Mazda Miata Roll Cage

A Baccalaureate thesis submitted to the
Department of Mechanical and Materials Engineering
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

Justin White

April 22, 2016

Thesis Advisor:
Professor Amir Salehpour
TABLE OF CONTENTS

TABLE OF CONTENTS ........................................................................................................ 1
LIST OF FIGURES ................................................................................................................ 1
ABSTRACT ............................................................................................................................. 2
PROBLEM STATEMENT ......................................................................................................... 2
BACKGROUND ...................................................................................................................... 2
  EXISTING PRODUCTS ......................................................................................................... 2
  MAJOR RULES AND REGULATIONS .................................................................................. 3
  CUSTOMER FEATURES ..................................................................................................... 4
DESIGN ................................................................................................................................. 5
  CALCULATIONS ................................................................................................................ 5
  DESIGN PROCESS .............................................................................................................. 5
  MATERIAL SELECTION .................................................................................................... 7
  DESIGN OPTIMIZATION .................................................................................................... 8
  MANUFACTURING ............................................................................................................. 11
WORKS CITED ...................................................................................................................... 12
APPENDIX A ........................................................................................................................ 13
  NATIONAL AUTO SPORT ASSOCIATION RULES (5) ......................................................... 13
  CHUMPCAR WORLD SERIES RULES (3) ........................................................................ 18
  24 HOURS OF LEMONS RULES (4) .................................................................................. 22
APPENDIX B ........................................................................................................................ 25
  MIATA ROLL CAGE SURVEY ............................................................................................... 25
APPENDIX C ........................................................................................................................ 26
  QFD ..................................................................................................................................... 26
APPENDIX D ........................................................................................................................ 27
  DRAWINGS ....................................................................................................................... 27
APPENDIX E ........................................................................................................................ 37
  SCHEDULE ....................................................................................................................... 37
APPENDIX F ........................................................................................................................ 38
  PROPOSED BUDGET ......................................................................................................... 38
  ACTUAL COST ................................................................................................................... 38

LIST OF FIGURES
Figure 1: Harddog M1 Bolt-In Roll Bar (1)
Figure 2: Miatacage.com First Generation Miata Pre-Fabricated Roll Cage (2)
Figure 3: NASA Diagonal Bar Diagram (5)
Figure 4: Design Configuration 1
Figure 5: Design Configuration 2
Figure 6: Stresses Resulting from FIA Loading Applied to Main Hoop
Figure 7: Stresses Resulting from FIA Loading Applied to Windscreen
Figure 8: Door bar Bending Stresses
Figure 9: NASA Roll Cage Guidelines (5)
Figure 10: ChumpCar Cage Regulations Outline (3)

ABSTRACT
A Mazda Miata was purchased with the intentions of building a cheap, yet competitive endurance race car to participate in the ChumpCar World Series. The focus of this report is the design and building of the required roll cage. The ChumpCar organization only specifies geometric regulation for roll cage design. The FIA rulebook was utilized to determine what is significant strength for a roll cage. All alterations to the car and the cage geometry meets ChumpCar’s standards.

PROBLEM STATEMENT
There are many budget racing series around where the value of the car is to be very low cost so teams can have a cheap way into a sanctioned motorsport even. The problem with these series is that the safety equipment drives up the cost greatly. The biggest of these cost is the roll cage that is mandated by these series. Having a roll cage made by a shop is common, but the cost of this can be in excess of a couple thousand dollars. However, it is very important that the cage is strong enough to withstand large impact in the events of a crash.

BACKGROUND
The three main racing series that rules and regulations that will be accommodated are National Auto Sort Association (1), ChumpCar World Series (2), and 24 Hours of Lemons (3). There are other organizations but these focus on pro racing and factory spec racing. Being that this cage will be fitted on a outdate model of vehicle, there would be a very small market for this cage in these series. The vehicle that the roll cage is being fitting to will be a first generation (1990-1997) Mazda Miata.

EXISTING PRODUCTS
The Mazda Miata has been used in motorsports since its debut. Because of this many products are available for use. Markets are flooded with bolt in roll bars as seen in figure 1 below (4).
Roll bars, like the one in figure 1, are not allowed to be used in any sort of wheel to wheel racing. MiataCage.com (5) offers pre-fabricated roll cages with different options to accommodate different racing organizations. The come pre-bent and are compatible with a hardtop installed on the Miata. Shown in figure 2 (5) below is one iteration of the product they offer.

Many use this company for simplicity and a quick finished item. The problems that exist with this product, is once installed, it doesn’t leave much room for tall people, and entering the car is difficult. These two issues will be addressed in the new design.

**MAJOR RULES AND REGULATIONS**

All series offer a complete rule book of regulations of fabricating a cage. Rules between them are very common and overlap from one to another. A few key points are the tubing sizes that are required, the number of lateral cross bars, the number of tie in points to the frame, and the base plate locations.
National Auto Sport Association (NASA) (1) have the most lenient regulations because this organization allows you to race against highly modified race cars. The rules provided by NASA are the most in depth when explaining the basics of cage building. One main point the must be addressed from their rules is the main hoop diagonal bar construction. The rules make it very clear that this bar should be 1 piece, or at least, in line when crossing the harness bar. Examples of what is needed were provided and can be seen in figure 3 below.

![NASA Diagonal Bar Diagram](image)

**Figure 3: NASA Diagonal Bar Diagram (1).**

ChumpCar World Series is the organization the car will be participating in. The rules of this organization coincide with the other two very closely. One regulation that is most stringent is that bars extending beyond the firewall is limited to two bars (2).

24 Hours of LeMons rules are the vaguest. Strict restrictions are given on the tubing that is used (3). The diameter and wall thickness required by this organization is 1.50” with a 0.120” wall thickness. This is the highest wall thickness, so this what will be used.

**CUSTOMER FEATURES**
- Tall main hoop for helmet clearance
- Nascar bars on the driver’s side for extra room and ease of entry/exit of car
- Mild steel tubing, seamless
- Rear tie-in points
- 100% compliant with NASA, ChumpCar, and 24 Hours of Lemons
- Mid chassis mounts to increase rollover stiffness
- Composed entirely of simple bends
DESIGN

The car being built will be participating mainly in the ChumpCar World Series (2). This series has vague regulations of what is required strength and geometry wise. FIA is an organization of international motorsports. There is thorough regulations for what is the required strength of a roll cage. These regulations are for race cars that travel at very high rates of speed. Being that the roll cage is being designed and installed in a Miata, speeds achieved will be significantly lower. The low power of the vehicle requires a balance between high safety, and lowest possible weight.

CALCULATIONS

The calculations in the event of a roll over are explained in depth in the FIA 2016 regulations (6). As per FIA standards, the roll cage must withstand a vertical given by Equation 1 below.

\[ F = 7.5(w) \]

Equation 1: FIA Vertical Load Calculation (7)

“F” in Equation 1 is the force applied and “w” is the vehicle weight with an additional 330 pounds added. The forces outlined by this corporation are far greater than ever will be seen by this vehicle. The National Highway Traffic Safety Administration states that vehicles weighing in less than 5000 pounds must withstand a load of 1.5 times the vehicle weight applied to the top of the roof (8). Speeds expected to be reach by the vehicle are less than 100MPH, indicating safety of the roll cage can be lower than the FIA regulations depict.

FIA also states that the bar along the top of the windscreen must be able to withstand a load calculated by Equation 2 below.

\[ F = 3.5(w) \]

Equation 2: FIA Windscreen Load Calculation (7)

“F” in Equation 1 is the force applied and “w” is the vehicle weight with an additional 330 pounds added. This load called to be applied at an angle of 25° off vertical (7).

DESIGN PROCESS

The initial design plan was to base the new cage off of the existing MiataCage.com cage (5). Once modeling and simulations were run on this design, major weakness was discovered in the main hoop and transferring forces applied to the windscreen. When applying the FIA regulation load, the stress in the main hoop beams were over twice the yield strength of the material. The decision was made to up the tubing size from .095” wall thickness to .120 wall thickness. This was still below the desired strength. Design configuration 1 can be seen in Figure 4 below.
Design Configuration 2 addresses the issues found in design configuration 1. Transmission of forces trough bars is achieved by having less bars dead-end into a joining bar. The main hoop’s strength was increased by adding two bars as additional bracing to the rearward support bars. Design Configuration 2 can be seen in Figure 5 below.

In addition to being stronger than configuration 1, configuration 2 adds space for the driver. The main hoop was angled to a 10° rearward angle. NASA states “the main hoop must consist of not more than four (4) bends maximum, totaling one hundred eighty (180) degrees +/- ten (10) degrees” (1). The main hoop in Design Configuration 2 capitalizes on the allowance of an additional 10° to create more room for the driver seat head containment.

All radiuses of Design Configuration 2 are 5.5 inches. This is based off the equipment that will be used when manufacturing that roll cage. The bender that will be used is a JD Model 2 bender and the die will be a 180° bend, 5.5 inch radius die.
**Material Selection**

The base plates for the roll cage are called out by NASA stating “welded mounting plates shall be at least 0.080-inch thick” (1). Due to the excessive rust on the chosen car, base plate thickness was decided to be increased to .125” . Plates will be made from 4340 sheet steel. Material strength of these plates can be seen in Table 1 below (9).

<table>
<thead>
<tr>
<th>Property</th>
<th>Value</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hardness, Rockwell C</td>
<td>35</td>
<td>Converted from Brinell hardness.</td>
</tr>
<tr>
<td>Tensile Strength, Ultimate</td>
<td>161000 psi</td>
<td></td>
</tr>
<tr>
<td>Tensile Strength, Yield</td>
<td>103000 psi</td>
<td></td>
</tr>
<tr>
<td>Elongation at Break</td>
<td>13.2 %</td>
<td></td>
</tr>
<tr>
<td>Reduction of Area</td>
<td>36 %</td>
<td></td>
</tr>
<tr>
<td>Modulus of Elasticity</td>
<td>29700 ksi</td>
<td>Typical for steel</td>
</tr>
<tr>
<td>Shear Modulus</td>
<td>11600 ksi</td>
<td>Typical for steel</td>
</tr>
</tbody>
</table>

Table 1: Base Plate Properties (9)

Tubing is called out by ChumpCar as follows “Minimum tubing size for cars weighing UNDER 2,500 pounds, as raced, must use a minimum tubing size of 1.50” x .095” (2). Due to the lower strength of .095” tubing, .120” is used. The material of the tubing is regulated by NASA and must be 4130 steel (1). Material properties for the tube material can be seen below in Table 2 (10).

<table>
<thead>
<tr>
<th>Property</th>
<th>Value</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hardness, Rockwell C</td>
<td>13</td>
<td>Converted from Brinell hardness.</td>
</tr>
<tr>
<td>Tensile Strength, Ultimate</td>
<td>97200 psi</td>
<td></td>
</tr>
<tr>
<td>Tensile Strength, Yield</td>
<td>63100 psi</td>
<td></td>
</tr>
<tr>
<td>Elongation at Break</td>
<td>25.5 %</td>
<td>in 50 mm</td>
</tr>
<tr>
<td>Reduction of Area</td>
<td>60 %</td>
<td></td>
</tr>
<tr>
<td>Modulus of Elasticity</td>
<td>29700 ksi</td>
<td>Typical for steel</td>
</tr>
<tr>
<td>Shear Modulus</td>
<td>11600 ksi</td>
<td>Typical for steel</td>
</tr>
</tbody>
</table>

Table 2: Tube Material Properties (10)
**DESIGN OPTIMIZATION**

Modeling of Design Configuration 2 was done using Solidworks 2015 Version. Using this program and the calculations above a load of 17,500 lbs. was applied to the top of the main hoop, as per FIA regulations. Forces that will be seen by this roll cage at the lower speeds that will be achieved are significantly less than FIA dictates. Below is Figure 6 and Table 3 is a diagram and values of the bending stress as a result of this load.

![Figure 6: Stresses Resulting from FIA Loading](image)

**Table 3: Stresses Resulting from FIA Loading**

<table>
<thead>
<tr>
<th>Element</th>
<th>Value (psi)</th>
<th>X (in)</th>
<th>Y (in)</th>
<th>Z (in)</th>
</tr>
</thead>
<tbody>
<tr>
<td>37</td>
<td>6.40E+04</td>
<td>27.5859</td>
<td>43.90885</td>
<td>-11.2226</td>
</tr>
<tr>
<td>50</td>
<td>4.97E+04</td>
<td>27.5859</td>
<td>43.90885</td>
<td>12.06332</td>
</tr>
<tr>
<td>65</td>
<td>5.42E+04</td>
<td>26.36104</td>
<td>36.8191</td>
<td>-25.7984</td>
</tr>
<tr>
<td>43</td>
<td>5.74E+04</td>
<td>27.5859</td>
<td>43.90885</td>
<td>-0.59318</td>
</tr>
</tbody>
</table>

Stresses seen by this load are near the yield strength of the material, but because FIA regulations are being used as guidance and are not required to be met, the stresses are accepted.
Loading applied to the front halo bar is specified by FIA as per Equation 2 above. The resulting force from this equation is 9900 lbs. The resulting stresses from this load can be seen below in Figure 8 and Table 5

![Figure 7: Stresses Resulting from FIA Loading](image)

<table>
<thead>
<tr>
<th>Element</th>
<th>Value (psi)</th>
<th>X (in)</th>
<th>Y (in)</th>
<th>Z (in)</th>
</tr>
</thead>
<tbody>
<tr>
<td>108</td>
<td>6.99E+04</td>
<td>27.5859</td>
<td>43.9085</td>
<td>14.65097</td>
</tr>
<tr>
<td>365</td>
<td>7.33E+04</td>
<td>1.61404</td>
<td>38.47742</td>
<td>-17.1298</td>
</tr>
<tr>
<td>398</td>
<td>7.72E+04</td>
<td>17.8973</td>
<td>-21.80636</td>
<td>-25.9607</td>
</tr>
<tr>
<td>262</td>
<td>3.13E+04</td>
<td>17.4778</td>
<td>-23.34563</td>
<td>25.73531</td>
</tr>
<tr>
<td>337</td>
<td>5.53E+04</td>
<td>4.48604</td>
<td>37.75689</td>
<td>1.558134</td>
</tr>
</tbody>
</table>

Table 4: Stresses Resulting from FIA Loading

The bending stresses in the bars due to the newly calculated load are higher than the yield strength. As per 3.2.3.2.2. Rule in ChumpCar which states “The total number of mounting points does NOT include welded tabs connecting any hoop to the body; however, a “tab” is defined as being not greater than 3/16” thick steel plate, no longer than six inches (6”), and a maximum of two (2) tabs may be placed within any 36” of tube”, the front of the halo hoop will be tied into the A pillars, and upper windscreen frame of the car. This will significantly increase the stiffness of the upright windscreen bars and top halo bar. This additional strength of the windscreen frame was not added to the simulation.
Geometry standards from ChumpCar (2) state that there must be 2 driver side door bars to pass inspection. Door bars were bent outward to extend the drivers comfort and make entry into the car as simple as possible. Side impact loading is not defined by the FIA. Loading applied to the driver’s side door bar was done based on the frictional resistance of the tires on pavement. The resulting load applied to the door bars is 2100 lbs. applied perpendicular to the door plane. Below in Figure 8 and Table 6 are the resulting bending stresses.

![Figure 8: Door bar Bending Stresses](image)

<table>
<thead>
<tr>
<th>Element</th>
<th>Value (psi)</th>
<th>X (in)</th>
<th>Y (in)</th>
<th>Z (in)</th>
</tr>
</thead>
<tbody>
<tr>
<td>506</td>
<td>1.54E+04</td>
<td>-7.19606</td>
<td>3.007044</td>
<td>26.369</td>
</tr>
<tr>
<td>514</td>
<td>1.58E+04</td>
<td>9.251401</td>
<td>1.878625</td>
<td>26.57017</td>
</tr>
<tr>
<td>504</td>
<td>1.18E+04</td>
<td>22.47418</td>
<td>19.68169</td>
<td>25.55486</td>
</tr>
</tbody>
</table>

Table 5: Door bar Bending Stresses

The stresses from the loading applied are approximately one third of the yield strength of the material. Because the Mazda Miata is a convertible, the rocker panels are the strongest portion of the car. The door bar ties into the rocker with two bars welded to based plates that are attached to the rocker panel. This ensures that any side impact will transfer into the chassis of the car along with distributing across the cage.
**MANUFACTURING**

The manufacturing of this roll cage was done with the intent of being as budget friendly as possible. Tools used was a JD2 Model 3 bender, JD2 TN-100 notcher, and a Lincoln 180C welder. In combination with the individual bar drawings seen in Appendix D, the Bendtech EZ software was used for locating where to start the bends on the bars. Bends were all done by hand and were measured after ~ 3° of bend spring back was taken into account.

To save as much weight as possible the doors were stripped of all inner bracing and components. All of the interior pieces of the car were scrapped for weight saving purposes. In total more than 300 lbs. was cut from the car.

The first installation was the baseplates. These were cut from .125” thick 4340 steel. Once these plates were fully welded in, the main hoop was tach welded into place. The top halo bar was then notched accordingly and tach welded to the main hoop. The upright bars along the windscreen were then installed and welded in place. The tach welds were then completed by welding a full 360° around the joints as required by ChumpCar. The next bars to be installed was the dash bar and two top diagonal bars. The diagonal bar was notched and welded in place meeting the rule of being within 12” of the outer most edge of the main hoop. The next bars to be installed were the rear supports and diagonal members. These were lined up with the top diagonal bars to aid with transmission of forces throughout the cage. The passenger door bar was next to be install, ensuring that the dash bar and this bar contact the upright supports at the same height. The driver’s door bars were the final bars to be installed. Cutting around the door sill along with the inner crash beam inside the door was done to create the widest driver’s compartment possible. Final supports were welded in tying the door bar into the rocker panel of the car.
WORKS CITED
APPENDIX A

NATIONAL AUTO SPORT ASSOCIATION RULES (5)

15.6 Roll Cage

15.6.1 Purpose
The basic purpose of the roll cage is to protect the occupant in case of a rollover or a collision. These rules apply to all classes, unless otherwise superseded by the class rules. Vehicles homologated by, or built to the specifications of FIA Group N, FIA Group C, JAF, SCCA, IMSA, and Grand AM, must conform to these rules, or may conform to their respective current class rules for roll cage requirements for guest groups and special events. Any vehicle that does not conform to the NASA cage rules, yet conforms to cage rules of another recognized sanctioning body (SCCA, IMSA, Grand Am, etc.), that wishes to compete in NASA events on a regular basis, may be ordered to make modifications within a time frame specified by the Race Director and approved by the Regional Director. Note- It is the responsibility of the driver to furnish a copy of any non-NASA rules applicable to his/her vehicle.

15.6.2 Intent Chassis
stiffening is a side benefit of a good roll cage system, but it is not the intent of these rules. Parts of the cage deemed by the Chief Scrutineer, to serve no practical purpose other than chassis stiffening may be considered in violation of the intent of these rules. (Note: Some class rules allow for chassis stiffening.) The Chief Scrutineer may order the removal of said parts, or require that the vehicle owner redesign, reconstruct, and re-certify the roll cage if warranted. The removal or redesign of the cage, whole or in part, to comply with these rules, does not imply that penalties will not be issued for violating the intent of these rules.

15.6.3 Installation
The cage may be removable or may be permanently welded, or any combination thereof, providing that all aspects of the cage meet these rules.

15.6.4 Padding
All roll cage surfaces that may come in contact with the driver should be padded with high-density padding such as Ethafoam or Ensolite.

15.6.5 Bends
None of the tubing may show any signs of crimping or wall failure. All bends should be Mandrel type. The center radius of the bends should not be less than three (3) times the outside diameter of the roll cage tubing.

15.6.6 Main Hoop
The main roll cage hoop should be as wide as the full width of the interior and must be as close to the roof as possible without violating CCR section #15.6.20 Inspection. One continuous length of roll bar tubing shall be used as the main hoop. The main hoop must consist of not more than four (4) bends maximum, totaling one hundred eighty (180) degrees +/- ten (10) degrees.
15.6.7 Diagonal Brace
One (1) diagonal brace should be used in the same plane as the main hoop. The diagonal should be one continuous path; meaning that it must conform to Diagrams 15.6.7a or 15.6.7b. Note- If the installation method from Diagram 15.6.7b is used, the builder should pay close attention to alignment. One end of the diagonal brace shall attach to the corner, or horizontal part of the main hoop above the driver’s head, within twelve (12) inches of the driver’s-side corner. The other end of the diagonal brace shall attach to the mounting plate (or to the main hoop as close to the mounting plate as practically possible) diagonally opposed to the driver’s head (passenger floor).

15.6.8 Forward Hoops
(Option 1) The forward hoops should extend from the main hoop (in a forward direction) to the floor by following the roof and the “A” pillar of the car. There should be a bar connecting the two (2) forward hoops at the top of the windshield mounted as close to the roof as possible without violating CCR Section #15.6.20 Inspection. The forward hoops should incorporate no more than four bends each. Optionally a “15.6.9 Halo Hoop (Option 2)” or “15.6.10 Front Hoop (Option 3)” construction may also be acceptable.

15.6.9 Halo Hoop
(Option 2) A “halo bar” extends from the main hoop (in a forward direction) following the roof line to the windshield then following along the top of the windshield, then following the roof line back to the main hoop, thus creating a “halo” over the driver’s head. A “halo” bar should be constructed of one (1) continuous piece of tubing. One (1) down tube following the “A” pillar should support the “halo” on each side of the car. The down tubes shall incorporate no more than two (2) bends each.

15.6.10 Front Hoop
(Option 3) A “front hoop” is a bar that extends up from the floor, then follows the “A” pillar up to the roof, then follows the roof line across the top of the windshield, then back down the other “A” pillar, and then terminates on the floor. There should be one (1) horizontal bar (following the roof line) connecting the main hoop and the forward hoop on each side of the car. The front hoop should incorporate no more than four (4) bends.

15.6.11 Rear Braces
The main hoop should have two (2) braces extending to the rear. The braces shall be attached as near as possible to the top of the main hoop, and no more than six (6) inches below the top. The braces should not contain any bends*. There must be at least 30 degrees between the plane of the main hoop and the plane of the rear braces. The main hoop rear braces may consist of an “X” pattern design. The main hoop braces may be mounted at the rear shock mounts or suspension pickup points (providing that the braces remain in compliance with all other sections of the CCR). They may go through any rear bulkhead(s) provided the bulkhead(s) is sealed around the cage braces. *There may be certain exceptions allowed for cars that cannot possible meet this “no bend” requirement. One exception is listed [Ref:(15.6.11.A)]. Other exceptions may be made if all of the required bars meet the specifications for a vehicle in the next heavier weight classification and the alternative design is submitted to the NASA National Office for special allowance.
15.6.11 A Rear Braces - Exceptions On cars where the rear window/bulkhead prohibits the installation of rear braces (Porsche 914, Pontiac Fiero, etc.) the main hoop should be attached to the body by plates welded to the cage and attached to the stock shoulder harness mounting location. There must also be a diagonal bar connecting the top of the main hoop to the lower front passenger side mounting point (“Petty bar”). Some cars built for racing in other recognized sanctioning bodies may be granted a waiver of this rule; however they must show proof of compliance with the current published rules for their class.

15.6.12 Door Bars / Side Impact Protection
At least two (2) door bars on the driver side and one (1) door bar on the passenger side are required in all vehicles. Note- an “X” design counts as two bars. Unless superseded by class rules, modifications to any non-chassis structure (such as door panels, inner door sheet metal, windows, door internals, etc.) may be made to accommodate any allowed door bar configuration. However, removal of material and / or modifications is limited to 1) the least amount to accommodate the door bar(s), and 2) can serve no other function. Holes in the door jamb (B-pillar) may be permitted to accommodate door bars; however the structure should not be “notched” so as to weaken it.

15.6.13 Mounting Points
The roll cage shall be mounted to the floor area, which includes rocker panels, of the car in six, seven, or eight points. The cage shall not go through the firewall. The seventh and eighth points must attach to the firewall or front fender wells. All cage attachment points must be mounted to plates or a mounting box (plinth). Each required cage bar shall terminate on a plate with a 360 degree weld to the mounting plate, except as specified in Section 15.6.14.B. There shall be only one (1) mounting “point” per plate. This point is defined as where the “required tube” mounts. All additional tubes mounted to that plate must be mounted as close to the required tube as possible [Ref: (15.6.14.B)]. It is recommended that plinth boxes use a bottom support plate in cases where the edges of the box may punch through the sheet metal.

15.6.14 Mounting Plates
Each mounting plate shall be no greater than one hundred (100) square inches, and no less than nine (9) square inches. Each mounting plate must be no greater than twelve (12) inches or less than two (2) inches on any side. Welded mounting plates shall be at least 0.080-inch thick. Plates may extend onto vertical sections of the structure. Any mounting plate may be multi-angled, but shall not exceed one hundred (100) square inches total including vertical sections.

- **15.6.14.A Mounting Plates** – Bolt-In Cage The attaching points of a bolt-in cage to the body must use reinforcing plates to sandwich the body. At least three (3) bolts are required for each bolt-in plate and the plate must be at least 3/16 inch thick. All hardware must be SAE Grade five (5) or better with 5/16” diameter minimum. All nuts must be held securely by a locking system such as safety wire, lock washer, Nylock, or jam-nuts. Nylock or nuts that use metal crimping to prevent loosening shall not be reused.
• **15.6.14.B Tube / Mounting Plate Specifications** Any number of tubes may attach to a plate so long as they are touching each other at the plate. There may be a small gap between tubes to allow welding 360 degrees around each tube. If there is no gap between the tubes, they must be welded around the base as much as possible to form a single figure-eight weld, AND the tubes must be welded to each other for two (2) inches up from the base plate.

15.6.15 **Welds**

All welding must be of the highest quality with full penetration. All tubes must be welded 360-degrees around the circumference of the tube. **15.6.16 Tube Structure Design / Body**

Tubes may touch the body in any place (not to violate CCR section #15.6.20 Inspection), but shall not be attached anywhere except as permitted by CCR Section #15.6.11.A Rear Braces - Exceptions. No deformation of the interior body panels is permitted, except that the horizontal part of the sheet metal (next to the driver’s and/or passenger’s head) between the top of the “B” pillar and the top of the “A” pillar, may be pushed in to accommodate the roll cage. The intent of this allowed deformation is strictly to allow for more headroom for the driver and/or passenger.

15.6.17 **Additional Reinforcement**

Any number of additional reinforcing bars are permitted within the structure of the cage provided that they are installed strictly for safety and do not violate CCR Section #15.6.2 Intent. This rule does not permit reinforcements in classes with spec cages. All required bars must be made of the same material and meet with at least the minimum specifications for size and thickness. Additional tubing may be of any size / dimension, however it should not create an unsafe situation.

15.6.18 **Roll Cage Tubing Sizes**

For the purposes of determining roll bar tubing sizes, vehicle weight is as raced, but without fuel and driver. Note: There is an allowance of minus 0.010 inches on all tubing thicknesses. Minimum tubing size for the roll cage is:

**Up to 1500 lbs**

- 1.375” x 0.095” Seamless Alloy (4130), Seamless mild steel (CDS Mechanical) or DOM 1.500” x 0.080” Seamless Alloy (4130), Seamless mild steel (CDS Mechanical) or DOM

**1501 - 2500 lbs**

- 1.500” x 0.095” Seamless Alloy (4130), Seamless mild steel (CDS Mechanical) or DOM 1.500” x 0.120” ERW* (No issuance of log books for cars with ERW cages) *Note- Specifications listed only for reference for inspection of grandfathered vehicles.

**2501 - 3000 lbs**

- 1.500” x 0.120” Seamless Alloy (4130), Seamless mild steel (CDS Mechanical) or DOM 1.750” x 0.095” Seamless Alloy (4130), Seamless mild steel (CDS Mechanical) or DOM 1.750” x 0.120” ERW* (No issuance of log books for cars with ERW cages) *Note- Specifications listed only for reference for inspection of grandfathered vehicles.
3001 - 4000 lbs 1.750” x .120” Seamless Alloy (4130), Seamless mild steel (CDS Mechanical) or DOM No ERW allowed.

Over 4000 lbs 2.000” x 0.120” Seamless Alloy (4130), Seamless mild steel (CDS Mechanical) or DOM No ERW allowed.

15.6.19 Bending Allowances
If the maximum number of bends permitted for any one bar is exceeded, all required components shall be made from the tubing size listed for the next heavier category and must be approved by a NASA race tech shop or scrutineer.

15.6.20 Inspection
A 3/16 inch inspection hole must be drilled in each of the required bars in a non-critical area for the purpose of determining wall thickness. All welds, except those mounted to plates on the floor, must be accessible for inspection (360 degrees).

15.6.21 Seat Back Support
A seatback support must be made to hold the seat from going back in the event of a crash. A plate should be used to distribute the load. No bolts, corners, or sharp objects should be placed in such a manner that could lead to a possible puncture of the driver in a high impact crash. Seat back support need not be attached to the seat itself. Proper design and installation is crucial to safety and it is recommended that the driver employ the services of a professional race car builder for this, as well as all other vehicle safety items. An exception may be made for those seats homologated to, and mounted in accordance with, FIA 8855-1999 or 8862-2009 standards. Those seats that qualify for the aforementioned exception must conform to the entire FIA 8855-1999 or 8862-2009 set of regulations, as applicable. This includes a mandatory seat replacement, or use of a seat back brace, for any seat more than five (5) years old (8855-1999) or more than ten (10) years old (8862-2009). Please reference the FIA regulations. http://www.fia.com/. Seatback supports should be located as shown below. Diagram courtesy of I/O Port Racing.

15.6.22 Shoulder Harness Bar
The shoulder harness bar shown in the cage diagram (below) as bar “H” – “G” must meet the minimum dimensions required for the cage design for the specific vehicle. The bar must intersect the required diagonal bar, but need not remain in the same plane as the main hoop (e.g. May bend aft-ward to allow more seat room behind the driver and /or passenger seat(s); as long as it intersects the required diagonal). The harness bar need not intersect the main hoop at any specific location (vertically), however the bar should be installed horizontally (parallel with the ground).
Figure 9: NASA roll cage guidelines

**CHUMPCar World Series Rules (3)**

Rules Rev. 16-1.1

3. SAFETY

3.1. All required driver’s safety equipment must be installed, implemented, and/or worn at all times while on the track. The participant agrees that the participant bears the ultimate responsibility at all times to ensure the proper installation and maintenance of participant’s driver’s safety equipment,
and compliance with all ChumpCar rules, regulations, and agreements, including but not limited to those contained in the BCR.

3.2. Roll-cages and Supporting Structure: A quality, well-fabricated, full roll-cage is required. Rollcages may be weld-in or bolt-in; roll-cage tubing joints may be welded or bolted, provided bolt-in methods meet conventional safety standards. Vehicles with a poorly built, improperly mounted, inadequately fitted or badly engineered roll-cage will NOT be allowed to compete.

3.2.1. At minimum, all roll-cages must include:

3.2.1.1. Full rear, main-hoop with either: (i) front-hoop appropriately braced to each other along the roofline; or, (ii) halo-hoop appropriately attached to two front vertical legs; or (iii) front vertical bars bent rearwards at the roofline, connecting to the rear main hoop and cross-braced horizontally along the upper windscreen line;

a. On all closed cars, the main hoop must be as close as possible to the roof (in height) and “B” pillars (in width).

b. The main hoop (behind the driver) must be the full width of the cockpit for all cars. It must be one continuous length of tubing with smooth bends and no evidence of mandrel crimping or wall failure. c. A 3/16” inspection hole must be drilled in the main hoop, such that a Tech Inspector has access to measure the wall thickness of the main hoop without obstruction.

3.2.1.2. Two driver-side door bars that will prevent cockpit intrusion (NASCAR-style or X-design is acceptable). a. The spacing between the fore and aft terminal ends of all door bars (including X-design) must include a separation of no less than six inches of open space when measured at the centerline of each bar. Triangulated bars that meet or join at the front hoop are allowed so long as the spacing of the upper and lower bars (attached to the main hoop) is a minimum of six inches when measured at the centerline of the tubing bar.

b. The upper door bar shall not be placed higher than the top of the door or window sill.

c. If the distance, measured at any point between the highest portion of the door sill or floor pan (whichever is higher) and the lowest edge of lower door bar is greater than ten inches (10”), a floor or lower-sill intrusion bar, mounted as low as possible on each side of the roll-cage, at or just above the door sill, joining the front hoop and the main hoop.

d. A minimum of one (1) door bar shall be required on the passenger side. This bar can be a floor- or sill- or mid-level door bar.

3.2.1.3. Appropriate main-hoop rear-supports (backstays) with no bends, located as close to 45 degrees from horizontal as practical;

3.2.1.4. One main-hoop diagonal support bar; installed in the same plane as the main hoop, with one end terminating in general proximity to the main hoop bend above the driver’s head and the other end terminating in general proximity to the lower end of the opposite side of main hoop. The diagonal support bar may be of one (1) or two (2) piece construction and it may intersect with or cross-through the horizontal support bar (used for seat belt harness attachment and/or seat support).

3.2.1.5. Complete 360-degree welds at all welded joints. All welds to be sufficient in heat, penetration, bead and consistency.

3.2.1.6. Each major load-bearing member must be formed from its own single, continuous tube.

3.2.1.7. Shoulder-harness bars strongly encouraged (over floor-mounted harnesses), and
virtually necessary for proper shoulder-harness mounting in some applications; dash bars are not required but very strongly encouraged. Your roll-cage GENERALLY better have the same main bars in the same main places as shown in the picture below or you’re going home.

3.2.2. Roll-cage Steel Tubing and Hardware (Vehicle Weight Without Driver):
a. Minimum tubing size for cars weighing UNDER 2,500 pounds, as raced, must use a minimum tubing size of 1.50” x .095.
b. Minimum tubing size for cars weighing OVER 2,500 pounds, as raced, must use a minimum tubing size of 1.75” x .095 or 1.50” x .120”.
c. For purposes of determining tubing sizes, the vehicle weight is as raced without fuel and driver.

3.2.2.1. Properly-bent, racecar-grade and -quality tubing is mandatory: no stretched or crushed bends allowed. DOM mild steel is very strongly recommended over ERW (seamed) tubing.

3.2.2.2. The radius of all bends in the roll cage (measured at centerline of tubing) must not be less than three times the diameter of the tubing.

3.2.2.3. All attachment points on the vehicle must be selected and reinforced as necessary so that, in an accident, the roll-cage will not punch through, tear, or grossly distort any roll-cage attachment point. Heavily rusted floor pans must be replaced or reinforced with sheet steel plate. HEAVILY RUSTED FLOOR PANS LEFT IN PLACE WILL NOT PASS TECH INSPECTION. Spreader plates, gussets, and/or other reinforcing hardware are generally required to meet this goal. Minimum 1/8” (0.125”) thick steel backing plates – not washers – must be present on the reverse or underside of any bolt-in cage location.

3.2.2.4. All mounting hardware is to be Grade 8 bolt hardware or better (no Grade 3 or 5 hardware will be allowed).
a. Minimum bolt size is 3/8” diameter. Fine or coarse thread is open.
b. All nuts should be self-locking (nylok / ovalated) or cotter-pinned or drilled and safetywired.

3.2.2.5. No waivers or “repair by next event” allowances will be granted on any roll-cage issue. Make sure it’s 100% right the first time.

3.2.2.6. All roll-cages / seats / drivers must be fit such that when the driver is securely belted inplace, the top of the driver’s helmet does not extend above the centerline of the main hoop. This applies to ALL drivers on the team. Any driver found in violation of this rule will be black- flagged and the car withdrawn from competition until repairs or modifications have been made and the car completes a re-tech inspection.

3.2.2.7. All roll cage tubing must be padded with high density roll bar padding wherever a driver’s extremity may contact the tube.

3.2.2.8. Cars may compete with bolt-in cages. Roll-cage design and construction must maintain typical SCCA/NASA standards. (Hardware per Item 12 – above.)

3.2.3. In order to prevent massively expensive roll-cages that start to look and act like a tubeframe chassis, ChumpCar has defined the “maximum, value-free” roll-cage. The “maximum, value-free” roll-cage includes all pads, points, tubes and triangulations necessary to maintain an extremely high degree of safety, while keeping costs in-check and keeping competition well-balanced.
Teams MAY exceed the design and application of the “maximum, value-free” rollcage; however, additional value will be assessed by the Tech Inspector, based on the perceived performance enhancement of the roll-cage.

![ChumpCar defined “maximum, value-free” roll-cage](image)

**Figure 10: ChumpCar cage regulations outline (3)**

As per Section 3.2 of ChumpCar’s Basic Competition Rules:

**The maximum, value-free roll-cage design:**

3.2.3.1. Will NOT feature more than 2 tubes inside the front engine or storage compartment and each tube MUST terminate prior to the centerline of the front axle.

3.2.3.2. Is limited to eight (8) body and/or frame mounting points – welded and/or bolted.

3.2.3.2.1. The total number of mounting points does NOT include a sub-frame to support a seat mount, provided that the seat sub-frame does not exceed two (2) chassis contact pads.

3.2.3.2.2. The total number of mounting points does NOT include welded tabs connecting any hoop to the body; however, a “tab” is defined as being not greater than 3/16” thick steel plate, no longer than six inches (6”), and a maximum of two (2) tabs may be placed within any 36” of tube.

3.2.3.3. Will NOT have more than four (4) tubes installed behind the main hoop and two (2) of these must include the main-hoop rear-support (backstay) bars.

3.2.3.4. Will NOT have any tubes or bars extend below the factory floor-pan.

**NOTE** – Reasonable protective and supportive square and/or round tubular structures may be installed around any SFI-FIA approved fuel cell PROVIDED that the structure DOES NOT connect to or tie-into any suspension point or suspension pick-up point or add to the general rigidity of the chassis or provide any performance advantage whatsoever. Fuel cell protective structures may be attached to portions of the main roll-cage; however, it will be a judgment call on the part of Tech Inspection as to whether the structure violates the restrictions stated herein. There is no appeal. ALL FABRICATION AND INSTALLATION MUST BE OF THE HIGHEST POSSIBLE PROFESSIONAL QUALITY OR YOU WILL BE INSTRUCTED TO REMOVE THE STRUCTURE BEFORE BEING ALLOWED ON-TRACK.
24 HOURS OF LE MONS RULES (4)

Cage Rules
FINDING OR BUILDING A ROLLCAGE
Before you put in a rollcage, you've got a decrepit $500 hooptie. After you put in a rollcage, you've got a thoroughbred competition machine. Really. And hey--as a side benefit, that rollcage might even prevent your heap's rusty scab of a body from collapsing right onto your head. Assuming you built it correctly.

Don't know what "built it correctly" means, exactly? Overwhelmed by the prospect of bending tubes, cutting metal, welding seams, and getting hot flaming sparks up your corn chute? Well then, you've got other options.

1) Use a professional cage builder/installer. Go to your town's local race shop or competition fabricator, drop the car off empty, and pick it up a few days later with a rollcage in place. This can cost a ton, or be shockingly cheap--it pays to shop around and get referrals. There's a huge spread on pricing, and it's not always associated with quality.

If you choose this route, make sure that both you and your builder understand LeMons’ cage requirements in advance: A lot of roundy-round and drag-racing series don't build their cages to anything approaching road racing standards. Whether you're doing the fabrication or handing it off to a pro, it's your butt (and your entry) on the line in the end. Make sure they understand what the LeMons rules dictate.

2) Buy a Pre-Made kit. One alternative to a scratch-built cage is buying a pre-made kit. These can be great, but all kits are not created equal. Most bolt-in kits are simply not heavy duty enough for serious road racing--currently, you must have a fully welded cage for LeMons racing. Also avoid kits sold as "drag cages" or "street cages." These rarely meet the requirements for wheel-to-wheel road racing.

3) Buy a Tubing Kit. Halfway between a real kit and pure DIY, these offer raw tubes that have been cut to approximate lengths. It's then up to you to bend, weld, and grind stuff accordingly.

4) Go with a known quantity. The LeMons Forum can be a good way to get in touch with teams that have gone through tech before; you can also get directly in touch with the LeMons staff for recommendations.

NOTES ON CAGE DESIGN
Cages should fit the cabin's original contours as closely as possible, but should also contain as few bends as possible. Obviously that means some tradeoffs. Stripping out the interior always gains you more room and more options. Removing the dash makes things even easier.

Use common sense when designing your cage. Bars that are too close to the driver will diminish both safety and comfort; avoid unnecessary curves or bends, since straight tubes are always the strongest; verify that your drivers can still get in and out of the car in a hurry;
make sure the tops of your team's helmets are comfortably lower than the top of the cage (at least two inches' clearance is a good rule of thumb). Again, this is car racing, not rocket science.

When visualizing your cage, imagine it made out of dried-out spaghetti. Now picture a fat dude perched right on top, pushing against the sides, or rocking it back and forth. Wherever the spaghetti breaks first is the weakest part of your layout. Return curves and compound curves are especially bad (and virtually always unnecessary). Use straight lines wherever you can, and triangulate wherever you can't.

LeMons' most basic cage requirement calls for at least six major mounting points to the car: two where the front hoop meets the car, two where the main hoop meets the car, and two where the main-hoop backstays (two straight reinforcing tubes connecting the top of the main hoop to stout mounting points at the rear) meet the car.

The windshield hoop and main hoop should be connected with at least a pair of straight tubes running as close to the roof's edges as possible. The door bars should run across the door opening between the front and rear hoops to protect the driver from a side impact. When positioning the door bars, try to balance impact protection and ease of entry/exit--the only thing worse than getting T-boned is not being able to bail out in a fire. Cutting out the stock inner doorskins will get you a lot more room to design safe but accessible door bars. Vertical reinforcing bars that tie the horizontal door bars together, and/or connecting the horizontal door bars to the rocker sill, are also good ideas.

A horizontal harness-mounting bar behind the driver is generally the best (and sometimes the only) place to anchor your shoulder straps. Keep in mind that the shoulder-strap anchors must be even with, or no more than 15 degrees below, the point of seat entry. Position your harness bar accordingly.

Finally, you must have one main-hoop diagonal support--the simplest way to accomplish this is to run a clean, straight tube from the driver's-side top corner of the main hoop to the passenger's side bottom cage-mounting pad at a more-or-less 45-degree angle. This bar will likely intersect your harness bar; you can make either the diagonal or the harness bar from two pieces to deal with that intersection, but the finished two-piece section must still form a very straight, very clean line.

TUBE TYPES
A single, continuous piece of tube, properly bended as needed, should be used for all major cage elements. This means if your main hoop comes up a few inches short, just build a new one that actually fits--don't try to extend it with short bits of tube grafted onto the ends. Spliced tubes, hoops made from multiple intersecting sections, and damaged tubes scavenged from other cages are always a no-no.

Bear in mind, all tubing isn't the same. Purpose-built rollbar tubing (the only thing we allow) is a whole lot stronger than muffler pipe, water pipe, or electrical conduit, and you won't find it at the local hardware store. This is special-order stuff. We highly recommend seamless,
drawn-over-mandrel (DOM) mild steel rollbar tubing. A cheaper but much less robust alternative is seamed (commonly called ERW) mild steel rollbar tubing. While LeMons allows either type, we feel the extra cost of DOM tubing is peanuts in light of the additional safety it buys. Want to be smart? Use DOM.

Rollbar tubing also comes in various sizes. The measurements that matter for our purposes are outside diameter (O.D.) and wall thickness. This is usually expressed as [O.D. in inches] x [wall thickness in inches]. For cars under 3000 pounds as raced, LeMons requires a minimum of 1.50" x .120" or 1.75" x .095" cage tubing. For cars over 3000 pounds, the spec grows to 1.75" x .120" or better.

MOUNTING POINTS
Cages must be welded at all joints, including connections to the car. All welds should be clean, deep, and as close to fully continuous as possible.

Sturdy mounting methods are required at every junction between rollcage and car. Usually, this means creating robust mounting plates where the tubes join the body or frame; you might even have to reinforce the area around the mounting plates to guarantee suitably sturdy attachment. And remember, as the tubes travel down toward their attachment points, they should be kept as straight as possible—any bends near the attachment points can significantly compromise strength. Under no circumstances should reverse bends be used under the dash—either run the tube straight down and accept the cramped access, or take out the dash (ie, do it right).

TUBE BENDS
All bends should be smooth and consistent and show zero abnormal crimping, crushing, stretching, narrowing, or other weirdness. These visual markers point to improper materials or handling, and will get you rejected in tech. The typical Harbor Freight bottle-jack bender isn’t nearly strong enough to properly bend rollbar tube of LeMons’ required diameters. A good, professional-grade hydraulic bender using the correct dies and reasonable radii is the least that you'll get away with. If you've got access to a professional mandrel bender, so much the better.

CAGE PADDING
Wherever any part of the driver's body might contact the cage during a crash, that area must be securely covered with high-density, purpose-built rollbar padding. You'll have to find this stuff from a speed shop—the pipe padding they sell at Home Depot won't do bupkis.

FINAL THOUGHTS
Once you've got the basic cage in place, we recommend adding extra diagonals and gusseting to increase overall strength. You can't really go wrong adding more strength, and nothing makes Friday tech inspection more pleasant than not having to scramble to find cage tubes and welders at 6:30 pm.
APPENDIX B

MIATA ROLL CAGE SURVEY
Please specify the importance of each point by circling a number (1 being the lowest, 5 the highest). There can be multiple of each number.

Cost of roll cage
1 2 3 4 5 N/A

Weight of roll cage
1 2 3 4 5 N/A

Modification/cutting on the car
1 2 3 4 5 N/A

Number of seat choices
1 2 3 4 5 N/A

Driver comfort while in car (head room, arm room)
1 2 3 4 5 N/A

Ease of entry/exit of car
1 2 3 4 5 N/A

Compatibility with hardtop
1 2 3 4 5 N/A

If there is any top priorities that are not listed, please list them below

<table>
<thead>
<tr>
<th></th>
<th>#1</th>
<th>#2</th>
<th>#3</th>
<th>#4</th>
<th>#5</th>
<th>#6</th>
<th>#7</th>
<th>#8</th>
<th>#9</th>
</tr>
</thead>
<tbody>
<tr>
<td>cost of cage</td>
<td>5</td>
<td>5</td>
<td>4</td>
<td>3</td>
<td>3</td>
<td>4</td>
<td>5</td>
<td>1</td>
<td>5</td>
</tr>
<tr>
<td>weight</td>
<td>2</td>
<td>5</td>
<td>2</td>
<td>4</td>
<td>5</td>
<td>3</td>
<td>5</td>
<td>3</td>
<td>5</td>
</tr>
<tr>
<td>modification to car</td>
<td>3</td>
<td>5</td>
<td>3</td>
<td>1</td>
<td>2</td>
<td>5</td>
<td>5</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>seat choices</td>
<td>2</td>
<td>1</td>
<td>4</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>5</td>
<td>5</td>
<td>1</td>
</tr>
<tr>
<td>driver comfort</td>
<td>4</td>
<td>1</td>
<td>4</td>
<td>5</td>
<td>4</td>
<td>4</td>
<td>5</td>
<td>5</td>
<td>3</td>
</tr>
<tr>
<td>ease entry/exit of car</td>
<td>2</td>
<td>5</td>
<td>3</td>
<td>4</td>
<td>3</td>
<td>1</td>
<td>5</td>
<td>5</td>
<td>1</td>
</tr>
<tr>
<td>hardtop compatibility</td>
<td>3</td>
<td>1</td>
<td>5</td>
<td>5</td>
<td>5</td>
<td>5</td>
<td>5</td>
<td>5</td>
<td>5</td>
</tr>
</tbody>
</table>
## APPENDIX C

### QFD

<table>
<thead>
<tr>
<th></th>
<th>tall main hoop</th>
<th>nascar bars</th>
<th>mild steel tubing</th>
<th>rear sub frame tie-in</th>
<th>2 front tie in bars</th>
<th>mandrel bends</th>
<th>weld in</th>
<th>rear diagonal bar</th>
</tr>
</thead>
<tbody>
<tr>
<td>cost of cage</td>
<td>0.16</td>
<td>1</td>
<td>10</td>
<td>1</td>
<td>7</td>
<td>1</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>weight</td>
<td>0.15</td>
<td>4</td>
<td>4</td>
<td>10</td>
<td>4</td>
<td>4</td>
<td></td>
<td>4</td>
</tr>
<tr>
<td>modification to car</td>
<td>0.12</td>
<td>7</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td>7</td>
<td>10</td>
<td></td>
</tr>
<tr>
<td>seat choices</td>
<td>0.12</td>
<td>10</td>
<td>10</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>driver comfort</td>
<td>0.16</td>
<td>10</td>
<td>10</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ease entry/exit of car</td>
<td>0.13</td>
<td>10</td>
<td>10</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>hardtop compatibility</td>
<td>0.17</td>
<td>10</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

| Target               | 7.9            | 7.2         | 3.1                | 2.2                   | 2.3                 | 1.1           | 1       | 2                 |


# APPENDIX E

## Schedule

<table>
<thead>
<tr>
<th>Task</th>
<th>Justin White Mazda Miata Roll Cage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Design I</td>
<td>8/24/2015 - 8/31/2015</td>
</tr>
<tr>
<td>Design Draft</td>
<td>9/7/2015 - 9/28/2015</td>
</tr>
<tr>
<td>Design II</td>
<td>11/23/2015 - 12/21/2015</td>
</tr>
<tr>
<td>Manufacture</td>
<td>4/8/2016 - TBD</td>
</tr>
<tr>
<td>Test</td>
<td>TBD</td>
</tr>
<tr>
<td>Tech Expo</td>
<td>TBD</td>
</tr>
</tbody>
</table>
# APPENDIX F

**Proposed Budget**

<table>
<thead>
<tr>
<th>Material</th>
<th>Cost per unit</th>
<th>Required Amount</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Material</td>
<td>$2.00 per foot</td>
<td>~ 120 Feet Required</td>
<td>$240.00</td>
</tr>
<tr>
<td>welding supplies</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gas $60</td>
<td></td>
<td></td>
<td>$60.00</td>
</tr>
<tr>
<td>Welding Rod - $40</td>
<td></td>
<td></td>
<td>$40.00</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>$100.00</td>
</tr>
<tr>
<td>tube bender</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bender - $295</td>
<td></td>
<td></td>
<td>$295.00</td>
</tr>
<tr>
<td>Die $330</td>
<td></td>
<td></td>
<td>$330.00</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>$625.00</td>
</tr>
<tr>
<td><strong>Overall Total</strong></td>
<td></td>
<td></td>
<td>$965.00</td>
</tr>
</tbody>
</table>

**Actual Cost**

<table>
<thead>
<tr>
<th>Material</th>
<th>Cost per unit</th>
<th>Purchased Amount</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Material</td>
<td>$1.65 per foot</td>
<td>140 feet purchased</td>
<td>$256.10</td>
</tr>
<tr>
<td>welding supplies</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gas $60</td>
<td></td>
<td></td>
<td>$60.00</td>
</tr>
<tr>
<td>Welding Rod - $40</td>
<td></td>
<td></td>
<td>$40.00</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>$100.00</td>
</tr>
<tr>
<td>tube bender</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bender - Borrowed</td>
<td></td>
<td></td>
<td>$330.00</td>
</tr>
<tr>
<td>Die $330</td>
<td></td>
<td></td>
<td>$330.00</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>$686.10</td>
</tr>
<tr>
<td><strong>Overall Total</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>