RACECAR CHASSIS DESIGN (VOLUME I) – CHASSIS DESIGN

A thesis submitted to the
Faculty of the Mechanical Engineering Technology Program
of the University of Cincinnati
in the partial fulfillment of the
requirements for the degree of

Bachelor of Science

in Mechanical Engineering Technology
at the College of Engineering & Applied Science

by

JOHN ELROD

Bachelor of Science University of Cincinnati

May 2011

Faculty Advisor: Amir Salehpour
ACKNOWLEDGEMENTS

First and foremost, I would like to thank the University of Cincinnati and all faculty members who have provided me with the skill sets that were essential in performing the research within this project. I would also like to thank Amir Salehpour, Greg Brown, and Ryan Carter who were all key individuals that made direct contributions to the “Racecar Chassis Design.” Without the efforts of the individuals previously mentioned, the success of this project would not have been possible.

TABLE OF CONTENTS

ACKNOWLEDGEMENTS ................................................................. II
TABLE OF CONTENTS ................................................................. II
LIST OF FIGURES ........................................................................ III
LIST OF TABLES ........................................................................ IV
ABSTRACT ................................................................................... V
INTRODUCTION: PROBLEM STATEMENT AND RESEARCH ............ 1
  PROBLEM STATEMENT: ............................................................. 1
  RESEARCH: ............................................................................. 2
CUSTOMER FEATURES AND REQUIREMENTS .............................. 4
  CUSTOMER SURVEY: ............................................................. 4
  CUSTOMER FEATURES: ......................................................... 5
  ENGINEERING CHARACTERISTICS: ........................................ 6
  PRODUCT OBJECTIVES: .......................................................... 7
RULES FOR AMERICAN IRON RACING SERIES ............................. 9
  NASA PRO RULES: ............................................................... 9
  ADDITIONAL RULES ............................................................ 14
TORSIONAL RIGIDITY AND CORRESPONDING FORMULAS .......... 15
  INTRODUCTION ................................................................. 15
  TEST CONDITIONS ............................................................. 16
  FORMULAS ........................................................................... 17
DESIGN SELECTION AND THEORY ............................................. 19
  CONCEPT - CASE 1 .............................................................. 21
  CONCEPT - CASE 2 .............................................................. 22
  CONCEPT - CASE 3 .............................................................. 23
  CONCEPT - CASE 4 .............................................................. 24
  ANALYSIS CALCULATIONS: ................................................ 25
  CONCEPT - CASE 5 .............................................................. 26
  ANALYSIS CALCULATIONS: ................................................ 27
  FABRICATION OF FINAL CHASSIS DESIGN: ......................... 28
  TESTING OF FINAL DESIGN (ACTUAL FABRICATED MODEL OF CHASSIS)... 33
Figure 29: Passenger Side “X-Style” Doorbar .......................... 31
Figure 30: Petty Bar ........................................................................................................ 31
Figure 31: Top View of Roll Cage ................................................................. 32
Figure 32: Driverside “Nascar-Style” Doorbar ........................................... 32
Figure 33: Front Shock Tower Reinforceent Member ....................................... 32
Figure 34: Testing - Gap under Rear Passenger Side Jack Stand .................. 33
Figure 35: Testing – Measurement of Deflection ........................................... 33
Figure 36: Testing - Applying Load of 200lbs ............................................. 33
Figure 37: Testing – Modified FEA Conditions ........................................... 34
Figure 38: Forecasted Build Cost ................................................................. 36
Figure 39: Actual Build Cost ........................................................................... 36

LIST OF TABLES
Table 1 - Customer Importance Table 2 - Customer Satisfaction 4
Table 3 – Engineering Characteristics 6
Table 4 - Test Data (Concepts 1-4) 25
Table 5 - Test Data (Concept 5) 27
The scope of this project includes design, analysis, and fabrication of a racecar chassis. The chassis development was carried out for a gentleman by the name of Greg Brown who races in a league called “American Iron Racing.” Overall, the goal of the chassis design is to enhance its overall rigidity which will allow for improved track performance. The prior is true since track performance is strongly related to chassis rigidity. While designing the chassis it was necessary to have competence in static analysis, as well as mechanical applications.

In order to analyze different design cases, computer models of the chassis were developed and studied in an effort to compare the functionality of all design cases. After each computer designed case reached completion a software study called “COSMO” allowed for Finite Element Analysis (FEA). FEA allowed for a measurement of torsional rigidity, deflection, and weight which were all critical aspects in the design of the chassis. By analyzing the effectiveness of design cases, an “optimized” design able to be developed and justified. The final design includes only beneficial design aspects that were observed in the different design case studies.

The optimized chassis design was studied in the computer base FEA in order to verify its effectiveness. After confirmation of the final design all further efforts were directed towards the fabrication of the real world model. The chassis fabrications were implemented with as much accuracy as possible by holding true to the design and selection of materials used to generate the computer model. After fabricating the chassis upgrades, the rigidity of the chassis was measured using modified testing conditions (see “Testing of Final Design” pg. 32). The testing was successful in verifying that the rigidity of the fabricated chassis is comparable to that of the computer generated design. Overall, the final product of the modified racecar chassis was a great success.
INTRODUCTION: PROBLEM STATEMENT AND RESEARCH

PROBLEM STATEMENT:

For many years Greg Brown who works for a custom-auto shop called Modular Depot, has participated in a race series called American Iron Racing. Over the years Greg has been very successful in the race league, including a first place finish. The car that has brought him great success is 1993 Mustang GT. Since the car is becoming outdated in terms of technology Greg has decided that in order to improve his performance on the track he will need to drive a more modern car. His solution is a 2005 Mustang GT coupe. Myself, and Ryan Carter have agreed to help Greg modify and strengthen his Mustang’s chassis, which will greatly enhance track performance since the rigidity of the chassis is directly related to performance ability. In order to improve the rigidity of the car’s frame we will mount sub-frame connectors, as well as a roll cage to the sub-frame of the car. Throughout this report nearly all focus will be placed on the design of sub-frame connectors since that will be my sole design task. However, in this introduction I will continue to explain how the two structures will function together so that the full design layout can be understood. Consider that the sub-frame connectors will be located on the bottom side of the car’s sub-frame (underneath the car) and that the roll cage will be located on the upper side of the sub-frame (inside the car). Now use the concept to idealize how the sub-frame connectors and roll cage can be married together by passing through the sub-frame and mating them directly to each other. When the two structures are married together a complete boxed in structure is created which yields great improvement to the overall rigidity of the car. Compare the concept to a bridge with triangular supports and you might understand the dynamics of the structure. Figure 1 (6) shows a car with sub-frame connectors mounted half way through its sub-frame along with a roll cage connecting mounted directly to the connectors. This setup is very similar to the setup that will be applied to Greg’s Mustang. The only difference in our design is that we plan to mount the sub-frame connectors completely under the sub-frame (not half way between), and only at specific mounting locations will the connectors pass through the sub-frame and mate to the roll cage.
**RESEARCH:**

As stated in the Problem Statement my sole focus is on design of the sub-frame connectors which means that the research along with all other aspects of the project (Survey Results, QFD, Schedule, Budget and Support Letter) pertains strictly to sub-frame connectors.

After interviewing Paul Berning (5), a mustang owner who intends to race his car competitively he made very clear that a stock mustang chassis is not rigid enough to handle added horsepower while under consistent high speed cornering. In conclusion to his statement he began to talk about the same modifications that will be made to the chassis of Greg’s mustang. Paul explained how custom building sub-frame connectors can be a more feasible approach when planning to join the sub-frame connectors to the roll cage since off the shelf connectors will not have mounting plates located at the mating points of our custom built frame. In conclusion to the interview the best approach would be to build custom sub-frame connectors, especially since Greg needs maximum performance and has agreed to supply all funding necessary. However, further is necessary to understand what aspects of off the shelf sub-frame connectors can be improved to enhance the performance of Greg’s mustang.

Figure 2 (2) depicts what is known as full length sub-frame connectors. These off the shelf connectors from Maximum Motorsports seem as if they would be quite rigid considering the dimensions (1.5” x 2” x 0.083” wall thickness) however, material type is not mentioned. In order to combat corrosion these sub-frame do offer a powder coated finish which will keep the connectors corrosion as long as the coating of paint stays intact which may be unlikely. Buying the connectors off the shelf save on time since design work would not be required. However, as mentioned in the interview with Paul mounting locations for mating the roll cage to the sub-frame may be somewhat limited without building custom connectors.
Figure 3 (3) depicts one side of an off the shelf sub-frame connector available through Kenny Brown (3). In comparison to the connectors on the previous page the connectors pictured below seem that they would provide much greater strength to a car frame for many reasons. These sub-frame connectors are made yellow zinc chromate which offers rust protection while maintaining easy weld characteristics. Since the material itself is corrosion resistant the connectors will remain highly corrosion resistant regardless of their condition. Concerning strength and overall rigidity this system employs two long sections that run along the length of the car as well as intermediate triangular supports. The two in combination without a doubt would provide much more rigidity than the simple straight connectors cited in Figure 2. Many aspects of the Kenny Brown connectors will be taken into consideration while designing the custom connectors for Greg’s mustang.

![Figure 3: Extreme Matrix Subframe System](image)

Figure 4 (4) depicts a common chassis upgrade called a strut tower brace. A strut tower brace mounts very slightly above the engine connecting right at the point around the top of a car’s struts. This type of upgrade would be considered less aggressive than sub-frame connectors but can still offer a degree of added rigidity to a car’s frame. The improvement characteristics are somewhat similar to those of sub-frame connectors. Only small degree of research was performed on tower bars since the benefit is not as considerable as sub-frame connectors. However, the addition of a tower bar will be considered if time and budget permits.

![Figure 4: Hotchkis Strut Tower Brace](image)
CUSTOMER FEATURES AND REQUIREMENTS

CUSTOMER SURVEY:

In regards to performing a customer survey for custom sub-frame connectors I was very selective as to the individuals that I selected. I distributed the survey to four members at Modular Depot as well as Greg since they will all have a hand in the project and understand the scope of design needs as well as the rules of the American Iron race league. The customer features that were included in the survey are pictured in the tables below and reflect how the participants responded to customer importance, and customer satisfaction. A ranking from 1-5 was used, 1 representing low, and 5 representing high importance/satisfaction. Also, notice that the rank importance of each customer feature is listed in chronological order.

<table>
<thead>
<tr>
<th>Customer Features</th>
<th>Customer Importance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Compliance with Race Stds</td>
<td>5.00</td>
</tr>
<tr>
<td>Maneuverability</td>
<td>4.80</td>
</tr>
<tr>
<td>Compatibility</td>
<td>4.40</td>
</tr>
<tr>
<td>Durability</td>
<td>4.00</td>
</tr>
<tr>
<td>Weight</td>
<td>3.80</td>
</tr>
<tr>
<td>Resistance to Corrosion</td>
<td>3.60</td>
</tr>
<tr>
<td>Ease of Installation</td>
<td>3.20</td>
</tr>
<tr>
<td>Ease of Manufacturing</td>
<td>3.00</td>
</tr>
<tr>
<td>Affordability</td>
<td>2.80</td>
</tr>
<tr>
<td>Ground Clearance</td>
<td>2.20</td>
</tr>
<tr>
<td>Safety</td>
<td>1.33</td>
</tr>
<tr>
<td>Appearance</td>
<td>1.25</td>
</tr>
</tbody>
</table>

Table 1 - Customer Importance

<table>
<thead>
<tr>
<th>Customer Features</th>
<th>Customer Satisfaction</th>
</tr>
</thead>
<tbody>
<tr>
<td>Safety</td>
<td>4.25</td>
</tr>
<tr>
<td>Ground Clearance</td>
<td>3.80</td>
</tr>
<tr>
<td>Maneuverability</td>
<td>3.80</td>
</tr>
<tr>
<td>Durability</td>
<td>3.60</td>
</tr>
<tr>
<td>Affordability</td>
<td>3.40</td>
</tr>
<tr>
<td>Ease of Installation</td>
<td>3.40</td>
</tr>
<tr>
<td>Appearance</td>
<td>3.20</td>
</tr>
<tr>
<td>Ease of Manufacturing</td>
<td>3.00</td>
</tr>
<tr>
<td>Compliance with Race Stds.</td>
<td>2.67</td>
</tr>
<tr>
<td>Compatibility</td>
<td>2.60</td>
</tr>
<tr>
<td>Resistance to Corrosion</td>
<td>2.60</td>
</tr>
<tr>
<td>Weight</td>
<td>2.60</td>
</tr>
</tbody>
</table>

Table 2 - Customer Satisfaction

Analyzing Customer Importance in Table 1 concludes that compliance with race standards and maneuverability are the two main concerns for the team at Modular Depot. Following close behind is concern for compatibility and durability. What this means shows is that an ideally designed sub-frame connector should meet race rules/standards, while providing the car with maximum performance. On the contrary aspects that weren’t as much of a concern were appearance, safety, and ground clearance with ranks of (1.25, 1.33, and 2.20) respectively. Since the sub-frame connectors will almost never be visible, and the fact that the parts will be installed on a race car that requires maximum performance appearance would be expected to be of little concern.

In Table 2 the Customer Features that ranked extremely low shall be of most concern since the features are viewed as poorly designed areas on sub-frame connectors that can be purchased off the shelf. Weight, with only a 2.60 satisfaction should be of high concern. In response to weight receiving a poor customer satisfaction, the feasibly of using an Aluminum-Alloy will likely be considered when performing design calculations.
CUSTOMER FEATURES:

The following list specifies customer features that are utmost importance in the design of the chassis. All customer features were given a weighted percentage based on results obtained through a QFD analysis (which can be found in Appendix C).

Compliance with Race Standards (17.51%)

Compatibility (17.41%):

Maneuverability (11.81%)

Resistance to Corrosion (10.36%)

Weight (8.75%)

Durability (8.31%)

Ease of Manufacturing (7.01%)

Ease of Installation (6.34%)

Affordability (4.62%)

Ground Clearance (3.57%)

Safety (2.63%)

Appearance (1.68%)
**ENGINEERING CHARACTERISTICS:**

The engineering characteristics specified below state which aspects of the chassis design are most important in terms of functionality. The weighted values were obtained through the QFD matrix which can be referred to in Appendix C.

<table>
<thead>
<tr>
<th>No. of Additional Cross-Members</th>
<th>Material Type</th>
<th>Precise Machining</th>
<th>No. of Mounting Locations</th>
<th>Nuts and Bolts are Standard Sizes</th>
<th>Manufacturability</th>
<th>Mounting Method (welding/bolting)</th>
<th>Wall Thickness of Tubing</th>
<th>Common Tubing Size/Geometry</th>
<th>Weld Strength/Quality</th>
<th>Compact Design</th>
<th>Paint Toughness (in metal is corrosive)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Absolute Importance</td>
<td>3.91</td>
<td>3.14</td>
<td>1.97</td>
<td>1.83</td>
<td>0.78</td>
<td>0.66</td>
<td>0.60</td>
<td>0.54</td>
<td>0.35</td>
<td>0.33</td>
<td>0.32</td>
</tr>
<tr>
<td>Relative Importance</td>
<td>0.27</td>
<td>0.21</td>
<td>0.13</td>
<td>0.12</td>
<td>0.05</td>
<td>0.04</td>
<td>0.04</td>
<td>0.04</td>
<td>0.02</td>
<td>0.02</td>
<td>0.02</td>
</tr>
</tbody>
</table>

Table 3 – Engineering Characteristics

**Six most important characteristics:**

Number of Additional Cross-Members: The number of additional cross-members added to the chassis will affect the final result of the chassis’ rigidity.

Material Type: The material selection will have a major impact on the overall rigidity of the final chassis design.

Precise Machining: Precise machining and fabrication will be crucial in achieving robust mounting locations. The mounting locations of chassis enhancements must be reinforced so that the enhancements can function at full potential.

Number of Mounting Locations: The number of mounting locations will determine the number of chassis reinforcement that can be applied.

Nuts and Bolts Standard Sizes: In order for facilitation of the fabrication process all nuts and bolts should be standard sizes.

Manufacturability: The final design of chassis reinforcements must reflect commonsense design which allows for feasible fabrication.
**PRODUCT OBJECTIVES:**

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. The product objectives will focus on chassis modifications that will be made on a competitive mustang racecar. The modifications are intended to improve the overall stiffness of the racecar’s chassis.

**Compliance with Race Standards (17.51%):**
1.) All chassis modifications will comply with race standards/rules.

**Compatibility (17.41%):**
1.) Chassis modifications will be designed so that they can be installed on the car without making major modifications to the chassis, such as cutting/removing stock sections of the sub-frame.
2.) The installer will simply weld, and/or bolt the sub-frame connectors to unoccupied areas of the frame.

**Maneuverability (11.81%):**
1.) Modifications will decrease overall bending of the chassis by 50%. In order to measure a baseline on the car will be jacked up from under the rear seat mount which will cause the front seat head rests to move closer to each other, and we will have taken measurements of the distance before and after jacking the car up. After installing the sub-frame connectors we will repeat the steps stated previously.

**Resistance to Corrosion (10.36%):**
1.) All components will be non-corrosive
   a.) If metal is not coated components will be made of non-corrosive metal (aluminum, Stainless Steel)
   b.) If metal is corrosive the components will be powder coated to provide protection.

**Weight (8.75%):**
1.) Chassis modifications will not exceed 500lbs in additional weight.

**Durability (8.31%):**
1.) Robust materials will be used to construct the sub-frame connectors
   a.) High carbon steel
   b.) High strength aluminum alloy
2.) Also the surface finish on all tubing sections will be non-corrosive so that the metal will not wither away and slowly degrade the strength of the structure.
3.) A design factor of 2.0 – 2.5 will be employed since the sub-frame connectors will experience dynamic loading, and the confidence level in design data will be considered average.
Ease of Manufacturing (7.01%):
1.) DFM (Design for Manufacturing) - The following processes are required to fabricate the sub-frame connectors.
   a.) Tube Bending: Certain section of the sub-frame connectors will require tube bending which will require a ‘tube bender.’
       (Tolerance = Resulting Angle +/-2.5°).
   b.) Liquid-State Welding (Fusion Welding): Fusion welding will be used to join multiple angled sections to the main tubing.
       (Tolerance = Full Visual Inspection Pass/Fail)
   c.) Drilling: Through hole drilling will be required at multiple locations to create mounting holes.
       (Tolerance = +/-0.025in from targeted location)
2.) After the design is finalized using computer aided design, a more detailed analysis of DFM will be performed along with a DFA (Design for Assembly) analysis.

Ease of Installation (6.34%):
1.) Chassis modifications will be able to be installed by one skilled welder/mechanic in less than 50 hours. If the design incorporates nuts and bolts they will be designed using standard sizes and will be able to be fastened using a common ratchet and socket set.

Affordability (4.62%):
1.) All chassis modifications will cost less than $1000 in materials.

Ground Clearance (3.57%):
1.) Ground clearance will not be reduced by more than 3.0in.

Safety (2.63%):
1.) Additional frame strength provided by the sub-frame connectors can help keep a car intact in the event of an accident.

Appearance (1.68%):
1.) Components will exhibit high precision in fabrication which will allow the material to function at its full potential. The precise fabrication will result in clean appearance.
   a.) Tube Bends:         (Tolerance = Resulting Angle +/-2.5°)
   b.) Welds:             (Tolerance = Full Visual Inspection Pass/Fail)
   d.) Mounting Holes (For Bolts):        (Tolerance = +/-0.025in from targeted location)
   e.) Powder Coat Paint (thickness = .050in):      (Tolerance = +/-0.010in)
RULES FOR AMERICAN IRON RACING SERIES

\textit{NASA Pro Rules:}

Before beginning the chassis design work it was important to understand the rules and regulations set by NASA. The rules must be followed in order for Greg’s mustang to be considered safe and acceptable to race in the series. Greg intends to use race his Mustang in the American Iron Extreme Class, which requires that the car meets guidelines specified by NASA in the “2001.4 CCR rule book.” The rule book is available online and is available to the public.

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. It should be able to withstand the weight of the car landing on the roof. 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 compete in NASA events on a regular basis, should 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. It is recommended that padding meeting SFI specification 45.1 be used.

15.6.5 Bends
None of the tubing may show any signs of crimping or wall failure. All bends must be Mandrel type. The center radius of the bends may 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 shall 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(all seen in figure 4) is used, the builder should pay close attention to alignment. One end of the diagonal brace shall attach to 60 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 shall extend from the main hoop (in a forward direction) to the floor by following the roof and the “A” pillar of the car. There shall 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 shall incorporate no more than four bends each.
15.6.11 Rear Braces
The main hoop must 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 must 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 shall be installed to form no more than a one hundred five (105) degree angle or no less than a seventy-five (75) degree angle with the main hoop when viewed from the top. 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 (not guaranteed) 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 must be attached to the body by plates welded to the cage and bolted 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 one (1) door bar on driver side and one (1) on the passenger side must be used. At least two (2) door bars on the driver side and one (1) door bar on the passenger side must be installed in all vehicles that obtain a new logbook after January 1st, 2007. All vehicles, regardless of date of manufacture or date of logbook issuance will be required to have at least two (2) door bars on the driver side and one (1) door bar on the passenger side starting January 1st, 2011. 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 jam (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 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 greater than twelve (12) inches or less than two (2) inches on a 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. Each mounting plate should have an area of not less than nine (9) square inches.

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 two (2) inches up from the base plate.

15.6.15 Welds
All welding must be of the highest quality with full penetration and shall conform to the American Welding Society D1.1, 1994 Edition, Structural Welding Code, Chapter 10, Tubular Structures and Standards for the material used. Arc welding should be used whenever possible. It is strongly recommended that the welder inspect all welds using Magnaflux™, x-ray, or other effective methods. 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.
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:
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 04/30/03)

*Note- Specifications listed for reference for inspection of grandfathered vehicles.

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 Head Support-Rear
This section applies to seats without an integral headrest. A head restraint must be used to help prevent whiplash. The head restraint should have a minimum area of thirty-six (36) square inches and be padded with a non-resilient material such as Ethafoam or Ensolite with a minimum thickness of one (1) inch. It is recommended that padding meeting SFI specification 45.2 be used.

15.6.22 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. 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 (8899-1999) or more than ten (10) years old (8862-2009). Please reference the FIA regulations.
**ADDITIONAL RULES**

In addition to the rules set by NASA, the America Iron requires an additional set of rules which supersede a few particular rules that are specified by NASA.

5.12 Roll Cage

The roll cage must comply with the roll cage standards of the NASA CCR. However, a roll cage may also provide additional chassis stiffening through the use of alternative mounting points. As such, the roll cage mounting points are unrestricted. The roll cage may also pass through the firewall and attach to the front shock towers. Additional bracing may also be welded to the front of the shock tower and extend forward and down to the forward most part of the original frame rail. This bracing may not pass through the shock tower and must not form the upper mounting point for an aftermarket SLA system as the SLA must still remain within the original shock tower. The mounting plate material must conform to the specification in the NASA CCR but the plate size and design is unrestricted. Interior body panels and sheet metal may be bent or altered to accommodate the roll bar design.

5.13 Door Safety Bars

All vehicles must meet the door safety bar requirements found in the NASA CCR at Section 15.6.12 but gutting of the door beyond what is solely necessary to fit cage bars is allowed.
TORSIONAL RIGIDITY AND CORRESPONDING FORMULAS

INTRODUCTION

Torsional rigidity is one of the most critical aspects that affect the performance ability of a car chassis. The rigidity of a racecar chassis is of utmost importance because a high stiffness value can allow suspension components to function in the exact manner that they were designed for. When a car’s chassis allows too much flex or torsion, the effectiveness of its suspension components begins to dwindle.

As a car passes around a corner the wheels exert an opposing force on the suspension and shock towers, which in turn applies a torque upon the chassis. When a car chassis is too flimsy/non-rigid the performance of the suspension is negatively affected, and the car experiences what is often referred to as body roll. Both of these aspects negatively affect the predictability of the car. Please view the figure below to gain a visual understanding how force input is applied through wheels and suspension, and ultimately applies a force to a car’s shock towers resulting in torsion of the chassis.

Figure 7: Applied Chassis Forces
**Test Conditions**

In order to attain reasonable test results, it was necessary to model the sub-frame of the 2005 Mustang with as much accuracy as possible. Developing an accurate computer model of the sub-frame (including sheet metal design), allows the computer software to measure the chassis in a way that would reflect its real world function.

After an accurate computer model of the chassis was developed, load conditions and chassis constraints were specified for testing that uses Finite Element Analysis (FEA). The test conditions included fixing the rear of the car (immovable), and applying 750lb forces to the front shock towers in opposing directions (see Figure 8). After the FEA computed the affects of the applied forces, deflection values were able to be measured from the top surface of the shock towers (see Figure 9).

![Figure 8: Test Conditions](image)

![Figure 9: Location of Deflection Measurement](image)
**FORMULAS**

**Torque:**

The first step in calculating the torsional rigidity is to calculate the applied Torque. In order to do so the applied Force should be multiplied by the effective length (mid-plane about the width of the chassis to the mid-plane of the shock tower). Please see Figure 10 for a visual reference of “effective length.”

\[ T = F \cdot d \]

![Figure 10: Effective Length](image)

**Angle of Twist:**

The second step in calculating torsional rigidity is to calculate the chassis’ angle of twist. Angle of twist can be calculated by dividing the deflection value by the effective length. The resulting angle of twist is naturally in radian terms, and therefore should be converted to degrees for use in stating “\( K_c \)” (Torsional Rigidity).

\[ \Phi = \frac{u_y}{L} \]

**Torsional Rigidity:**

Torsional Rigidity is considered to be the relationship of applied torque versus angular twist (\( \Phi \)). Torsional rigidity is designated by the symbol (\( K_c \)). Throughout the design calculations, torsional rigidity was calculated in terms of (ft-lb/degree).

\[ K_c = \frac{Torque}{\Phi} \]
Making use of Torsional Rigidity Values:

A torsional rigidity value was calculated for every concept that was studied. The rigidity values were beneficial in helping understand the effectiveness of the chassis upgrades.
DESIGN SELECTION AND THEORY

Developing a CAD model of the mustang’s stock sub-frame was one of the most crucial aspects in being able understand exactly how the dynamics of adding sub-frame connectors effects the performance of the stock sub-frame. Also, the CAD model of the stock sub-frame allowed for a baseline measurement of the sub-frame’s rigidity. Numerous dimensions were recorded and plotted using Greg’s Mustang in order to develop an accurate CAD model of a 2005 Mustang sub-frame. The picture below shows the baseline sub-frame that was used for taking initial deflection measurements. Notice the members in the picture that are highlighted in blue, these structural members represent the seat mounts that serve a dual for the cars frame, they increase the rigidity of the frame as well as provide mounting locations for the driver and passenger seats.
The ultimate goal is to increase the overall rigidity of the mustang’s frame through adding additional support members. In an effort to enhance rigidity, it is common practice to add structural members that join the front section of a sub-frame to the rear (otherwise known as sub-frame connectors, which were described in the “Introduction” and “Research” sections). However, cars that employ a full roll-cage gain only a minor benefit from the addition of sub-frame connectors. The previous is true because many of the tubing sections that make-up a roll cage run lengthwise along a cars sub-frame. In the picture below, the arrow points to a cluster of typical roll-cage members (known as door bars) that provide similar enhancements to sub-frame connectors.

![Door Bars](image)

**Figure 12: Door-Bars**

Since Greg’s mustang will employ a full roll-cage, typical sub-frame connectors would not provide a substantial gain in rigidity, and would therefore be relatively un-effective. Rather, custom sub-frame connectors were designed since a custom design can provide more complex/effective solutions. The custom sub-frame connectors were designed with the intention of joining the driver side frame rail to the passenger side frame rail, which increase overall rigidity along the width of the frame. The approach of the custom design was derived from the knowledge that the roll-cage would fulfill the need for structural reinforcement along the length of the frame.
**CONCEPT - CASE 1**

For design Case 1, the CAD model of the unmodified stock sub-frame was tested in order to obtain baseline data that could be used for comparing other design cases. As shown previously, the stock sub-frame uses seat mount beams (pictured in blue) to reinforce the frame in the width direction.

![Figure 13: Concept (Case 1)]
CONCEPT - CASE 2

Design Case 2 was developed to test the effects of removing the original seat mount beams, and replacing them with one structural member that runs from one side of the car to the other, passing through the transmission tunnel. The beams that have been described are picture in dark grey (see Figure 14). The design is not only intended for enhanced rigidity, but would also help meet a racing rule that specifies the requirement of a “drive shaft loop,” which is highlighted in blue (see Figure 15).

Figure 14: Concept (Case 2)

Figure 15: Drive Shaft Loop
**Concept - Case 3**

Design Case 3 was developed to test the effects of removing the original seat mount beams, and replacing them with two parallel members that run from one side of the car to the other, both passing through the transmission tunnel. This concept is useful for understanding whether or not the added weight of twin beams can be justified through rigidity gain. Even though the drive shaft loop is not visually pictured for this “Case,” the loop is attaches to the rear member in the same way as Case 2. The beams that have been described are highlighted in blue (see Figure 16).

![Figure 16: Concept (Case 3)](image-url)
**CONCEPT - CASE 4**

Design Case 4 was derived using the same design theory as Case 3, but also employs a diagonal support member to join the two parallel members together. Case 4 is the most extreme of the four designs in terms of the number of support beams. The beams described in Case 4 are highlighted in blue (see Figure 17).
ANALYSIS CALCULATIONS:

After testing the four different designs, the results revealed that Case 4 provides the most significant gain in rigidity (3.59% improvement over the “Base” stock sub-frame). Considering the fact that the modifications implemented in concept four weigh 24.65lbs, it does not seem justifiable to implement the modifications in the final design of the chassis. As a second effort to improve the sub-frame connector design concept, the modification was tested in conjunction with a full roll cage design. It was necessary to test sub-frame connectors with the implementation of a full roll cage since the roll cage would without a doubt impact the effectiveness of the sub-frame connectors.

### Table 4 - Test Data (Concepts 1-4)

<table>
<thead>
<tr>
<th>Case #</th>
<th>Modification</th>
<th>Uy pass. (in)</th>
<th>Uy drivers (in)</th>
<th>Average Uy (in)</th>
<th>φ (rad)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Base</td>
<td>2.598</td>
<td>2.256</td>
<td>2.427</td>
<td>0.0975</td>
</tr>
<tr>
<td>2</td>
<td>Added Beam Support (w/ drive shaft loop)</td>
<td>3.065</td>
<td>2.849</td>
<td>2.957</td>
<td>0.1188</td>
</tr>
<tr>
<td>3</td>
<td>Added Second Beam Support (Offset from First Beam)</td>
<td>3.106</td>
<td>2.701</td>
<td>2.904</td>
<td>0.1166</td>
</tr>
<tr>
<td>4</td>
<td>Added Diagonal Beam Support (Connects the Two Parallel Beams)</td>
<td>2.450</td>
<td>2.236</td>
<td>2.343</td>
<td>0.0941</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Case #</th>
<th>Modification</th>
<th>U (deg)</th>
<th>Kc</th>
<th>Weight (lb)</th>
<th>% Rigidity Increase</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Base</td>
<td>5.59</td>
<td>6684.63</td>
<td>358.82</td>
<td>N/A</td>
</tr>
<tr>
<td>2</td>
<td>Added Beam Support (w/ drive shaft loop)</td>
<td>6.81</td>
<td>5486.50</td>
<td>360.92</td>
<td>-17.92%</td>
</tr>
<tr>
<td>3</td>
<td>Added Second Beam Support (Offset from First Beam)</td>
<td>6.68</td>
<td>5587.60</td>
<td>375.25</td>
<td>-16.41%</td>
</tr>
<tr>
<td>4</td>
<td>Added Diagonal Beam Support (Connects the Two Parallel Beams)</td>
<td>5.39</td>
<td>6924.28</td>
<td>383.46</td>
<td>3.59%</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Case #</th>
<th>Modification</th>
<th>Weight Increase overall original (lb)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Base</td>
<td>N/A</td>
</tr>
<tr>
<td>2</td>
<td>Added Beam Support (w/ drive shaft loop)</td>
<td>2.10</td>
</tr>
<tr>
<td>3</td>
<td>Added Second Beam Support (Offset from First Beam)</td>
<td>16.43</td>
</tr>
<tr>
<td>4</td>
<td>Added Diagonal Beam Support (Connects the Two Parallel Beams)</td>
<td>24.64</td>
</tr>
</tbody>
</table>
CONCEPT - CASE 5

Design Case 5 was developed and studied in order to understand the dynamics of sub-frame connectors when applied in conjunction with a full roll cage. The Figures below depict the full X style design that was studied in Case 5. The members connect one side of the car to the other by joining them to pre-existing frame members on the “stock” sub-frame.
**Analysis Calculations:**

Table 4 (pictured to the left), show the deflection and rigidity increase of 18 different cases that were studied for the design of the roll cage. The values reported in case 17 reflect the rigidity of the chassis and roll cage without the implementation of the addition of the “X-Style” sub-frame connectors. The values reported in Case 18 reflect the effectiveness of adding the “X-style” sub-frame connectors.

Case 17 yielded a 937.1% increase in rigidity over the stock chassis, while Case 18 yielded 1081.4% increase. This means that the addition of the sub-frame connectors provides a **144.3%** increase in rigidity.

Unfortunately, after speaking to the project customer (Greg Brown), we concluded that the performance of the sub-frame connectors is not significant enough to include them in the final chassis design due to their weight addition of 50.0lbs.

After it was discovered that sub-frame connectors would not be applied to the final chassis design, all further research and design was directed towards optimizing the roll cage for strength and rigidity. The research and design of the roll cage is considered to be a continuation of the research performed in this project. Design of the roll cage can be referred to in Volume II of this project, which is titled “Racecar Chassis Design (Volume II) – Roll Cage Design.”

<table>
<thead>
<tr>
<th>Modification Upgrade</th>
<th>Uy: Passenger Side (in)</th>
<th>Uy: Driver Side (in)</th>
<th>Uy: Average (in)</th>
<th>Rigidity Increase (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 base model</td>
<td>1.166</td>
<td>1.126</td>
<td>1.146</td>
<td></td>
</tr>
<tr>
<td>2 add lower hor x tube</td>
<td>1.143</td>
<td>1.116</td>
<td>1.130</td>
<td>1.5%</td>
</tr>
<tr>
<td>3 add lower window</td>
<td>0.910</td>
<td>0.897</td>
<td>0.904</td>
<td>26.8%</td>
</tr>
<tr>
<td>4 add lower shock</td>
<td>0.568</td>
<td>0.575</td>
<td>0.572</td>
<td>100.5%</td>
</tr>
<tr>
<td>5 add upper shock mount</td>
<td>0.745</td>
<td>0.732</td>
<td>0.739</td>
<td>55.2%</td>
</tr>
<tr>
<td>6 just drivers side upright</td>
<td>0.742</td>
<td>0.726</td>
<td>0.734</td>
<td>56.1%</td>
</tr>
<tr>
<td>7 add Vertical Uprights</td>
<td>0.733</td>
<td>0.725</td>
<td>0.729</td>
<td>57.2%</td>
</tr>
<tr>
<td>8 add rear diag</td>
<td>0.296</td>
<td>0.267</td>
<td>0.282</td>
<td>307.1%</td>
</tr>
<tr>
<td>9 make x in rear diag</td>
<td>0.260</td>
<td>0.274</td>
<td>0.267</td>
<td>329.2%</td>
</tr>
<tr>
<td>10 add main hoop diag</td>
<td>0.245</td>
<td>0.250</td>
<td>0.248</td>
<td>363.0%</td>
</tr>
<tr>
<td>11 add roof cluster</td>
<td>0.194</td>
<td>0.197</td>
<td>0.196</td>
<td>486.2%</td>
</tr>
<tr>
<td>12 add petty bar</td>
<td>0.092</td>
<td>0.233</td>
<td>0.163</td>
<td>605.2%</td>
</tr>
<tr>
<td>13 add window bar</td>
<td>0.095</td>
<td>0.197</td>
<td>0.146</td>
<td>684.9%</td>
</tr>
<tr>
<td>14 add strut bar</td>
<td>0.093</td>
<td>0.190</td>
<td>0.142</td>
<td>709.9%</td>
</tr>
<tr>
<td>15 add only short front diag</td>
<td>0.086</td>
<td>0.170</td>
<td>0.128</td>
<td>795.3%</td>
</tr>
<tr>
<td>16 add only long front diag</td>
<td>0.077</td>
<td>0.147</td>
<td>0.112</td>
<td>923.2%</td>
</tr>
<tr>
<td>17 both diag no x bottom</td>
<td>0.077</td>
<td>0.144</td>
<td>0.111</td>
<td>937.1%</td>
</tr>
<tr>
<td>18 add x on bottom</td>
<td>0.070</td>
<td>0.124</td>
<td>0.097</td>
<td>1081.4%</td>
</tr>
<tr>
<td><strong>Fully Optimized</strong></td>
<td>0.043</td>
<td>0.208</td>
<td>0.126</td>
<td>813.1%</td>
</tr>
</tbody>
</table>

Table 5 - Test Data (Concept 5)
**Fabrication of Final Chassis Design:**

A number of specialized tools were needed to fabricate the Final Chassis Design. The project custom (Greg Brown) was able to supply and/or borrow all of the required tools, which included a tubing bender, notching tool, hydraulic shear, MIG welder, plasma cutter, and a cutoff abrasive saw. The pictures included on this page and the following page show the actual tools that were used throughout the fabrication process.

![Figure 20: Tubing Bender & Notching Tool](image1)

![Figure 21: Hydraulic Shear](image2)

![Figure 22: MIG Welder](image3)
Figure 23: Plasma Cutter

Figure 24: Cutoff Abrasive Saw
The pictures on this page and the following page show the progression of the roll cage throughout fabrication.

Figure 25: Mainhoop

Figure 26: Reinforced Mounting Box for Rear Downtube

Figure 27: Driverside “A Pillar” Member
Figure 28: Rear Downtubes

Figure 29: Passenger Side “X-Style” Doorbar

Figure 30: Petty Bar
Figure 31: Top View of Roll Cage

Figure 32: Driverside “Nascar-Style” Doorbar

Figure 33: Front Shock Tower Reinforceent Member
**TESTING OF FINAL DESIGN (ACTUAL FABRICATED MODEL OF CHASSIS):**

After fabrication of the final chassis design was completed a test method was developed in order to understand the effectiveness of the chassis enhancements. Since it was impossible to test the chassis under the same conditions that were specified in the computer analysis; the testing modified so that the results could be analyzed comparatively to the computer data.

The first step in the testing was to position the chassis over four jack stands. The jack stand located under the rear of passenger side was lowered from the chassis leaving a gap of 0.75in (the gap was precisely set using a set of high quality calipers). The figure below shows 0.75in gap, while the other three jacks remained in contact with the chassis.

![Figure 34: Testing - Gap under Rear Passenger Side Jack Stand](image)

After we set the gap to 0.75inches, Greg Brown (the customer), stood on the rear of the car while I stood on the front (see Figure 36). It was necessary for me to stand on the front of the chassis while Greg stood on the back so that the gap created between the chassis and jack stand would not close completely. Dial calipers were used to measure the amount of deflection as Greg applied his body weight of 200lbs to the rear of the car (see Figure 35). Dial calipers were used to measure the amount of deflection (see Figure 35). We recorded an approximate deflection value of 0.007in.

![Figure 36: Testing - Applying Load of 200lbs](image)  
![Figure 35: Testing – Measurement of Deflection](image)
**COMPARISON OF DEFLECTION VALUES** - **(FINAL DESIGN VS COMPUTER MODELED (FEA))**:

In the front end research of the chassis design a computer model of the Optimized Chassis was tested and analyzed using software analysis called Finite Element Analysis (FEA). The original FEA test conditions were setup in a manner that fixed the rear of the chassis, while an upward force of 750lbs was applied to the passenger side, and a downward force of 750lbs was applied to the driver side. The resulting deflection was measured at the top of the front shock towers.

Unfortunately, the actual fabricated chassis was not able to be tested under the same conditions as the “original” FEA. As a result an entirely new FEA study was developed to reflect the exact same conditions that were applied during the testing of the fabricated model (see Figure 37). The modified FEA analysis which applied a 200lb load to the rear of the chassis, resulted in a deflection of 0.004in.

Understand that the modified testing was developed in order to address the issue that multiple front support members were not able to be included in the fabrication. The customer (Greg) chose to hold off on fabrication of the front members since the car has not received its engine placement, which will likely set dimensional limitations.
After finding the comparable deflection from the model, percent error from the FEA model to the real chassis can be calculated.

- Deflection (Fabricated model) = 0.007in
- Deflection (Computer model) = 0.004in

- Percent Error = (Experimental Value – Theoretical Value / Theoretical Value)
- (0.004-0.007 / 0.004)x100 = **75% error in the fabricated model compared to the FEA model.**

In conclusion, the fabricated model yields a 75% greater deflection than the FEA. One likely factor that caused greater deflection in the fabricated model is the fact that the front reinforcement members were not fully installed. Also, since a 200lb force was applied to the front section of the chassis in order to keep the chassis planted on the jack stands, the applied force may have resulted in additional torsion (which may also cause increased deflection). Although the percent error is relatively high, it seems feasible to believe that if all test conditions were equal the results would be much closer.
PRODUCT MANAGEMENT

**BUDGET:**

The forecasted build cost was quite conservative at $2,250. In total the chassis fabrication cost was only $550, which is $1,700 cheaper than the forecasted cost.

**Forecasted Build Cost**

<table>
<thead>
<tr>
<th>Materials, Components, or Labor</th>
<th>Forecasted Amount</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 7/8 Dom Tubing</td>
<td>$450.00</td>
</tr>
<tr>
<td>Welding Materials</td>
<td>$250.00</td>
</tr>
<tr>
<td>Tube Notching</td>
<td>$500.00</td>
</tr>
<tr>
<td>CNC Tube bending</td>
<td>$500.00</td>
</tr>
<tr>
<td>Installation (welding of Cage)</td>
<td>$550.00</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>$2,250.00</strong></td>
</tr>
</tbody>
</table>

Figure 38: Forecasted Build Cost

**Actual Build Cost**

<table>
<thead>
<tr>
<th>Material, Components, and Labor</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tubing (1.75&quot; DOM x 0.095&quot; wall thickness)</td>
<td>$480.00</td>
</tr>
<tr>
<td>Sheet Metal (10&quot; x 6&quot;, 1/8&quot; thick)</td>
<td>$50.00</td>
</tr>
<tr>
<td>Welding Material</td>
<td>$20.00</td>
</tr>
<tr>
<td>Tubing Notcher (Borrowed)</td>
<td>N/A</td>
</tr>
<tr>
<td>Installation (Self Performed)</td>
<td>N/A</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>$550.00</strong></td>
</tr>
</tbody>
</table>

Figure 39: Actual Build Cost
REFERENCES:

APPENDIX A: RESEARCH

Interview with customer, Oct. 23, 2010
Paul Berning, Mustang Owner, 2635 Karst Rd., Lawrenceburg, IN, 47025.
Customer has a late model mustang that he is preparing to be used competitively on a race track.
Stock chassis setup is not stiff enough for increased engine power, and cornering needs. Needs to stiffen chassis by using sub-frame connectors.
Customer has all necessary tools required for chassis modifications.
Customer is contemplating between buying off the shelf sub-frame connectors, or building custom sub-frame connectors.
Customer may be forced to have to custom build sub-frame connectors due to competition regulations.
Customer needs to install sub-frames that will provide maximum performance during competition.

Sub-frame connectors stiffen mustang chassis. Offered in a black powder coated finish. A stiff chassis will help improve ride quality and performance. The longest sub-frame connector available, at 65". MM XL Series sub-frame connectors are 95% stiffer than standard sub-frame connectors.
Made of 1.5" x 2" x .083" wall thickness rectangular tubing.
Price = $159.97

Buy off the shelf
Buying off the shelf rather than custom building could save time and help meet deadline for race day
Easy weld on application
Additional design modifications to sub-frame connectors may be limited compared to building custom from scratch
Engineering design work has already been completed and would save design time
Powder Coating offers corrosion resistance

10/24/2010
MM Full Length Sub-frame Connectors, 1979-04, powder-coated
The Ultimate in Under Car Chassis Support
Kit Includes:
Double Cross Sub-frame Connectors
Jacking Rails
Extreme Matrix Brace
The ultimate in Mustang frame strengthening!
Stiffens your chassis, not the ride
Improves ride quality
A MUST for all convertibles and hard driving applications
Helps reduce squeaks and rattles
Creates a "Two Sub-frames frame" under your Mustang
Heavy-duty, light-weight design
Improves traction, handling, and braking
No loss of ground clearance
Built-in rails to jack car up for added convenience
Price = $349.00

Price is more than other sub-frame connectors, but design offers greater overall strength

Buy off the shelf

Buying off the shelf rather than custom building could save time and help meet deadline for race day

Additional cross members provide extra strength compared to sub-frame connectors that employ only a straight bar member.

Complex cross members may present an issue by failing to meet rules/requirements of the race league that customer plans to compete in

Easy weld on application

Additional design modifications to sub-frame connectors may be limited compared to building custom from scratch

Engineering design work has already been completed and would save design time

http://store.kennybrown.com/product/chassis-support/extreme-matrix-subframe-system

10/24/2010
Extreme Matrix Sub-frame System
Pair of Steeda Sub-frame Connectors for 2005-2010 Mustang Coupes.

Steeda's 3-point torque box and frame rail braces are made from 4130 Chrome-Moly material. This material is twice as strong as mild steel. These braces are specifically designed for the S197 Mustang. They tie together the inner/outer frame rails and the rear lower control arm mount. Our braces are silver powder-coated and come with mounting hardware. Can be bolted with supplied hardware but a welded installation is recommended for maximum benefit from these braces.

*Does not fit convertibles.  
Price = $246.95

Buy off the shelf

Offers the ability to strengthen sub-frame in by joining inner and outer frame rails (unlike full length connectors that only connect front and rear sub-frame)

For maximum performance should be used in combination with full length sub-frame connectors

Cross members may present an issue by failing to meet rules/requirements of the race league

Can be either bolted or welded onto sub-frame

Engineering design work already completed by highly respected for racing team (Steeda)

Chrome-Moly material is superior in strength compared to other brands which often use mild steel

10/24/2010  
STEEDA SUBFRAME
Strut Tower Braces

- Easy Bolt On Installation
- Reduces Chassis Flex
- Increases Steering Response
- An Effective Deterrent from Excessive Engine Bay Flex

Our Strut Tower Braces are designed from either Hotchkis’ exclusive Aluminum Oval Tubing or Carbon Steel, depending on application.

These Strut Tower Braces help reduce body rattles and cowl shake, especially on convertibles.

Price = $224-308

Buy off the shelf
Helps reduce chassis flex
Enhances steering response
Helps reduce engine bay flex
Strut Tower could be used to further enhance overall rigidity of frame structure
May not fit mustang application

Further custom modifications may be limited since overall structure design is already complete

Custom design rather than purchasing off the shelf may offer the ability to make design more robust

Custom design may yield better performance (and cost/design time will not be an issue)

http://www.stillen.com/product.asp?id=HOTSTRTWR1&c=SU&m=all
11/7/2010
Hotchkis Strut Tower Brace
APPENDIX B: CUSTOMER SURVEY AND RESULTS

Race Car Chassis

CUSTOMER SURVEY:
Please complete this survey in order to help understand what factors/aspects of custom chassis modifications are most important to you. The survey lists a variety of components that are key requirements concerning quality and thoughtfully built chassis modifications.

How important is each feature to you for the design of racecar chassis modifications?
Please circle the appropriate answer.  1 = low importance  5 = high importance

<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>
<th>Averages</th>
</tr>
</thead>
<tbody>
<tr>
<td>Safety</td>
<td>1(2)</td>
<td>2(1)</td>
<td>3</td>
<td>4</td>
<td>5</td>
<td>N/A(2)</td>
<td>1.33</td>
</tr>
<tr>
<td>Affordability</td>
<td>1</td>
<td>2(2)</td>
<td>3(2)</td>
<td>4(1)</td>
<td>5</td>
<td>N/A</td>
<td>2.80</td>
</tr>
<tr>
<td>Durability</td>
<td>1</td>
<td>2(2)</td>
<td>3(1)</td>
<td>4(3)</td>
<td>5(1)</td>
<td>N/A</td>
<td>4.00</td>
</tr>
<tr>
<td>Resistance to Corrosion</td>
<td>1</td>
<td>2(1)</td>
<td>3(1)</td>
<td>4(2)</td>
<td>5(1)</td>
<td>N/A</td>
<td>3.60</td>
</tr>
<tr>
<td>Weight</td>
<td>1</td>
<td>2(1)</td>
<td>3</td>
<td>4(3)</td>
<td>5(1)</td>
<td>N/A</td>
<td>3.80</td>
</tr>
<tr>
<td>Ease of Installation</td>
<td>1</td>
<td>2(1)</td>
<td>3(4)</td>
<td>4(1)</td>
<td>5</td>
<td>N/A</td>
<td>3.20</td>
</tr>
<tr>
<td>Ground Clearance</td>
<td>1(1)</td>
<td>2(2)</td>
<td>3(2)</td>
<td>4</td>
<td>5</td>
<td>N/A</td>
<td>2.20</td>
</tr>
<tr>
<td>Maneuverability</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4(1)</td>
<td>5(4)</td>
<td>N/A</td>
<td>4.80</td>
</tr>
<tr>
<td>Appearance</td>
<td>1(3)</td>
<td>2(1)</td>
<td>3</td>
<td>4</td>
<td>5</td>
<td>N/A</td>
<td>1.25</td>
</tr>
<tr>
<td>Ease of Manufacturing</td>
<td>1</td>
<td>2(1)</td>
<td>3(3)</td>
<td>4(1)</td>
<td>5</td>
<td>N/A</td>
<td>3.00</td>
</tr>
<tr>
<td>Compatibility</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4(3)</td>
<td>5(2)</td>
<td>N/A</td>
<td>4.40</td>
</tr>
<tr>
<td>Compliance with Race Stds.</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5(4)</td>
<td>N/A</td>
<td>5.00</td>
</tr>
</tbody>
</table>

How satisfied are you with the readily available racecar chassis modifications?
Please circle the appropriate answer.  1 = very UNSatisfied  5 = very satisfied

<table>
<thead>
<tr>
<th>Feature</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4(3)</th>
<th>5(1)</th>
<th>N/A</th>
<th>Averages</th>
</tr>
</thead>
<tbody>
<tr>
<td>Safety</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4(3)</td>
<td>5(1)</td>
<td>N/A</td>
<td>4.25</td>
</tr>
<tr>
<td>Affordability</td>
<td>1</td>
<td>2</td>
<td>3(3)</td>
<td>4(2)</td>
<td>5</td>
<td>N/A</td>
<td>3.40</td>
</tr>
<tr>
<td>Durability</td>
<td>1</td>
<td>2</td>
<td>3(2)</td>
<td>4(3)</td>
<td>5</td>
<td>N/A</td>
<td>3.60</td>
</tr>
<tr>
<td>Resistance to Corrosion</td>
<td>1(1)</td>
<td>2(1)</td>
<td>3(2)</td>
<td>4(1)</td>
<td>5</td>
<td>N/A</td>
<td>2.60</td>
</tr>
<tr>
<td>Weight</td>
<td>1(1)</td>
<td>2(1)</td>
<td>3(2)</td>
<td>4(1)</td>
<td>5</td>
<td>N/A</td>
<td>2.60</td>
</tr>
<tr>
<td>Ease of Installation</td>
<td>1</td>
<td>2</td>
<td>3(3)</td>
<td>4(2)</td>
<td>5</td>
<td>N/A</td>
<td>3.40</td>
</tr>
<tr>
<td>Ground Clearance</td>
<td>1</td>
<td>2</td>
<td>3(2)</td>
<td>4(2)</td>
<td>5(1)</td>
<td>N/A</td>
<td>3.80</td>
</tr>
<tr>
<td>Maneuverability</td>
<td>1</td>
<td>2(1)</td>
<td>3(3)</td>
<td>4(2)</td>
<td>5</td>
<td>N/A</td>
<td>3.80</td>
</tr>
<tr>
<td>Appearance</td>
<td>1</td>
<td>2(1)</td>
<td>3(2)</td>
<td>4(2)</td>
<td>5</td>
<td>N/A</td>
<td>3.20</td>
</tr>
<tr>
<td>Ease of Manufacturing</td>
<td>1</td>
<td>2(2)</td>
<td>3(1)</td>
<td>4(2)</td>
<td>5</td>
<td>N/A</td>
<td>3.00</td>
</tr>
<tr>
<td>Compatibility</td>
<td>1(1)</td>
<td>2(1)</td>
<td>3(2)</td>
<td>4(1)</td>
<td>5</td>
<td>N/A</td>
<td>2.60</td>
</tr>
<tr>
<td>Compliance with Race Stds.</td>
<td>1</td>
<td>2(1)</td>
<td>3(2)</td>
<td>4</td>
<td>5</td>
<td>N/A</td>
<td>2.67</td>
</tr>
</tbody>
</table>

How much would you be willing pay for a common chassis modification? $200-$500(1), $500-$1000(3), $1000-$2000(1).
### APPENDIX C: QUALITY FUNCTION DEPLOYMENT ANALYSIS

**John Elrod**
**Race Car Chassis**

- 9 = Strong
- 3 = Moderate
- 1 = Weak

<table>
<thead>
<tr>
<th>Aspect</th>
<th>Wall Thickness of Tubing</th>
<th>No. of Additional Cross-Members</th>
<th>No. of Mounting Locations</th>
<th>Common Tubing Size/Geometry</th>
<th>Material Type</th>
<th>Nuts and Bolts are Standard Sizes</th>
<th>Weld Strength/Quality</th>
<th>Precise Machining</th>
<th>Paint Toughness (if metal is corrosive)</th>
<th>Mounting Method (welding/bolting)</th>
<th>Manufacturability</th>
<th>Compact Design</th>
<th>Customer importance</th>
<th>Designer’s Multiplier</th>
<th>Current Satisfaction</th>
<th>Planned Satisfaction</th>
<th>Improvement ratio</th>
<th>Modified Importance</th>
<th>Relative weight</th>
<th>Relative weight %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Safety</td>
<td></td>
<td>1</td>
<td>3</td>
<td></td>
<td>1</td>
<td>1</td>
<td>1.33</td>
<td>1.50</td>
<td>4.25</td>
<td>3.00</td>
<td>0.7</td>
<td>1.41</td>
<td>0.03</td>
<td>2.63</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Affordability</td>
<td></td>
<td>1</td>
<td>3</td>
<td>9</td>
<td>3</td>
<td>3</td>
<td>2.80</td>
<td>1.00</td>
<td>3.40</td>
<td>3.00</td>
<td>0.9</td>
<td>2.47</td>
<td>0.05</td>
<td>4.62</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Durability</td>
<td></td>
<td>3</td>
<td>9</td>
<td>3</td>
<td>9</td>
<td>3</td>
<td>4.00</td>
<td>1.00</td>
<td>3.60</td>
<td>4.00</td>
<td>1.1</td>
<td>4.44</td>
<td>0.08</td>
<td>8.31</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Resistance to Corrosion</td>
<td></td>
<td>9</td>
<td></td>
<td></td>
<td></td>
<td>3</td>
<td>3.60</td>
<td>1.00</td>
<td>2.60</td>
<td>4.00</td>
<td>1.5</td>
<td>5.54</td>
<td>0.10</td>
<td>10.36</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Weight</td>
<td></td>
<td>3</td>
<td>3</td>
<td>9</td>
<td></td>
<td></td>
<td>3.80</td>
<td>0.80</td>
<td>2.60</td>
<td>4.00</td>
<td>1.5</td>
<td>4.68</td>
<td>0.09</td>
<td>8.75</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ease of Installation</td>
<td></td>
<td>9</td>
<td>3</td>
<td>9</td>
<td></td>
<td></td>
<td>3.20</td>
<td>1.20</td>
<td>3.40</td>
<td>3.00</td>
<td>0.9</td>
<td>3.39</td>
<td>0.06</td>
<td>6.34</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ground Clearance</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>2.20</td>
<td>1.10</td>
<td>3.80</td>
<td>3.00</td>
<td>0.8</td>
<td>1.91</td>
<td>0.04</td>
<td>3.57</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Maneuverability</td>
<td></td>
<td>9</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>4.80</td>
<td>1.00</td>
<td>3.80</td>
<td>5.00</td>
<td>1.3</td>
<td>6.32</td>
<td>0.12</td>
<td>11.81</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Appearance</td>
<td></td>
<td>3</td>
<td>3</td>
<td></td>
<td></td>
<td></td>
<td>1.25</td>
<td>1.15</td>
<td>3.20</td>
<td>2.00</td>
<td>0.6</td>
<td>0.90</td>
<td>0.02</td>
<td>1.68</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ease of Manufacturing</td>
<td></td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td></td>
<td>3.00</td>
<td>1.25</td>
<td>3.00</td>
<td>3.00</td>
<td>1.0</td>
<td>3.75</td>
<td>0.07</td>
<td>7.01</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Compatibility</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>4.40</td>
<td>1.10</td>
<td>2.60</td>
<td>5.00</td>
<td>1.9</td>
<td>9.31</td>
<td>0.17</td>
<td>17.41</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Compliance with Race Standards</td>
<td></td>
<td>9</td>
<td>9</td>
<td></td>
<td></td>
<td></td>
<td>5.00</td>
<td>1.00</td>
<td>2.67</td>
<td>5.00</td>
<td>1.9</td>
<td>9.36</td>
<td>0.18</td>
<td>17.51</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Abs. importance</strong></td>
<td></td>
<td>0.54</td>
<td>3.91</td>
<td>1.83</td>
<td>0.35</td>
<td>3.14</td>
<td>0.78</td>
<td>0.33</td>
<td>1.97</td>
<td>0.31</td>
<td>0.60</td>
<td>0.66</td>
<td>0.32</td>
<td>14.73</td>
<td>53.47</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Rel. importance</strong></td>
<td></td>
<td>0.04</td>
<td>0.27</td>
<td>0.12</td>
<td>0.02</td>
<td>0.21</td>
<td>0.05</td>
<td>0.02</td>
<td>0.13</td>
<td>0.02</td>
<td>0.04</td>
<td>0.04</td>
<td>0.02</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
APPENDIX D: PRODUCT OBJECTIVES

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. The product objectives will focus on chassis modifications that will be made on a competitive mustang racecar. The modifications are intended to improve the overall stiffness of the racecar’s chassis.

Compliance with Race Standards (17.51%):
All chassis modifications will comply with race standards/rules.

Compatibility (17.41%):
Chassis modifications will be designed so that they can be installed on the car without making major modifications to the chassis, such as cutting/removing stock sections of the sub-frame.
The installer will simply weld, and/or bolt the sub-frame connectors to unoccupied areas of the frame.

Maneuverability (11.81%):
Modifications will decrease overall bending of the chassis by 50%. In order to measure a baseline on the car will be jacked up from under the rear seat mount which will cause the front seat head rests to move closer to each other, and we will have taken measurements of the distance before and after jacking the car up. After installing the sub-frame connectors we will repeat the steps stated previously.

Resistance to Corrosion (10.36%):
All components will be non-corrosive
If metal is not coated components will be made of non-corrosive metal (aluminum, Stainless Steel)
If metal is corrosive the components will be powder coated to provide protection.

Weight (8.75%):
Chassis modifications will not exceed 500lbs in additional weight.

Durability (8.31%):
Robust materials will be used to construct the sub-frame connectors
a.) High carbon steel
b.) High strength aluminum alloy
Also the surface finish on all tubing sections will be non-corrosive so that the metal will not wither away and slowly degrade the strength of the structure.
A design factor of 2.0 – 2.5 will be employed since the sub-frame connectors will experience dynamic loading, and the confidence level in design data will be considered average.
Ease of Manufacturing (7.01%):
   DFM (Design for Manufacturing) - The following processes are required to fabricate the sub-frame connectors.
   Tube Bending: Certain section of the sub-frame connectors will require tube bending which will require a ‘tube bender.’
   (Tolerance = Resulting Angle +/-2.5°).
   Liquid-State Welding (Fusion Welding): Fusion welding will be used to join multiple angled sections to the main tubing.
   (Tolerance = Full Visual Inspection Pass/Fail)
   Drilling: Through hole drilling will be required at multiple locations to create mounting holes.
   (Tolerance = +/-0.025in from targeted location)
   After the design is finalized using computer aided design, a more detailed analysis of DFM will be performed along with a DFA (Design for Assembly) analysis.

Ease of Installation (6.34%):
Chassis modifications will be able to be installed by one skilled welder/mechanic in less than 50 hours. If the design incorporates nuts and bolts they will be designed using standard sizes and will be able to be fastened using a common ratchet and socket set.

Affordability (4.62%):
All chassis modifications will cost less than $1000 in materials.

Ground Clearance (3.57%):
Ground clearance will not be reduced by more than 3.0in.

Safety (2.63%):
Additional frame strength provided by the sub-frame connectors can help keep a car intact in the event of an accident.

Appearance (1.68%):
Components will exhibit high precision in fabrication which will allow the material to function at its full potential. The precise fabrication will result in clean appearance.
   a.) Tube Bends: (Tolerance = Resulting Angle +/-2.5°)
   b.) Welds: (Tolerance = Full Visual Inspection Pass/Fail)
   d.) Mounting Holes (For Bolts): (Tolerance = +/-0.025in from targeted location)
   e.) Powder Coat Paint (thickness = .050in): (Tolerance = +/-0.010in)
## APPENDIX E: SCHEDULE

### SCHEDULE (Part I) - Race Car Chassis

<table>
<thead>
<tr>
<th>Milestone Date</th>
<th>Winter Quarter</th>
<th>Spring Quarter</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>January</td>
<td>February</td>
</tr>
<tr>
<td>Record Dimensions of car</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Proof of Design Statement</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Proof of Design Agreement</td>
<td>14</td>
<td></td>
</tr>
<tr>
<td>Perform Design Calculations</td>
<td></td>
<td>5</td>
</tr>
<tr>
<td>Design Sub-Frame Connectors in CAD</td>
<td>5</td>
<td></td>
</tr>
<tr>
<td>Collaborate with Race Team</td>
<td></td>
<td>5</td>
</tr>
<tr>
<td>Consider Design Changes</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Design Freeze</td>
<td></td>
<td>5</td>
</tr>
<tr>
<td>Order Parts for Assembly</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Work on Draft/Presentation</td>
<td></td>
<td>4</td>
</tr>
<tr>
<td>Oral Design Report</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Finalize Design Report</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Design Report Due</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
### SCHEDULE (Part II) - Race Car Chassis

<table>
<thead>
<tr>
<th>Milestone Date</th>
<th>January</th>
<th>February</th>
<th>March</th>
<th>April</th>
<th>May</th>
<th>June</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>3-8</td>
<td>9-15</td>
<td>16-22</td>
<td>23-31</td>
<td>1-5</td>
<td>6-12</td>
</tr>
<tr>
<td>Assemble and Mount Sub-Frame Connectors</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Test and Consider Improvements</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Implement Changes/Improvements (if needed)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Final Data Collection</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Demo to Adviser</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>9</td>
<td></td>
</tr>
<tr>
<td>Demo to Faculty</td>
<td></td>
<td></td>
<td></td>
<td>16</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Complete Oral Presentation</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Oral Presentation</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>27</td>
<td></td>
</tr>
<tr>
<td>Complete Final Report</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Final Report</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
APPENDIX F: FORCASTED BUDGET

<table>
<thead>
<tr>
<th>Materials, Components, or Labor</th>
<th>Forecasted Amount</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 7/8 Dom Tubing</td>
<td>$450.00</td>
</tr>
<tr>
<td>Welding Materials</td>
<td>$250.00</td>
</tr>
<tr>
<td>Tube Notching</td>
<td>$500.00</td>
</tr>
<tr>
<td>CNC Tube bending</td>
<td>$500.00</td>
</tr>
<tr>
<td>Installation (welding of Cage)</td>
<td>$550.00</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>$2,250.00</strong></td>
</tr>
</tbody>
</table>

Note: Modular Depot has agreed to pay for materials and all other costs (see agreement in Support Letter).
APPENDIX G: SUPPORT LETTER

Modular Depot will supply all of the materials and tools needed to complete the chassis fabrication on the 2009 Mustang Road race car. This will include but not be limited to tubing, welding supplies, grinding disks and the facility to do the work.

Greg Brown
513-200-4077