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# **RAD CAR: Restructuring of the chassis and body**

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## **ABSTRACT**

This paper covers the project of designing and constructing the RAD Car chassis as part of the requirement for a senior design class. This paper discusses methods of redesigning and constructing a new mold section, complete chassis, and jig fixtures. Also discussed are the steps that were taken to accomplish such a project which included the feasibility of different designs, the choices for these designs, and the costs associated with manufacturing and production.

## **INTRODUCTION**

The RAD Corporation (Recycled Automotive Design) was formed in 1991 by a group of Mankato State University students to construct a concept car that combined components of a donor vehicle with a custom chassis/body design that was constructed by students.

A group of three Automotive Engineering Technology students worked from the summer of 2002 to the spring of 2003 to redesign and construct a second generation improved version of the old design. The students worked in collaboration with a company, RAD MotorWorks LLC, which funded the project. After completion the project will be turned over to the company for completion and the car will be displayed at the 2003 SEMA (Specialty Equipment Manufacturers Association) show in Las Vegas, Nevada as a company prototype.

## **PROJECT OUTLINE**

### **MOLD**

There are several reasons that an improved front exterior design was in order. Three of the major focus points included in the project are discussed below:

1- The passenger compartment has room for ergonomic improvement. At highway speeds there is a significant amount of air turbulence in the seating compartment, causing safety concerns because of disturbances to the driver.

2 – The front windshield's visibility does not support the majority of taller drivers.

3 – The radiator opening in the body was not supplying enough air movement across the radiator to provide adequate cooling of the motor in the majority of driving conditions.

To solve the air turbulence problem, the sources had to be identified. This was determined mostly to be a lack of side structures (doors) and windshield curvature. The first experiment was the addition of mach-up doors and placing them in where they should normally be. Testing was done with several different shapes and designs made from thick cardboard. After finding the perfect combination for the shape of the door, plans were made to construct a plug and mold. A decision was made to construct doors in the form of a plug. Then after the plug is constructed, fiberglass can be laid over the plug to form a mold.

The door plugs were made of particle board wood and fiberglass construction. Fiberglass construction consisted of several layers of fiberglass embedded with epoxy resin. The resin acts as a hardener to make the

cloth solid and stiff. A catalyst is added to the resin to speed up the chemical reaction.

The design of the doors had to be done separately for each side because the original mold is not symmetric. Not only is the mold non-symmetrical, but each mold has to be a reverse of the other. A small piece of household window sealing tape (strapping tape) was laid down first to cause an indentation in the plug. This section is where the door will seal to the body as shown in Figure 1. The first layer to go over the body was the masking tape. The second layer of tape was strapping tape. Strapping tape is slippery and works well with mold release wax to release the fiberglass. The door seal was placed to give a shape for the seal. Once the tape was done, a layer of mold release wax was applied over it to ensure a complete release.

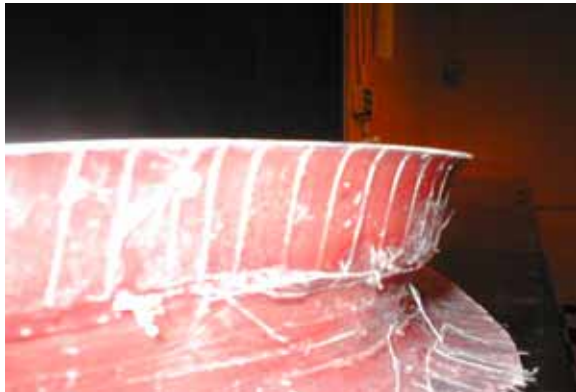


Figure 1, Door edge seal.

A thin layer of fiberglass soaked with resin and catalyst was laid over the waxed area and let hardened. When this hardened it will become the bottom sealing side of the door. To speed the catalyst process, heat guns were used. Once ready, the addition of pre-cut wood was laid on top of the fiberglass to attain the exterior shape of the door.

Once the filler had hardened the door plugs were ready to be removed from the car. Once removed, the door plugs were filled and sanded to achieve the exterior shape that was desired (see Figure 2).



Figure 2, Final shape of door.

The windshield on the first prototype vehicle (owned by Neil Majeski) is angled differently than the red RAD car

owned by MSU (pictured in Figure 2). Neil's RAD car windshield angle is too far up, with respect to the normal horizontal axis) and does not follow the curvature of the body. The MSU RAD car windshield angle is too far down, and as shown in Figure 3, does not allow taller drivers full visibility.



Figure 3, Windshield height and visibility.

The student team decided that the windshield angle needed to be changed to accommodate more drivers. Research on different types of windshield from different types of vehicles was done at City Glass, a local auto glass shop in Mankato, Minnesota. The specifications provided by City Glass's catalogs did not provide sufficient dimensions to make a clear judgment on a correct windshield fitment. The ideal windshield that was desired would be taller but retain the same width as the current design. This is because there will be no changes to the width of the body to accommodate a different windshield. A suitable one would have to be found given the width dimensions only.

This task proved to be extremely challenging because of the complexity of the dimension parameters and the availability of such designs from a large variety of OEM (Original Equipment Manufacture) vehicles. Only OEM vehicles were considered based on the cost factor and availability of specialty glass. Research was conducted on specialty glass companies, but none were found to be within reasonable cost. Such examples of prices researched exceeded 5 times the amount of a normal windshield. City Glass ordered several different windshield designs and had them shipped in. These windshields were then fitted to the body to ensure proper fitment.

After all of the research was conducted on windshield designs, the chosen decision ended up being the same as the original. The visibility problem was resolved by using other parameters involved with the placement of the windshield. These parameters included redesigning the factors that relate to the vision of the driver at a given height. These changes included lowering the seating position of the driver, and increasing the windshield angle (compared to the MSU RAD car; decreased compared to Neil Majeski's RAD car). The windshield placement was also moved 2 inches upward in reference to the windshield pillars. This allowed more top half visibility, but less lower half visibility which prevents the driver from seeing obstacles in the road directly in front

of the car. This decision was weighed in favor because overall visibility was gained in the more favorable area, safety.

The third area of the body that required attention was the front nose clip. The style of the front nose clip was modified to increase the air movement across the radiator and to enhance the appearance to present a “new design” approach to a modernized version of the car. The headlights were removed and changed to a flip up/hidden style and the front opening was widened. The side markers and turn signals were moved to a different location. The locations of the lights had to coincide with state and federal laws. The construction of the new front clip plug was similar to the door plug. The front section was made using the old mold piece. The shaping of the new design took place from there. Excessive body filler was used, and the process was very labor intensive.

## CHASSIS DESIGN

The chassis design was based off of requirements for production. There were certain issues that were associated with the original design that needed attention. These include:

- 1- The wheel base is 89 inches. The racing sanctions intended for use require a 90 inch minimum wheelbase.
- 2 - The front suspension design is inadequate for mass production. Research for an improved design was completed.
- 3 -The rear suspension has limited applications and does not meet the design requirements for the new design.
- 4 - Chassis tube lengths are required to be uniform for mass production. This ensures a quality product.

## WHEELBASE

The wheelbase of the original chassis design is 89 inches, which is less than current rulings of the SCCA and NHRA racing safety rules stating that a minimum of a 90 inch wheelbase is required to compete.<sup>5,6</sup> This is a small but significant measurement. RAD MotorWorks, LLC's owner wanted to compete with the car in events held by these sanctions. After researching the rulebooks of the National Hot Rod Association (NHRA) and the Sports Car Club of America (SCCA), we discovered that in order to compete, the wheelbase must be lengthened. There were other rules that we encountered when researching that affected the design. By utilizing these sanctioned racing outfits rules, the chassis was designed to meet what was believed to be the best overall design to meet or exceed the safety rules as described in the book.

There were two different options for increasing the wheelbase. The first would be to elongate the body and

chassis. The other would be to elongate the wheel well openings and chassis. The chosen method was to lengthen the chassis and trim the wheel well openings. This will also allow the use of larger tires and save the work of lengthening the body, which is quite labor intensive.

## FRONT SUSPENSION

The original front suspension design consists of components from a late 1970's Chevrolet Monza. The original project scope (1991) was to design a “kit car” utilizing components from another car. During the time of the first build of the car there were only a few companies producing quality independent front suspension kits, and an even smaller handful of small, lightweight rear wheel drive cars that had independent front suspension from the factory. At the time this was considered a good choice.<sup>1</sup>

Research and evaluations on different designs of front suspensions was completed. Different types of front suspensions include MacPherson strut style, trailing link, unequal length double a-arm, equal length double a-arm, swing axle and beam axle.

There are three things to control in terms of front axle movement; caster, camber and toe. In a solid beam axle the camber and caster are built into the design. A solid beam axle move straight up and down and therefore so does the spindle. Thus, there is no change in caster or camber in a turn or load. This will save the tires from wearing unevenly due to suspension flex and wear, which is why this suspension is common on heavy and medium duty trucks.<sup>4,7</sup>

A MacPherson strut style suspension incorporates the shock absorber and the upper control arm into one system that utilizes only one lower control arm. There is a cost, space and weight advantage by not having these parts, which is why this suspension is common on front wheel drive cars.

The trailing link suspension is common on Volkswagen Beetles and uses two arms to support the steering knuckles. The trailing links bend when a heavy load is applied to them; this causes changes in suspension angles.

An equal length double a-arm uses two links that are in a parallelogram. However there is no positive camber gain. To solve this one of the arms is shortened. This is then known as the unequal length double a-arm suspension.

A decision was made to use the independent front unequal length double a-arm (also known as a short/long arm suspension SLA). Front suspension design requires the consideration of all components, their arrangement, and performance expectations. SLA has several advantages that match the desired performance output of the chassis and car characteristics, such as good

handling and stability. The SLA also provides a lot of room in the engine compartment to accommodate larger V8 engines. The longer and shorter a-arms provide negative camber when turning into a corner and the suspension compresses. Having negative camber gain in corners provides more of the tire tread on the ground, thus gaining more traction and have better performance. The advantage of this gain in camber is that the outside tire stays perpendicular to the ground, where it develops maximum cornering power. The amount of camber gain is determined by the length of the swing arm and the height of the instant center<sup>4</sup>.

After researching different methods and costs of manufacturing and installing a SLA suspension a decision to purchase a manufactured kit that would be sold in component form was made. Ford Motor Company manufactured an independent front suspension in the mid 1970's for its Mustang II line. This suspension became popular with street rod builders because they were plentiful and has many of the same advantages as listed earlier. In the 1980's many businesses started manufacturing "modified versions" of that suspension and naming them after the Ford Mustang II to identify with purchasers.

Heidt's Hot Rod Shop, Inc. was chosen to purchase the front suspension for several reasons. The shock mounts are one-piece T.I.G. welded in place, the anti-dive angle is built in for ease of installation. The inner uprights are vertical, which is the strongest known design available to keep the frame from twisting under load. The main crossmember is made from only two formed pieces for maximum strength and accurate fit. The control arms are made of tubular steel and feature fully adjustable camber/caster holes.<sup>7</sup>

The Heidt's IFS design is also cost effective. At a cost of \$1995.00 it makes designing and manufacturing a front suspension for small production appealing as a viable choice.

## REAR SUSPENSION

The original rear suspension is a four-link design. This design is ideal for use in straight line acceleration. The four-link also has a lot more moving parts that require more maintenance and possibly more failure points. The four-link uses four longitudinal bars to locate the axle fore and aft of the axle to control the torque loads of acceleration and braking. However these links provide no lateral control. Usually a Panhard bar is used to control sway in corners, however it is difficult to control roll understeer because the links on each side of the car must remain parallel with each other.<sup>4, 8</sup>

A rear suspension that could handle as well as the front suspension was desirable. There are a few companies that manufacture and sell prefabricated kits for rear suspensions, but their fitment is very limited and their cost is high. The manufacturing and design of a simple

rear suspension that performs well and is cost efficient was required.

As before, with the decision of the front suspension an evaluation of different suspension styles and their performance characteristics was required. The decision was to use a solid rear axle, for simplicity, strength and cost. Once the decision was made on the type of drive axles to be used, a suspension was designed that could accommodate it.

There are a variety of ways to design a rear suspension when utilizing a solid axle. The first step is to find the design requirements. A rear suspension that performed as well as the front suspension and has good lateral control was necessary. Some of the undesirable characteristics of rear suspension design are binding during acceleration and braking, and having no thrust angle in the alignment of the rear axle to the front. Thrust angle can cause a car to wander or it can assist cornering, but only in one fixed direction.

Some of the different types of rear suspensions associated with solid axles are the Hotchkiss drive, link arm, and torque arm.<sup>4</sup>

The Hotchkiss drive system is more commonly known as having leaf springs mounted longitudinally on each side of the car resting on or under the axle. The leaf springs are also used to locate the rear axle and support the weight of the vehicle. Their weight and size are a major disadvantage. This was one of the first types of suspension systems used on cars, and is still used on many trucks and heavy load vehicles.

The torque arm rear suspension uses a separate long arm to control the torque created. This bar is located in the center of the axle and is mounted longitudinally. Still links or springs must be used to locate the axle.

The link arm was chosen and in particular the three-link. The three-link suspension uses two parallel links on each side of the axle and a third link attaches to the top of the rear axle housing on the centerline. Many newer racing cars use a three-link suspension; this is where the evaluation for this design was started. The design allows for optimum roll steer and adjustment. The three-link is simple and very adjustable by locating the top link up or down in height. A three-link can increase anti-squat, which improves weight transfer and traction. It also eliminates the characteristic four-link suspension bind. Because a three-link has an adjustable longer bar in the center, it lowers the roll center and prevents lateral axle movement.<sup>4, 8</sup>

There are very few companies selling three link rear suspensions because each one is customer tailored to the different dimension of each chassis. The decision was to design and manufacture the rear suspension versus purchasing it. A decision on the location of the links was found by utilizing a Computer Aided Drafting system and found the necessary length of the links. We

purchased the brackets, lower control arms, and the links that were designed for race cars from Speedway and rod ends from Aurora Inc.

The parts cost was minimal as the majority of the rear suspension is in its design, rather than construction. The total cost for the rear suspension (parts only) was \$55.61 without shocks and springs.

### UNIFORM CHASSIS TUBE LENGTHS

The new chassis is planned to go into small mass production of a few units per year by RAD MotorWorks, LLC. In order to acquire accuracy and precision from unit to unit they must be uniformity and detail in the prototype. The more uniform and accurate the first prototype is; the closer each model after that will be to the ideal.

To manufacture the chassis a type and thickness of steel would need to be chosen. The original RAD car was composed of 1.25 x 1.25 inch (1/8 inch wall thickness) square tubing with aluminum paneling accompanying it. This chassis was tested primarily for its strength and rigidity. The type of testing that was done was simple. A hoist was placed under a corner of the car and the chassis showed no deflection. The second criterion for making a decision was benchmarking of other companies with similar products. This was used to aid the decision. Some of the companies that were benchmarked were Panoz,<sup>1, 2</sup> Factory Five Racing, and Hendricks Motorsports.

There are several materials that can be used to manufacture an automotive chassis. Some of these choices include steel, plastic, and FRP (Fiber Reinforced Plastic). There has been a significant amount of advances made in plastics engineering in the recent years, however these technological advances are extremely costly and are beyond the scope of this project. FRP's have been in used in the automotive industry for more than 40 years. There are some chassis's that are composed entirely of FRP's. FRP's represent a significant weight savings versus conventional steel, and in most cases have comparable strength. The RAD car's body is composed of FRP. However, the cost to design and manufacture a chassis from FRP is expensive and complicated compared to steel.

Steel was chosen for a few reasons. First and foremost steel was used to keep manufacturing costs down; this is a common practice in the majority of the automotive industry. Second, steel is easier to work with when compared to the complexity of FRP's. Any accidents or wrongly made parts during production can be remade at a lower cost.<sup>9</sup>

The decision was to stay with steel tubing. Steel tubing also has two categories, square or round tubing. Now another set of choices presented itself and again more

decision making was in order. The decisions were made keeping in mind some of the main manufacturing principles and goals of the project and the company.

Round tubing is a good choice because it is strong. It also is lighter in weight as compared to square tubing of the same nominal thickness and dimension. In the case in Table 1, round tubing is 78.5% of the weight of square tubing. The moment of inertia is the measure of the ability of a cross-sectional area to resist bending or buckling. For this same dimension, the moment of inertia for round tubing is considerable lower (69% reduction), so it has less stiffness (when compared to square), though not as much if the moment is normalized by the cross-sectional area. "Normalizing" means to divide some value by some other value so that everything is equal. This situation requires comparing the stiffness relative to weight; this is why the moment of inertia is divided by the cross-sectional area.<sup>2, 4, 8</sup>

| Criteria               | //////////                 | //////////                 |
|------------------------|----------------------------|----------------------------|
| Tube Type              | Square                     | Round                      |
| Dimension              | 2.00 x 2.00 inch           | 2.00 inches dia.           |
| Wall Thickness         | 0.125 inch                 | 0.125 inch                 |
| Area                   | 0.9375 inch <sup>2</sup>   | 0.7363 inch <sup>2</sup>   |
| % weight of square     | 100%                       | 78.5%                      |
| Moment of Inertia      | 0.5518 inches <sup>4</sup> | 0.3250 inches <sup>4</sup> |
| % Inertia of square    | 100%                       | 58.9%                      |
| Normalized Inertia     | 0.5885 inches <sup>2</sup> | 0.4414 inches <sup>2</sup> |
| % Normalized of square | 100%                       | 75.0%                      |

Table 1, Round versus square tubing.

Round tubing is used on most racing cars, for the reasons listed before. The only disadvantage of round tubing is its cost. When compared to square tubing, it is higher.

Round tubing is expensive to fabricate because of the labor involved in mating tubes together. Square tubing requires only cutting straight edges with angles.

The final decision was to use square tubing for these reasons:

1. Cost – Square tubing is less expensive. From a manufacturing standpoint, this will cost less to produce and will require a lower selling price.<sup>1</sup>

2. Fabrication – Aluminum paneling is going to be used to seal the interior from the road and weather conditions. The paneling is also used for structural support in the chassis. Square tubing has flat surfaces that are beneficial for attaching the paneling to. Although paneling can be fitted to round tubing, there is more labor involved. Another fabrication advantage that square tubing has over round is that it can be cut at flat



angles to mate to other square tubes. Round tubing requires radius fitment cutting to mate each part to each other. Round tubing can be bent to make a corner fitment, but a tubing bending machine would be required for the company to purchase one for manufacturing. Instead, a simple metal cut off saw will be purchased for a significantly lower price to cut the square tubing.<sup>1, 2, 4, 8</sup>

3. Chassis Strength – After researching, it was discovered that square tubing accompanied with aluminum paneling will be more than adequate to use for the chassis. Although the round tubing does have a weight advantage, it was not significant enough (justifiable) of an advantage as compared to the advantages that square tubing offers in its fabrication and cost.

The decision was to stay with the same nominal size of tubing as used in the original RAD car. Neil Majeski's experience with steel manufacturing and purchasing was useful here. Neil had suggested that the 1.25 x 1.25 inch tubing is one of the most commonly available sizes of square steel tubing and therefore the purchase cost would be lower.<sup>1</sup>

The original chassis design used the 1.25 x 1.25 inch tubing as the single size in the entire chassis. The original design front end suspension could be accommodated to this size steel easily. The choice to install a Heidt's front suspension meant that a 2 x 3 inch tube would be required for the crossmember provided in the kit to fit to. The choice for the 3-link rear suspension also meant that the chassis needed a strong center section and end points for the links to attach to. The 1.25 x 1.25 inch steel cannot properly accommodate the chosen front suspension, and might not be strong enough to handle the requirements of the rear suspension.

A choice was made to use 2 x 2 inch (1/8 inch wall thickness) square tubing as the main frame rails. This was done for strength to accommodate all of the suspension components in the rear and the front, and to virtually eliminate chassis twist during acceleration, braking and cornering by transferring the energy in the right areas. The remainder of the chassis was constructed of 1.25 x 1.25 (1/8 inch wall thickness) square tubing.

The prototype was fabricated on a jig table. A jig table is a table that is made of thick steel to ensure that each piece of the chassis is welded together on a level plane (Figure 12). The jig table was designed and manufactured by two Manufacturing Engineering Technology (MET) students at MSUM. The discussion of the design and construction of the jig table or its components is beyond the scope of this paper.

Fixtures were set on the table to get accurate measurements on the location of parts. This was constructed by a third MET student. The fixtures are made of aluminum and have clamps bolted to them to

hold the chassis components in their correct locations while welding together. This allows manufacturing time to be significantly decreased because the measurements of angles do not have to be measured each time a piece is fitted to the chassis. As shown in Figure 4, chassis tubes are held in by clamps, and are ready for welding.



Figure 4, Chassis jig table, fixtures and clamps.

#### CAD DRAWINGS

A Computer Aided Drafting program (CAD) was used to draw the chassis and components. There are several design programs that are available to MSUM AET students that can be utilized for this type of project. The students consulted Dr. Andrew Markowski, a CAD instructor in the AMET department, to aid in the decision. He stated that the majority of the industry is still using Mechanical Desktop 5 or a version similar to it. He suggested that other programs such as Pro-E and AutoCAD 2000i would not be as beneficial to this project due to the increased difficulty in created dimensions and modifying them.<sup>3</sup>

So the decision went to Mechanical Desktop 5. Another situation that aided the student's decision was that all of the students involved, including Neil Majeski, have experience using this software.

There are two drawings that were made for the chassis. The first one was made to get an idea of what pieces go where. The original RAD car chassis dimensions were copied into the CAD system. This proved to be an exercise that allowed the students to brush up on their skills using the system. It also allowed the designers to visually see the chassis in a 3 dimensional setting. By doing this the designers saw room for improvements that might not have otherwise been seen with the chassis drawn by freehand or still connected to the car.

The next step was to design a new chassis based on the requirements found during the suspension and chassis steel decisions. Some of the improvements that were made to the design were as follows:

1. The addition of the 2 x 2 inch main frame rail. This was necessary to accommodate the new suspension components. As mentioned earlier, this was

also a benefit to the strength and energy transfer of the chassis. The 2 x 2 inch section connected the rear suspension to the front completely.

2. The addition of cross bars in the door paneling area and in the firewall. This was again done to add strength to the chassis, mostly in the areas of severe cornering or acceleration and energy transfer. The cross bars in the door panel area are also set at a certain height that allows the body section to rest on it with more surface area than the original design. This will in turn provides a stronger base for the door area of the body which, because of the body design, is stepped on frequently when entering or exiting the car. This will prevent cracking of the body in that area.

3. The lowering of the fuel cell holding area. When viewed with the body mounted on the chassis (in the original RAD car) there is room for the fuel cell to be lowered vertically. By lowering the fuel cell location, the center of gravity is lowered. By lowering the center of gravity, the performance of the car is increased. This was yet another scope and desired function of the intended design.<sup>4,8</sup>

Other main components that were drawn using CAD include the engine, transmission, and drivetrain. To design the main chassis dimensions the components had to be drawn first. Then the chassis could be dimensioned around them for proper fitment. For example, the improved design chassis is set up for the option of installing a small block V8 or a big block V8, with a manual or automatic transmission. The chassis dimensions are drawn to accommodate a big block V8 and an automatic transmission because that combination requires the most space. Although the first prototype will not have this combination, it is available to the consumer, for the manufacturer to install without making any chassis adjustments for fitment. The only adjustments that would need to be made would be to the mounting points.

Another component that was drawn before designing the chassis was the fuel cell. The fuel cell is a very important and overlooked area of a car. The NHRA and SCCA rulebooks cover fuel cell safety aspects in great detail. Both racing sanctions have similar rules, so it was not necessary to design any more than one fuel cell holding area. The NHRA and SCCA rulebooks for 2003 state that the fuel cell (or gas tank) must be held in place inside a cage consisting of 1/8 inch thick steel<sup>2</sup>. This was, by coincidence, the thickness of the tubing that is used in the rest of the car. Although it could have been argued that this rule should have been a factor in the decision making process because competing within these sanctions was part of the original intention.

Once the improved design was completed, the prototype started to take shape. Some of the pieces were not dimensionally drawn correct and there were several mistakes made during production because the students were still getting accustomed to the higher level of

difficulty and intensity the project required. To adjust for this, the prototype was fabricated to fit the major measurements, such as the wheelbase and length and width of major components and accessories. The major pieces were constructed first and then the less important parts were fitted to that. After the prototype was spot welded to hold shape, measurements were taken and then a second, correct, design was drawn in CAD. This was done so that the drawing would represent a more realistic and correct version of the chassis that fit the jig.

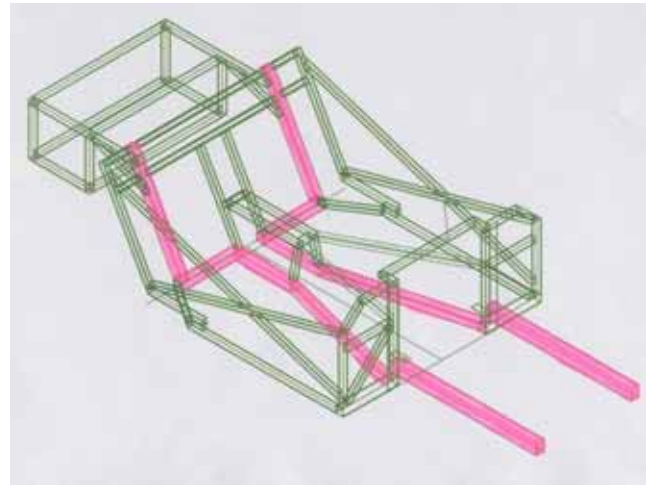


Figure 5, CAD drawing of the chassis. The 2 x 2 inch main frame rails are highlighted.

The MET students designed and manufactured the chassis jig table from the main component measurements. The final draft includes tube thicknesses and perfect measurements as the prototype was built.

The sheet metal that covers the passenger compartment for strength was also drawn on CAD. This turned out to be a great advantage. By using a CAD system, the optimum layout for cutting sheet metal using the least amount of material necessary was found. This practice is used widely in the manufacturing industry to save money and time by not wasting material.

## CONCLUSIONS

Once the chassis is completed Neil Majeski, of RAD MotorWorks, LLC., will take final delivery of the product. Neil will also take delivery of the CAD chassis and component drawings, cost reports, and parts list. The cost report and parts list are located in Appendix C and D, respectively. After completion of this project the team has a great understanding of the many aspects of vehicles and chassis design and manufacturing processes. These areas included composite mold and body design and fabrication, chassis design and criteria selection, jig design and construction, material selection, group communication skills, manufacturing techniques, testing and evaluation techniques and other cumulative skills that progressed as the project went on.



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