect during the entire competition.

10.5.2 Any violation of this rule by a team member will cause the expulsion of the entire team. This applies to both team members and faculty advisors.

10.5.3 Any use of drugs, or the use of alcohol by an underage individual, will be reported to the local authorities.

10.6 Parties
Disruptive parties either on or off-site should be prevented by the Faculty Advisor.

10.7 Trash Clean-up
10.7.1 Cleanup of trash and debris is the responsibility of the teams. The team's work area should be kept uncluttered. At the end of the day, each team must clean all debris from their area and help with maintaining a clean paddock.

10.7.2 Teams are required to remove all of their material and trash when leaving the site at the end of the competition. Teams that abandon furniture, or that leave a paddock that requires special cleaning, will be billed for removal and/or cleanup costs.
ARTICLE 11: GENERAL RULES

11.1 Dynamometer Usage
If a dynamometer is available, it may be used by any competing team. Vehicles to be dynamometer tested must have passed all parts of technical inspection.

Fuel, ignition and drivetrain tuning will be permitted while testing on the dynamometer.

11.2 Problem Resolution
Any problems that arise during the competition will be resolved through the Operations Center and the decision will be final.

11.3 Forfeit for Non-Appearance
11.3.1 It is the responsibility of teams to be in the right place at the right time.

11.3.2 If a team is not present and ready to compete at the scheduled time they forfeit their attempt at that event.

11.3.3 There are no make-ups for missed appearances.

11.4 Drivers Meetings - Attendance Required
All drivers for an event are required to attend the pre-event drivers meeting(s). The driver for an event will be disqualified if he/she does not attend the driver meeting for the event.

11.5 Personal Vehicles
Personal cars and trailers must be parked in designated areas only. Only FSAE competition vehicles will be allowed in the track areas.

11.6 Motorcycles, Bicycles, Rollerblades, etc.—Prohibited
The use of motorcycles, quads, bicycles, scooters, skateboards, rollerblades or similar person-carrying devices by team members and spectators in any part of the competition area, including the paddocks, is prohibited.

11.7 Self-propelled Pit Carts, Tool Boxes, etc. - Prohibited
The use of self-propelled pit carts, tool boxes, tire carriers or similar motorized devices in any part of the competition site, including the paddocks, is prohibited.

ARTICLE 12: PROTESTS

12.1 Required Review - Any team that intends to protest a rule, score, judge's decision or any other aspect of the competition, must present the issue to SAE staff for discussion, and possible resolution before the protest is filed.

12.2 Cause for Protest - A team may protest any rule interpretation, score or official action (unless specifically excluded from protest) which they feel has caused some actual, non-trivial, harm to their team, or has had a substantive effect on their score. Teams may not protest rule interpretations or actions that have not caused them any substantive damage.
12.3 Protest Period - Protests must be filed within one-half (½) hour after the action being protested has occurred or the scores for the activity involving the protest subject are posted.

12.4 Protest Format - Protests must be in writing and submitted to designated organizer or SAE staff.

12.5 Protest Bond - The protesting team must post a twenty-five (25) point bond to be deducted from their score if the protest is denied.

12.6 Decision - The decision of the officials regarding any protest is final.

ARTICLE 13: PIT RULES

13.1 Vehicle Movement
13.1.1 Vehicles may not move under their own power anywhere but on the practice or competition tracks, or as otherwise directed by the organizers.

13.1.2 Off track vehicles must be pushed at a normal walking pace by means of a "Push Bar", with all four (4) wheels on the ground, a team member sitting in the cockpit to steer and brake and with another team member walking beside the car.

13.1.3 Cars with wings are required to have two team members walking on either side of the vehicle whenever the vehicle is being pushed.

13.1.4 During performance events when the excitement is high, it is particularly important that the car be moved at a slow pace in the pits.

13.1.5 The walking rule will be enforced and a point penalty of twenty five (25) points will be assessed for each violation.

13.2 Push Bar
13.2.1 Each car must have a removable device that attaches to the rear of the car that allows two (2) people, standing erect behind the vehicle, to push the car around the event site.

13.2.2 This device must also be capable of decelerating, i.e. slowing and stopping the forward motion of the vehicle and pulling it rearwards. It must be presented with the car at Technical Inspection.

13.3 Smoking - Prohibited
Smoking is prohibited in all competition areas.

13.4 Fueling and Refueling
Officials must conduct all fueling and refueling.
Engine Running in the Paddock

Engines may be run in the paddock provided the car has passed technical inspection and the following conditions are satisfied:
A. The car is on a sturdy and adequate stand, and
B. The drive wheels are at least 10.2 cm (4 in) off the ground, or the drive wheels have been removed.

ARTICLE 14: DRIVING RULES

14.1 Driving Under Power
14.1.1 Cars may only be driven under power (a) when running in an event, (b) on the practice track and (c) during brake test or (d) during any powered vehicle movement specified and authorized by the organizers.

14.1.2 For all other movements cars must be pushed at a normal walking pace using a push bar.

14.1.3 Violation of this rule will result in a two hundred (200) point penalty for the first violation and expulsion of the team for a second violation.

14.2 Driving Off-site
Driving off-site is absolutely prohibited. Teams found to have driven their vehicle at an off-site location during the period of the competition will be excluded from the competition.

14.3 Practice Track
14.3.1 A practice track for testing and tuning cars may be available at the discretion of the organizers. The practice area will be controlled and may only be used during the scheduled practice times.

14.3.2 Practice or testing at any location other than the practice track is absolutely forbidden.

14.3.3 Driving a vehicle outside of scheduled events or scheduled practice will result in a two hundred (200) point penalty for the first violation and disqualification for a second violation.

14.3.4 Cars using the practice track must have all parts of the technical inspection sticker.

14.4 Situational Awareness
Drivers must maintain a high state of situational awareness at all times and be ready to respond to the track conditions and incidents. Flag signals and hand signals from course marshals and officials must be immediately obeyed.

ARTICLE 15: DEFINITIONS

15.1 DOO - A cone is “Down or Out”—if the cone has been knocked over or the entire base of the cone lies outside the box marked around the cone in its undisturbed position.

15.2 DNF - Did Not Finish

15.3 Gate - The path between two cones through which the car must pass. Two cones, one on each side of the course define a gate: Two sequential cones in a slalom define a gate.
15.3.1 Entry Gate - The path marked by cones which establishes the required path the vehicle must take to enter the course.

15.3.2 Exit Gate - The path marked by cones which establishes the required path the vehicle must take to exit the course.

15.4 Staging Area - An area prior to the entry to an event for the purpose of gathering those cars that are about to start.

15.5 OC - A car is Off Course if it does not pass through a gate in the required direction.