Baja SAE Frame Design

A Baccalaureate thesis submitted to the
School of Dynamic Systems
College of Engineering and Applied Science
University of Cincinnati

in partial fulfillment of the
requirements for the degree of

Bachelor of Science

in Mechanical Engineering Technology

by:

Brooks Biteman

April 2013

Thesis Advisor:

Professor Allen Arthur
ABSTRACT

Baja SAE is an annual intercollegiate competition in which team’s race a once seat: all-terrain vehicle powered by a ten horsepower Briggs and Stratton engine. Mechanical Engineering Technology Students at the University of Cincinnati design and build the vehicle not only for the competition but also as a required design project for senior students. As the lead for the frame, I was faced with the challenge of designing a completely new frame from the ground up that would work in harmony with the other components of the car without adding unnecessary members. I was also given the challenge of designing the frame with mounting tabs, body panels and a seat to be less than or equal to 120 lbs.

INTRODUCTION

The Society of Automotive Engineers (SAE) Mini Baja was originated at the University of South Carolina in 1976. The main objective for the Mini Baja competition was to design and fabricate a one-man all-terrain vehicle having more than two wheels that could compete with manufactured versions from the viewpoint of safety, appearance, design, performance, and ultimately cost. The University of Cincinnati was among the first teams to compete during the first ever Mini Baja competition and will be competing on June 6 - 9 in Rochester, New York.

The main objective for this year’s team was to design a lighter and smaller vehicle than last year. The team focused on a new lighter frame, a more simple brake system, correcting suspension problems, lowering the center of gravity, and eliminating the transmission. These new design changes will result in a better handling and more user-friendly vehicle.

DESIGN

OBJECTIVE – For the 2013 season we chose to design and build a completely new car using none of the 2012 car parts. In addition to this the car was to me lighter and smaller. This meant designing a new frame that was lighter and more compact that would work with the newly designed suspension, steering, and drive train systems. With that in mind, the design would also have to comply with all Baja SAE requirements. The team was able to reduce the weight of the frame to 74 lbs by reducing the length, height and width of the frame. In addition to this, it was designed so that all of the suspension components mounting locations did not only serve one purpose like on the 2012 car. All in all the frame came in at just under 110 lbs after all tabs, body panels, and safety restraints were installed staying under budget.

DESIGN - The UC Baja team designed and fabricated a frame that focused on safety, durability, manufacturability, and weight. The main elements of the roll cage consist of RRH, RHO, FBM, LC, FLC, LBD, LFS, SIM, FAB, and USM. The Baja SAE rules for 2013 state that the primary members RRH, RHO, FBM, LC, and FLC be made of a material with a bending stiffness and strength equal or greater than 18% carbon steel and have an O.D. of 1.0 in [4], and a wall thickness of 0.12 in. Secondary members of the chassis also had to have the same minimum bending stiffness and strength of the primary members but could have a minimum tube size of 1.0 in. O.D. with a wall thickness of 0.035 in [4].

MATERIAL SELECTION – For the 2013 year the team decided to stay with the AISI 4130 Chromalloy steel tubing. The 2013 Baja SAE rules specify using a material greater than or equal to 18% carbon steel which has an ultimate strength of 63.8 ksi, yield strength of 53.7 ksi, and a bending strength of 3,513 in-lb. The primary members of the frame are made with 1.25 in. O.D. with a wall thickness of 0.065 in. The AISI 4130 in this tube size has an ultimate strength of 97.2 ksi, yield strength of 63.1 ksi, and a bending strength of 4,301 in-lb. Secondary members were made from AISI 4130 as well but with a 1.0 in. O.D. with a wall thickness of 0.035 in. [5]

MANUFACTURABILITY – The team used SolidWorks to create a 3D model of the frame. This provide the team with a way to visualize what the frame was going to look like as well as confirm that all of the other components of the car would mount to the frame without additional members being added in the build process. By having each member of the frame modeled in the software it allowed the team to have exact lengths and bends that the tubing needed to be cut and bent to. This made it much easier when it came time to building the frame.
This year the team was able to have Cartesian Tube Profiling from Ontario, Canada CNC bend the tubes and laser cut them exactly as they were drawn in SolidWorks. This proved to be a much more precise method compared to previous year’s teams using the manual tube bender and a hole saw and jig. It allowed the team to assemble the frame without the use of a jig and have it TIG welded saving weight in the form of filler metal used for the welds.

DESIGN ANALYSIS – The frame has seen many revisions from the beginning of the design process. Upon finishing the design there were 10 designs over all. By working with the other members of the team the frame has been modified to work with the other sub systems of the car. Once the frame design was set, optimization could be done to reduce weight.

Figure 1: Frame Concept #3

Figure 2: Frame Concept #8
- These first frame designs were heavy and did not work well with the front and rear suspension systems

The frame analysis was completed using SolidWorks Finite Element Analysis (FEA). The team focused on three areas of impact; the front, side and top corner. Using the software the team was able to make changes to the frame to give it a minimum safety factor of 1.3 [6] and not exceeding the yield strength of the material.

Figure 3: Final Frame Side View

Figure 4: Final Frame Isometric View

The loading conditions were based on data published by The Motor Insurance Repair Research Centre [1]. The data shows impulse time and G’s forces caused by crashes ranging from 18 - 52 km/h (11 - 32 mph)

Using the projected vehicle/driver mass of 250kg, the impact force was calculated base of a g-load of 10. [7]

\[ f = ma \]
\[ f = 250kg \times 10g's \times (9.81 \text{ m/s}^2) \]
\[ f = 24525 \text{ N} \]

**Impulse Time**

\[ f_{avg} = \frac{\Delta v}{\Delta t} \]
\[ \Delta t = m \cdot \frac{\Delta v}{f_{avg}} \]
\[ \Delta t = 250kg \frac{15.6464 \text{ m/s}}{24525 \text{ N}} \]
\[ \Delta t = 0.16 \text{ seconds} \]
Top Impact Calculations

\[ f_{avg} = \frac{m \Delta v}{\Delta t} \]
\[ f_{avg} = 250kg \frac{(9.9m/s - 0m/s)}{0.16 s} \]
\[ f_{avg} = 15468.75 N \]

Front and Side Impact Calculations

\[ f_{avg} = m \frac{\Delta v}{\Delta t} \]
\[ \Delta t = m \frac{\Delta v}{f_{avg}} \]
\[ \Delta t = 250kg \frac{15.6464m/s}{24525 N} \]
\[ \Delta t = 0.16 \text{ seconds} \]
\[ f = ma \]
\[ f = 250kg \times 10g \times (9.81 m/s^2) \]
\[ f = 24525 N \]

Table 1: Steel Comparison [5]

<table>
<thead>
<tr>
<th>Material</th>
<th>1018 Steel</th>
<th>4130 Steel</th>
</tr>
</thead>
<tbody>
<tr>
<td>O.D.</td>
<td>1</td>
<td>1.25</td>
</tr>
<tr>
<td>Wall Thickness (in)</td>
<td>0.12</td>
<td>0.065</td>
</tr>
<tr>
<td>Ultimate Strength (ksi)</td>
<td>63.8</td>
<td>97.2</td>
</tr>
<tr>
<td>Yield Strength (ksi)</td>
<td>53.7</td>
<td>63.1</td>
</tr>
<tr>
<td>Bending Strength (in-lb)</td>
<td>3,513</td>
<td>6625.5</td>
</tr>
<tr>
<td>Weight (lb/ft)</td>
<td>1.12</td>
<td>0.833</td>
</tr>
<tr>
<td>Elongation at Break</td>
<td>15.00%</td>
<td>25.50%</td>
</tr>
<tr>
<td>Modulus of Elasticity (ksi)</td>
<td>29700</td>
<td>29700</td>
</tr>
<tr>
<td>Bending Stiffness (kip-in2)</td>
<td>981</td>
<td>1,278</td>
</tr>
</tbody>
</table>

Bending Strength of AISI 4130:

\[ S_y = 97200 \text{ psi} \]
\[ S_y \frac{I}{c} = \frac{97200 \text{ psi} \times 0.0426in^4}{0.625in} = 6625.5lb \cdot in \]

Scenario 1: Front impact hitting a tree at 35mph

- 35 – 0 mph in 0.16 seconds
- \( f = 5513.4 \text{ lbf} \)
- 10g load
- 46.4 ksi bending force
- FOS = 2.1
- 0.11 in. deformation

Stress

![Figure 5: Front Impact Stress (Side View)](image)

![Figure 6: Front Impact Stress (Isometric View)](image)

![Figure 7: Front Impact Stress (Max Stress Point)](image)
Scenario 2: 15 foot jump landing on the top of the roll cage at one corner
- 22 mph
- f = 3477.5 lbf
- 6.31 g load
- 96.5 ksi bending force
- FOS = 1.0
- 0.23 in. deformation

**Stress**

**Displacement**
Scenario 3: Side impact hitting a tree at 35mph

- 35 – 0 mph in 0.16 seconds
- $f = 5513.4\ \text{lbf}$
- 10g load
- 93.7 ksi bending force
- FOS = 1.0
- 0.38 in. deformation
In addition to the front, top and side loading conditions the frame was also subjected to forces by the front and rear suspensions. By working with the suspension designers forces were determined to simulate the shocks bottoming out after landing a jump or sudden changes in terrain. The data showed that it would take 14000 lbf to fully compress the shocks. To simulate the real world load this force was stepped up to 16000 lbf and FEA was conducted to show the torsional stiffness of the frame. From the analysis it showed that the frame has a torsional stiffness of 570 lbs-ft/deg.

OTHER COMPONENTS

- Firewall
- Body Panels
- Restraint System
- Seat

The firewall was made from a solid sheet of 0.020” aluminum per the rules of the competition. Body panels were fabricated from High Density Polyethylene (HDPE) plastic which is 1/3 the weight of aluminum.

The restraint system and seat was purchased from Summit Racing. The team opted to purchase a seat due to the high risk of injury if the seat were to fail.

PROOF OF DESIGN

For two months the chassis was tested along with the other components of the car. It was subjected to a variety of conditions simulating what would be seen in off road use to test the durability and strength of the design. When at the first competition at Tennessee Tech the car was rolled twice and was also involved in a head on impact by running into a ditch that stopped the car similar to hitting a tree. After all the testing and crashes the frame retained its structural integrity and did not deform or break. This proves the design was built strong enough to withstand the extreme loading conditions seen in this type of off road racing.

CONCLUSION

This year the frame has seen many changes in a effort to save weight, retain strength, and work with the other systems of the car. By using SolidWorks the design was able to be changed to optimize the design for max weight savings and still prove strong enough to survive the harsh conditions of off-road racing. Through the software the team was also able confirm that the other systems of the car would work correctly with the design. In the end the frame, body panels, firewall, and safety restraints came in under 110 lbs and proved to be strong enough to survive the conditions seen at competition.
Works Cited / References


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CONTACT INFORMATION

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DEFINITIONS, ACYNMS, ABBREVIATIONS

FEA: Finite Element Analysis
lbs: Pounds force
in: Inches “: Inch
%: Percent
LFS: Lower Frame Side
RRH: Rear Roll Hoop
SIM: Side Impact Member
APPENDIX A

CUSTOMER SURVEY

Recreational Vehicle Frame
CUSTOMER SURVEY

In order to improve our products, Company XYZ would like customer input about a NEW up and coming vehicle frame. This survey is measuring the importance of selected features that are important to the design process.

### How important is each feature to you for the design of an Off-road vehicle frame?
Please circle the appropriate answer.  
1 = low importance  
5 = high importance  
N/A

<table>
<thead>
<tr>
<th>Feature</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>N/A</th>
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<tbody>
<tr>
<td>Safety</td>
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<td></td>
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<td></td>
<td></td>
<td>N/A</td>
</tr>
<tr>
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<td></td>
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<td></td>
<td></td>
<td>N/A</td>
</tr>
<tr>
<td>Frame Length</td>
<td></td>
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<td></td>
<td></td>
<td>N/A</td>
</tr>
<tr>
<td>Weight</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>N/A</td>
</tr>
<tr>
<td>Durability</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>N/A</td>
</tr>
<tr>
<td>Compatibility</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>N/A</td>
</tr>
<tr>
<td>Ease of Entering/Exiting</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>N/A</td>
</tr>
</tbody>
</table>

### How satisfied are you with the current Off-road front suspension?
Please circle the appropriate answer.  
1 = very UNsatisfied  
5 = very satisfied  
N/A

<table>
<thead>
<tr>
<th>Feature</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
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<tbody>
<tr>
<td>Safety</td>
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<td></td>
<td></td>
<td>N/A</td>
</tr>
<tr>
<td>Frame Width</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>N/A</td>
</tr>
<tr>
<td>Frame Length</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>N/A</td>
</tr>
<tr>
<td>Weight</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>N/A</td>
</tr>
<tr>
<td>Durability</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>N/A</td>
</tr>
<tr>
<td>Compatibility</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>N/A</td>
</tr>
<tr>
<td>Ease of Entering/Exiting</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>N/A</td>
</tr>
</tbody>
</table>

### How much would you be willing to pay for a complete Off-road Vehicle Frame?

$100-$200  $200-$500  $500-$1000  $1000-$2000  $2000-$3000

Thank you for your time.
## APPENDIX B

### HOUSE OF QUALITY

<table>
<thead>
<tr>
<th>Customer Requirements</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>CP</th>
<th>A</th>
<th>B</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Safety</td>
<td>0.25</td>
<td>9</td>
<td>3</td>
<td></td>
<td></td>
<td></td>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2 Durability</td>
<td>0.20</td>
<td>3</td>
<td>9</td>
<td></td>
<td></td>
<td></td>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3 Weight</td>
<td>0.25</td>
<td>9</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4 Frame Width</td>
<td>0.05</td>
<td>3</td>
<td>9</td>
<td></td>
<td></td>
<td></td>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5 Frame Length</td>
<td>0.05</td>
<td>9</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>6 Compatibility</td>
<td>0.10</td>
<td>3</td>
<td>3</td>
<td></td>
<td></td>
<td></td>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>7 Ease of Entering/Exiting</td>
<td>0.05</td>
<td>1</td>
<td>9</td>
<td></td>
<td></td>
<td></td>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>8 Price</td>
<td>0.05</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>9</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

| Total Importance      | 1.00 | 2.85 | 1.80 | 2.40 | 1.50 | 0.30 | 0.45 | 1.00 |   |

<table>
<thead>
<tr>
<th>Engineering Characteristics (units)</th>
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<tbody>
<tr>
<td>Factor of Safety</td>
</tr>
<tr>
<td>Product Lifetime (years)</td>
</tr>
<tr>
<td>Weight (lbs)</td>
</tr>
<tr>
<td>Inches (in.)</td>
</tr>
<tr>
<td>Number of Upgradable Parts Available (#)</td>
</tr>
<tr>
<td>Time (Seconds)</td>
</tr>
<tr>
<td>Cost ($ )</td>
</tr>
</tbody>
</table>

Customer Satisfaction Rating (0.00 - 1.00)
APPENDIX C

CUSTOMER FEATURES LIST

<table>
<thead>
<tr>
<th>List of Customer Features</th>
</tr>
</thead>
<tbody>
<tr>
<td>Includes general extensive list</td>
</tr>
<tr>
<td>Includes condensed list (no more than 15 items)</td>
</tr>
<tr>
<td>Grammar is parallel</td>
</tr>
<tr>
<td>Does not include design criteria</td>
</tr>
<tr>
<td>Complete and filtered</td>
</tr>
<tr>
<td>Items grouped logically</td>
</tr>
<tr>
<td>Includes specialized items discovered in research</td>
</tr>
<tr>
<td>File submission</td>
</tr>
<tr>
<td>File is submitted in the assignment box (never e-mailed)</td>
</tr>
</tbody>
</table>

Brainstorming List

Safe
Price
Ease of Manufacturing
Ease of use
Verifiable Results
Ease of Access
Reliability
Durability
Ease of Cleaning
Compatibility
Ease of Adjustment
Resistance to Impacts
Repeatability

Customer Features

Price
Safety
Ease of operation
Consistent results
Reliability
Durability
Size
Compatibility
Based on the survey, the product objectives are the list of features that are taken into consideration. These customer features were cross-referenced with engineering characteristics and are organized from strong to weak. The engineering characteristic is below each feature. The objectives/methods is followed by the method or objective that will be used for the prototype design. The following is a list of product objectives and how they will be obtained or measured to ensure that the goal of the project was met.

1. Safety 25%
   a. High Importance
2. Durability 20%
   a. High Importance
3. Weight 25%
   a. High Importance
4. Frame Width 5%
   a. Low Importance
5. Frame Length 5%
   a. Low Importance
6. Compatibility 10%
   a. Avg. Importance
7. Ease of Entering/Exiting 5%
   a. Low Importance
8. Price 5%
   a. $1000-2000
APPENDIX E
RESEARCH

Cornell University’s 2012 car

- 308 lbs
- Uses carbon fiber for body panels and suspension parts
- Use of the correct size tubing for frame with smaller tubing for secondary members
- Having the side members taper out from the base to save weight while allowing enough room to drive

Louisville University’s 2012 car

- Very short
- Use of the correct size tubing for frame with smaller tubing for secondary members
- No unnecessary members added
APPENDIX F

SCHEDULE

Research and Design: June 1 – Nov. 7

Design Optimization: October 20 – Nov. 7

Fabrication of Frame: Nov. 8 – Dec. 25

Assembly: Dec. 26 – Jan. 1
The original budget set for the Chassis was set at $3,000.00. Due to unforeseen expenses regarding safety restraints (the seat) we overspent by $250.00. This cost was justified by having a much more safe vehicle for the driver.
WEIGHT

Weight Distribution (lbs)

- Steering: 35 lbs (4%)
- Gearbox: 40 lbs (11%)
- Diff. + Rear Axle: 35 lbs (9%)
- Brakes: 20 lbs (5%)
- Engine: 60 lbs (16%)
- Rear Suspension: 50 lbs (13%)
- Front Suspension: 50 lbs (13%)
- Frame + Composites: 110 lbs (29%)
ARTICLE 8: ROLL CAGE

B8.1 Objective
The purpose of the roll cage is to maintain a minimum space surrounding the driver. The cage must be designed and fabricated to prevent any failure of the cage’s integrity.

B8.2 Lateral Space
Minimum space is based on clearances between the driver and a straight edge applied to any two points on the roll cage; an example is shown. The driver's helmet shall have 152 mm (6 in.) clearance, while the driver's shoulders, torso, hips, thighs, knees, arms, elbows, and hands shall have 76 mm (3 in.) clearance. Clearances are relative to any driver selected at technical inspection, seated in a normal driving position, and wearing all required equipment.

For any member to be a part of the roll cage, that member must conform to B8.3.1, otherwise it is assumed to have no contribution (a-arms are an example of members which do not conform to B8.3.1)

If there are any triangulating members joining the RHO to the vertical members of the Rear Roll Hoop (RRH-B8.3.2), and these triangulating members conform to B8.3.12, then the virtual side surfaces may be extended by an outboard crease over the triangulating members.

The driver's helmet shall have 152 mm (6 in.) clearance to the side surfaces.
The driver's shoulders, torso, hips, thighs, knees, arms, elbows, and hands shall have 76 mm (3 in.) clearance to the side surfaces.

B8.2.1 Vertical Space
The driver's helmet shall have 152 mm (6 in.) clearance from any two points among those members that make up to top of the roll cage. These members are: the RHO members (exclusive of any covering or padding); the RRH upper ,LC; and the LC between points C. In an elevation (side) view, no part of the driver's body, shoes, and clothing may extend beyond the envelop of the roll cage

B8.3 Roll Cage Structure

B8.3.1 Elements of the Roll Cage
The roll cage must be a space frame of tubular steel. The required members of the roll cage are illustrated in Figs.RC2 and RC4. Primary members must conform to B8.3.12. Primary members are:
Rear Roll Hoop (RRH)
Roll Hoop Overhead Members (RHO)
Front Bracing Members (FBM)
Lateral Cross Member (LC) in Rule B8.3.3
Front Lateral Cross Member (FLC) in Rule B8.3.4

Secondary members must be steel tubes having a minimum wall thickness of 0.89 mm (.035 in) and a minimum outside diameter of 25.4 mm (1.0 in): Secondary members are:
Lateral Diagonal Bracing (LBD)
Lower Frame Side (LFS)
Side Impact Member (SIM)
Fore/Aft Bracing (FAB)
Under Seat Member (USM)
All Other Required Cross Members
Any tube that is used to mount the safety belts

Roll cage members which are not straight must not extend longer than 711 mm (28 in.) between supports. Small bend radii (<152 mm, 6 in.) at a supported end of a member are excepted, and are not considered to make a member not-straight. The minor angle between the two ends of a not-straight tube must not exceed 30°.

Note: Required dimensions between roll cage members are defined by measurements between member centerlines, except where noted.

B8.3.2 Rear Roll Hoop (RRH)
The RRH is a structural panel behind the driver’s back, and defines the back side of the roll cage. The driver and seat must be entirely forward of this panel. The RRH is substantially vertical, but may incline by up to 20° from vertical. The minimum width of the RRH, measured at a point 686 mm (27 in.) above the inside seat bottom, is 736 mm (29 in.). The vertical members of the RRH may be straight or bent, and are defined as beginning and ending where they intersect the top and bottom horizontal planes (points Aa and Aa, and Ba and Bb in Fig.RC1). members must be continuous tubes (i.e., not multiple segments joined by welding). The vertical members must be joined by LC members at the top and bottom. The LC members must be continuous.

Appendix A3
**B8.3.2.1 Rear Roll Hoop Lateral Diagonal Bracing (LDB)**

The RRH must be diagonally braced. The diagonal brace(s) must extend from one RRH vertical member to the other. The top and bottom intersections of the LDB members and the RRH vertical members must be no more than 127 mm (5in.) from the RRH top and bottom horizontal planes, respectively. The angle between the LDB members and the RRH vertical members must be greater than or equal to 20°. Lateral bracing may consist of more than one member.
The forward ends of the RHO members (intersection with the LC) define points CR and CL (Fig. RC3). Points CR and CL must be at least 305 mm (12 in.) forward of a point, in the vehicle’s elevation view, defined by the intersection of the RHO members and a vertical line rising from the after end of the seat bottom. This point on the seat is defined by the seat bottom intersection with a 101 mm (4 in.) radius circle which touches the seat bottom and the seat back. The top edge of the template is exactly horizontal with respect to gravity.
Points CR and CL must also be no lower than the top edge of the template, 1041.4 mm (41 in) above the seat. Note: the top edge of the template is exactly horizontal with respect to gravity.

RC 3

Figure 5

B8.3.4 Lower Frame Side Members (LFS)
The two Lower Frame Side members define the lower right and left edges of the roll cage. These members are joined to the bottom of the RRH and extend generally forward, at least as far as a point forward of every driver’s heels, when seated in normal driving position. The forward ends of the LFS members are joined by an LC, the Front Lateral Cross (FLC – Fig. RC4). The intersection of the LFS members and the FLC define the points AF_R and AF_L. 22 © 2013 SAE International. All Rights Reserved. Printed in USA 2013 Baja SAE Rules

Figure 6
RC 4
B8.3.5 Side Impact Members (SIM)
The two Side Impact Members define a horizontal mid-plane within the roll cage. These members are joined to the RRH and extend generally forward, at least as far as a point forward of every driver’s toes, when seated in normal driving position. The forward ends of the SIM members are joined by an LC. The intersection of the SIM members with this LC define the points $S_{FR}$ and $S_{FL}$. The SIM members must be between 203 mm (8 in.) and 356 mm (14 in.) above the inside seat bottom (Fig. RC3).

**NOTE:** Every driver’s feet must be entirely behind the plane defined by points $A_{FR}$ and $S_{FR}$. If the LC between $S_{FR}$ is below the driver’s toes then an additional LC must run between the FBM members above the driver’s toes.

B8.3.6 Under Seat Member (USM)
The two LFS members must be joined by the Under Seat Members. The USM must and pass directly below the driver where the template in RC3 intersects the seat bottom. The USM must be positioned in such a way to prevent the driver from passing through the plane of the LFS in the event of seat failure.

B8.3.7 Front Bracing Members (FBM)
Front bracing members must join the RHO, the SIM and the LFS (Fig. RC5). The upper Front Bracing Members (FBMUP) must join points $C$ on the RHO to the SIM at or behind points $SF$. The lower Front Bracing Members (FBLLOW) must join points $AF$ to points $SF$. The FBM must be continuous tubes. The angle between the FBMUP and the vertical must be less than or equal to 45 degrees. 23 © 2013 SAE International. All Rights Reserved. Printed in USA 2013 Baja SAE Rules

![Figure 7](image-url)
B8.3.8 Fore/Aft Bracing (FAB)

The RRH must be restrained from rotation and bending in the elevation plane by a system of triangulated bracing. Bracing must either: 1) Rear Bracing - directly restrain both points B from longitudinal displacement in the event of failure of the joints at points C; or 2) Front Bracing - restrain both points C from longitudinal and vertical displacement, thus supporting points B through the RHO members. Better design will result if both front and rear bracing are incorporated.

Members used in the FAB systems must not exceed 1016 mm (40 in.) in unsupported length. Triangulation angles (projected to the elevation view) must be at least 20°.

B8.3.8.1 Front Bracing

Front systems of FAB must connect the FBM members to the SIM members (on the same sides). The intersection with the FBM members must be within 127 mm (5 in.) of points C. The intersection with the SIM members must be vertically supported by further members connecting the SIM members to the LFS members.

B8.3.8.2 Rear Bracing

Rear systems of FAB must create a structural triangle, in the elevation view, on each side of the vehicle. Each triangle must be aft of the RRH, include the RRH vertical side as a member, and have one vertex near Point B and one vertex near either Point S or Point A.

The third (after) vertex of each rear bracing triangle must additionally be structurally connected to whichever point, S or A, is not part of the structural triangle. This additional connection is considered part of the FAB system, and is subject to B8.3.1, but may be formed using multiple joined members, and this assembly of tubes, from endpoint to endpoint, may encompass a bend of greater than 30 degrees.

Attachment of rear system FAB must be within 127 mm (5 in.) of Point B, and must be within 51 mm (2 in.) of points S and A. In the plan view, the rear bracing structural triangles must not be angled more than 20 degrees from the vehicle centerline. The after vertices (right/left) of the FAB structural triangles must be joined by an LC.

B8.3.9 RHO/FBM Gusseting

If the RHO and FBM on one side of the vehicle are not comprised jointly of one tube, bent near point C, then a gusset is required at point C to support the joint between the RHO and the FBM.
**B8.3.10 Tube Joints**

**B8.3.10.1** Roll cage element members which are made of multiple tubes, joined by welding, must be reinforced with a welding sleeve. Many roll cage elements are required to be continuous tubes, and may not be made of multiple pieces. Tubes which are joined at an angle need not be sleeved.

**B8.3.10.2** Sleeves must be designed to fit tightly on the inside on the joint being reinforced. External sleeves are not allowed. Sleeves must extend into each side of the sleeved joint, a length of at least two times the diameter of the tubes being reinforced, and be made from steel at least as thick as the tubes being reinforced.

**B8.3.10.3** The general arrangement of an acceptable sleeved joint is shown in Fig.RC9. A butt weld and four rosette welds (two on each tube piece, on holes of a minimum diameter of 16 mm (0.625 in.) are required.

**B8.3.10.4** A minimum of 4 linear inches of weld is required to secure the sleeve inside the joint, including the butt joint and the rosette welds.