SAE Mini Baja Frame Design

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Team 01

Concept Generation and Selection

Document

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Contents

Design Problem

The Northern Arizona University chapter of SAE has not won a Mini Baja competition in recent years. The team goal is to win an event at the competition. To achieve this, the frame will design and construct the lightest possible frame.

The purpose of the frame is to protect the driver in the event of a collision or rollover, and to provide a chassis to mount the other subsystems. A minimum spacing between the driver and the frame must be maintained to ensure driver safety, and minimum strength requirements must be met. There are also specific requirements for the geometry of the frame as shown in Figure 1. There must be a gap of at least 6 inches in all directions between the driver's head and the frame, and there must be a 3 inch gap for the driver's body. [1] The frame must be constructed of an SAE standardized tubing size or an equivalent size of similar strength. A 64 inch tall driver weighing 250 pounds must be able to sit comfortably in the vehicle with all the proper safety devices. The frame must be no wider than 64 inches and no longer than 108 inches.

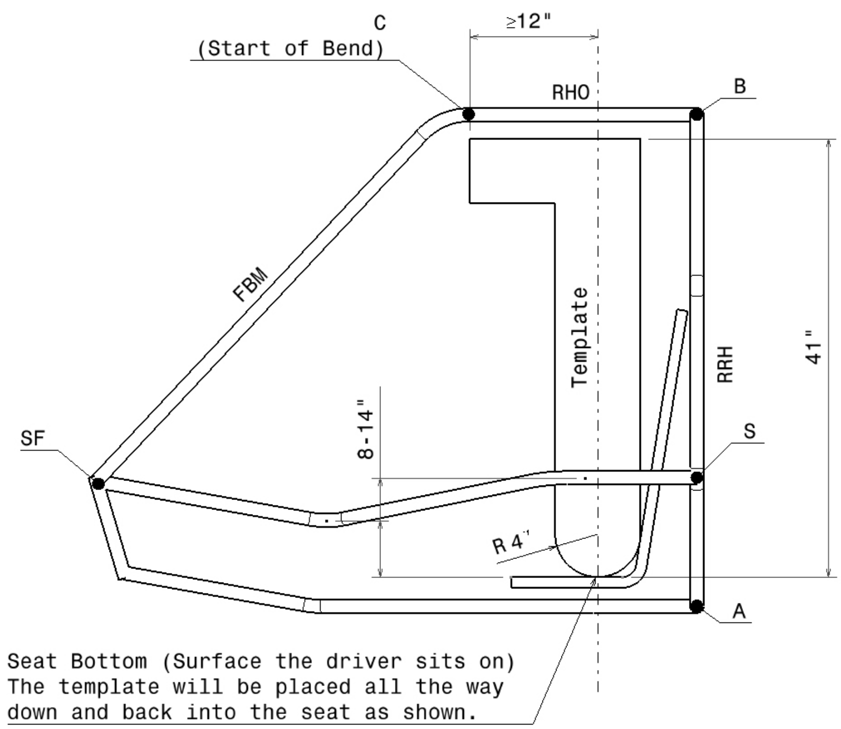

Figure 1: Clearance for the driver [1]

Tubing Selection

The 2014 SAE Baja rulebook specifies a standard tubing selection of AISI 1018 steel, with 1-inch outside diameter and a wall thickness of 0.120-inch. However, SAE does allow alternate selections as long as the team uses steel tubing and can prove that their selection has equivalent bending strength and stiffness. The tubing must have a minimum diameter of 0.5-inch and a minimum wall thickness of 0.065-inch. The tubing selection is independent of the frame geometry and thus was a completely separate decision process.

The most common alternate steel choice in the Baja competition is AISI 4130, because it has significantly higher ultimate tensile strength and yield strength than AISI 1018. [2] Both 4130 and 1018 have the same density, but 4130 produces a much stronger frame for the same weight. The equations defining bending stiffness and bending strength are shown below:

$$Stiffness = E \cdot I \tag{1}$$

$$Strength = \frac{S_y \cdot I}{c} \tag{2}$$

Where:

E = Young's modulus

I = second moment of area

S_y = yield strength

c = distance from neutral axis to extreme fiber

[3] Young's modulus is 29,700 ksi for all steels, and the yield strength for AISI 4130 is 63.1 ksi. AISI 1018 has a yield strength of 53.7 ksi. Calculated values for the bending stiffness and strength for the SAE specified tubing as shown in Table 1.

Table 1: Properties of SAE specified AISI 1018 tubing.

Diameter [in]	Wall Thickness [in]	Stiffness [in-lb]	Strength [in^2-lb]
1.000	0.120	971.5	3.513

[4] Calculated properties for a variety of available AISI 4130 tubing sizes and comparisons with the standard tubing's relative stiffness, strength, and weight are shown in Table 2. The relative measures are simply the property of the 4130 tube as a percentage of the property of the SAE specified AISI 1018 tube.

Table 2: Properties of AISI 4130 tubing of various sizes.

Diameter [in]	Wall Thickness [in]	Stiffness [%]	Strength [%]	Weight [%]
1.000	0.120	100	118	100
1.125	0.083	113	119	81.9
1.125	0.095	126	131	92.7
1.250	0.065	130	122	72.9
1.375	0.065	176	150	80.6
1.500	0.065	231	181	88.3

The lightest tubing size that exceeds the SAE minimum requirements is AISI 4130 steel, 1.250-inch outside diameter tubing with 0.065-inch wall thickness. This is the tubing we have selected to use regardless of the frame design. AISI 1018 tubing of the same size is less expensive and still meets the SAE minimum requirements, but is not as safe. If sufficient funds are not available for the AISI 4130 steel, the AISI 1018 of the same size will be used as a backup selection.

Concept Generation

The team came up with four different designs for the overall frame geometry. Each design considered conforms to the 2014 SAE Mini Baja Rules. Below, the advantages and disadvantages for each design are discussed.

Frame Design 1

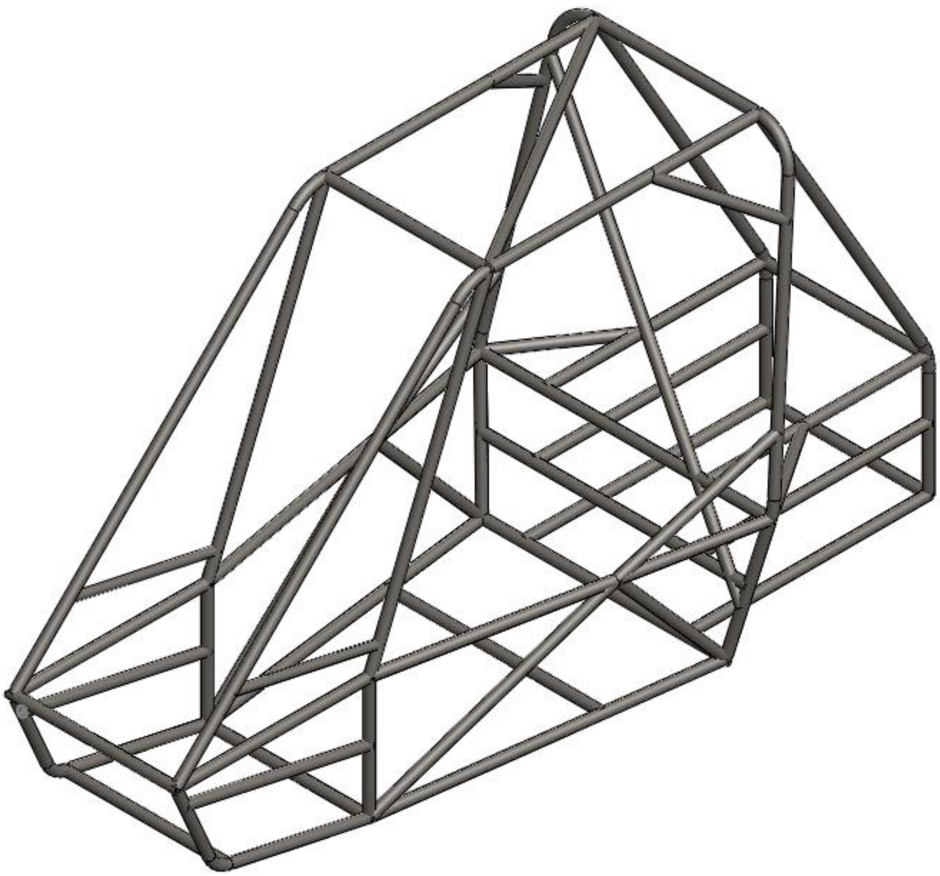

Figure 2: Design 1

Advantages of Design 1:

- Rear roll hoop and cage will provide increased rigidity in frame. There is cross bracing to increase the strength of the roll hoop.
- Wider frame will allow driver to exit vehicle in case of emergency
- Shorter frame length will allow for better handling throughout course

Disadvantages of Design 1:

- Highest amount of tubing will make this the heaviest frame.
- The height of the frame affects the center of gravity potentially causing the vehicle to be less stable.
- Highest number of individual tubes will decrease ease of manufacturability. More tubes will need to be cut and welded together to complete the frame.

Frame Design 2

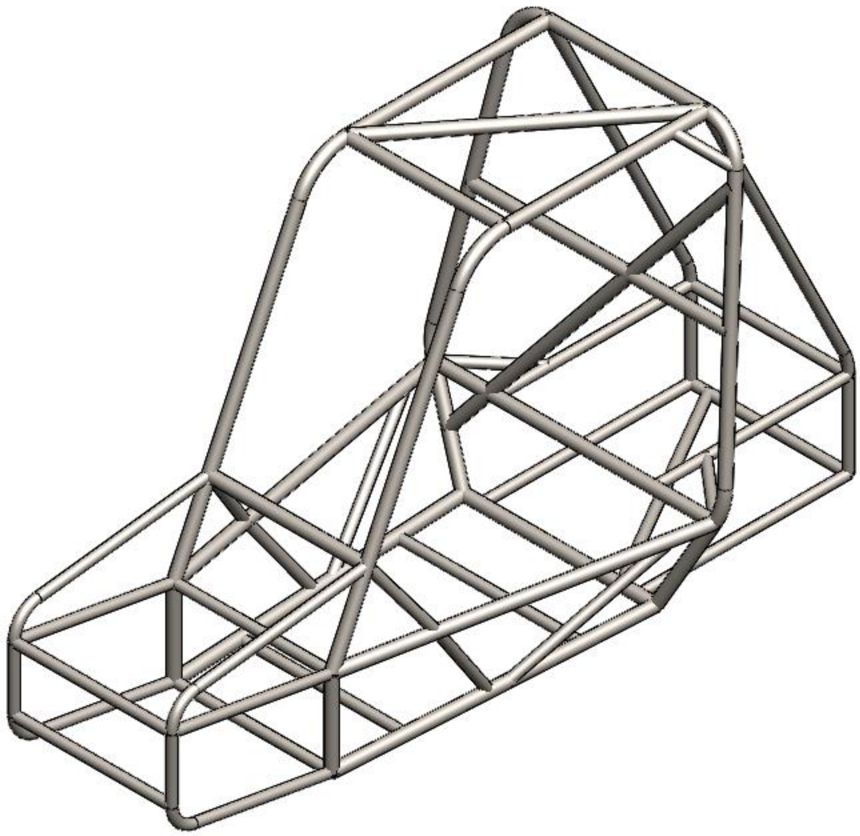

Figure 3: Design 2

Advantages of Design 2:

- Least amount of material used will make for the lightest frame
- Shortest wheelbase will make this the most maneuverable frame because the turning radius will decrease.
- Least number of individual tubes will make this the easiest frame to manufacture as it will require the least cutting and welding of individual tubes.

Disadvantages of Design 2:

- The lack of tubing could affect frame rigidity as there are less members to transfer the loads.
- The height of the frame affects the center of gravity potentially causing the vehicle to be less stable.

Frame Design 3

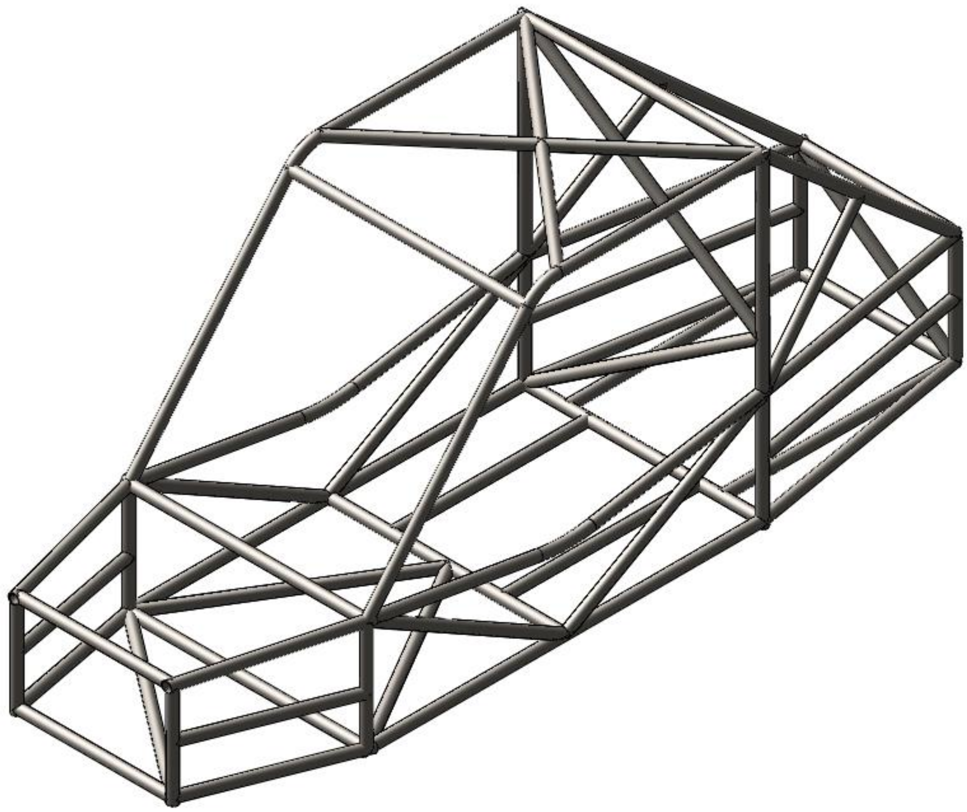

Figure 4: Design 3

Advantages of Design 3:

- Longer frame allows for a longer wheel base increasing the overall stability of the vehicle
- Higher number of individual tubes allows for frame stiffening at specific points increasing the overall rigidity of the frame.
- Low number of bends allows for easier manufacturing because less operations will have to be performed to the pipes saving time.

Disadvantages of Design 3:

- Longer frame decreases maneuverability. The long frame will increase the turning radius
- Large amount of material results in heavy frame which will hinder performance.

- High number of individual tubes will decrease ease of manufacturability. More tubes will need to be cut and welded together to construct the frame taking up more time and resources.

Frame Design 4

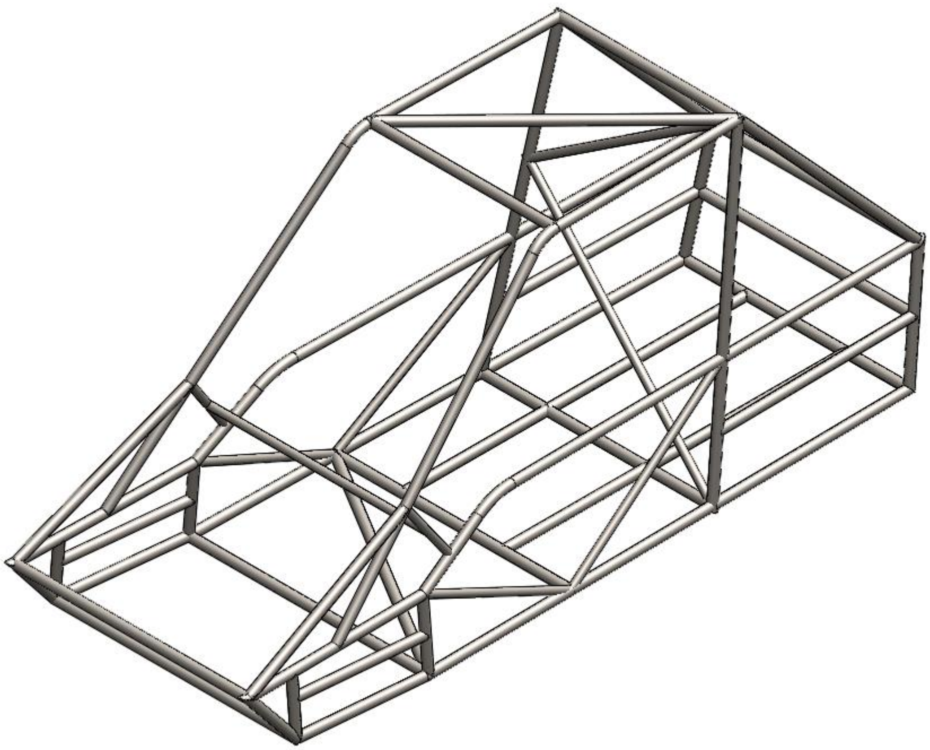

Figure 5: Design 4

Advantages of Design 4:

- Longer frame allows for a longer wheel base increasing the overall stability of the vehicle
- Relatively large interior space will allow taller drivers to operate the vehicle.
- Low number of bends allows for easier construction of the frame.

Disadvantages of Design 4:

- Longer frame increases the turning radius thus decreasing vehicle maneuverability.
- A tall frame will raise the center of gravity. A high center of gravity could cause a vehicle rollover.

- High number of individual tubes will decrease ease of manufacturability. More tubes will need to be cut and welded together to construct the frame taking up more time and resources.

Decision Matrix

The team reviewed the four designs and created a decision matrix shown in Table 3. The relative weight of each criterion indicates its importance in the decision process. The weights were restricted to a nine, five, or one because we cannot determine subtle differences at this point in the design process. Raw data was used to populate the design columns for simplicity. The goal was to minimize each of the criteria, thus the lowest overall score is the winner.

Table 3: Decision Matrix

	Weight	Design 1	Design 2	Design 3	Design 4
Amount of Material (ft)	9	109	94	105	107
Length (in)	5	83	78	100	100
Width(in)	1	32	33	30	31
Height (in)	5	45	44	39	44
Number of Bends	1	10	10	4	4
Number of individual tubes	1	65	43	50	55
Total		1728	1542	1724	1773

The team selected a relative weight of nine for the amount of material needed to build the frame because this directly correlates to the final weight of the frame. Because the tubing selection is independent of the frame design, only the length of tubing required was considered.

The team selected a relative weight of five for the length and height of the frame. The length of the frame affects the maneuverability of the vehicle as well as high speed stability, and the height affects the center of gravity. Although a long length increases the stability, the maneuverability of the vehicle is much more important. The length needs to be minimized to decrease the turning radius and reduce the chance of high-centering on obstacles. A shorter length frame will also make the vehicle easier to transport when not in use. The height also needs to be minimized to reduce rollover risk.

A relative weight of one was assigned to the width, number of bends, and number of tubes. The width of the frame is not the outside width of the vehicle, and does not directly affect clearance or stability. The number of bends and the number of tubes were used to quantify the manufacturability of the frame. The more bends and individual tubes required, the more operations there are to construct the frame. All of these criteria also need to be minimized.

The decision matrix indicates that design 2, shown in Figure 3, is the best fit for our objectives. This design has the least amount of material needed and has smaller overall dimensions than the others. It requires more bends than other designs given, but the light weight and small dimensions make up for this minor disadvantage.

Welding Type Selection

The NAU Machine Shop has three types of welding equipment availbe to use: Gas Metal Arc Welding (GMAW), Shielded Metal Arc Welding (SMAW), and Gas Tungsten Arc Welding (GTAW).

SMAW (commonly known as stick welding) requires an electrode, an electrode holder and a ground to the metal to be able to weld the tubing together as shown in Figure 6. [5] Stick welding requires no prep-work whatsoever and the workpiece can be very dirty without any loss in weld strength. However, this process would be very difficult for welding the frame because it is difficult in tight spaces and requires a special type of electrode for AISI 4130. This type of welding also creates a lot of spatter and left over welding material which must be removed afterward. SMAW requires no prep-work but is time consuming and difficult at awkward angles and in tight spaces.

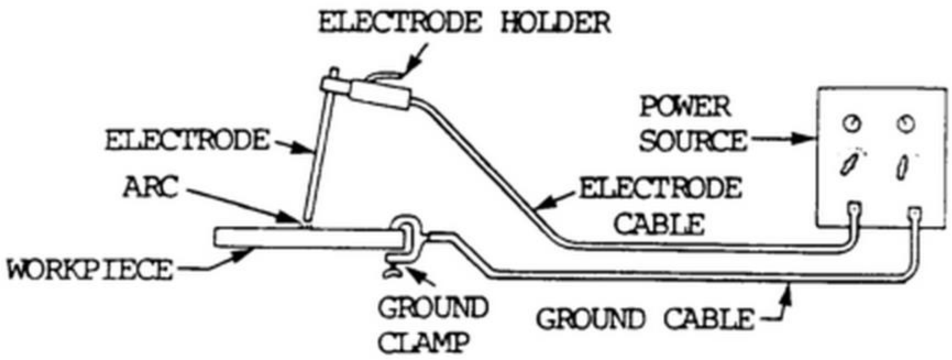

Figure 6: Shielded Metal Arc Welding [5]

GTAW (also known as tungsten inert gas, or TIG) would be the most time consuming type of welding process. This type of process uses an electrode, a torch, a ground and a foot pedal for controling the amperage of the torch current while welding [Figure 7]. [6] The welder must simultaneously control the torch and the foot pedal while manually feeding filler rod into the weld. This process will create no spatter or slag and is the cleanest type of welding process because it requires no clean up. However, it requires a lot of pre-weld prepping and meticulous cleaning of the material, or a weak weld will result. When there are tight or hard to reach spots this welding process becomes very difficult because of the coordination it requires to perform correctly.

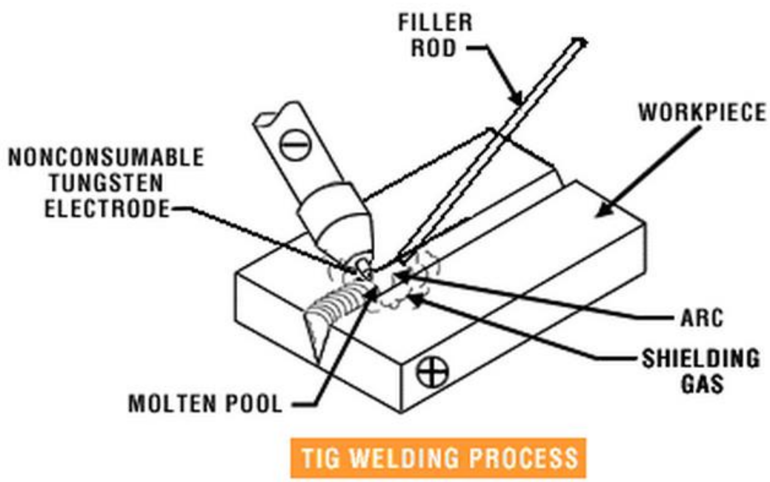

Figure 7: Gas Tungsten Arc Welding

GMAW (also known as metal intert gas, or MIG) welding is process that uses an electrode holder and a ground with a constant wire fed through the electrode holder, as shown in Figure 8. [7] A wire continously feeds through the electrode holder, eliminating the need for the welder to add filler by hand. The electrode holder itself is also small and easy to fit in tight spaces. This type of welding requires little or no prep-work, only produces minimal spatter, and requires very little cleaning after welding. This is the easiest process to use in joining the different parts of the frame together because no special rod is needed and it is easy to weld at odd angles and in tight spaces. The process we choose to weld this frame is the GMAW or MIG process because it will be easier than the other processes and one process does not produce a stronger weld than the other. This is the process the team chose for the construction of the frame because of its simplicity and user-friendliness

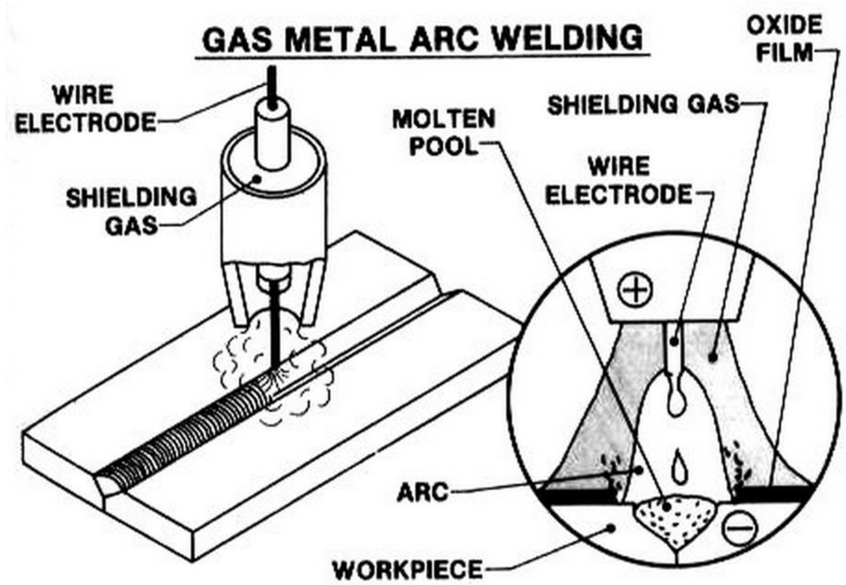

Figure 8: Gas Metal Arc Welding [8]

Project Plan

The team has finished the material selection and the constraints and requirements tasks. A sponsorships packet has also been created that the team can distribute to companies to ask for donations. Good progress is being made on all other tasks. The deadlines originally created were unreasonable and had to be moved. The preliminary frame design deadline was moved to October 28, 2013. This allowed the team to spend more time on frame design and selection. The ordering of materials was pushed back until November 8, 2013. This will allow the necessary stress analysis calculations to be performed allowing the team to make minor changes to the overall frame design before the materials will be ordered.

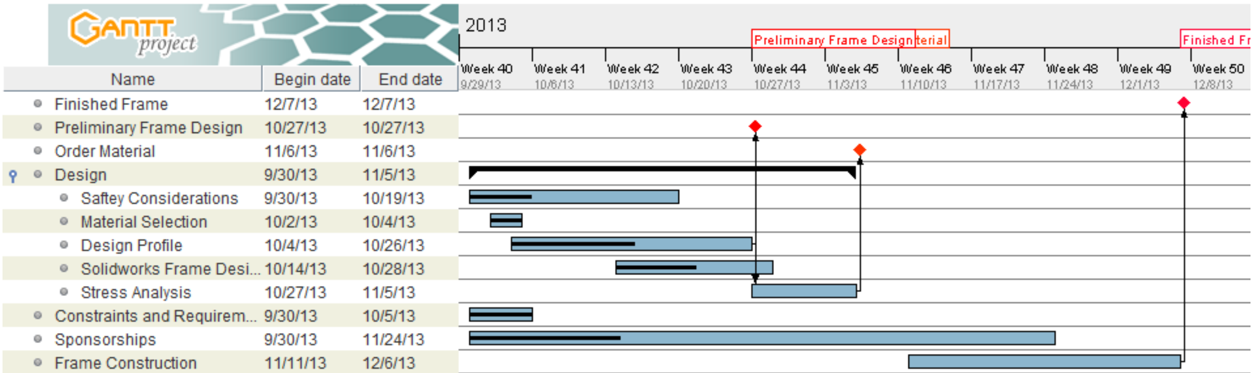

Figure 9: Team 01 Gantt chart

Conclusion

The team's goal is to build the lightest frame possible to maximize performance. The standard SAE tubing selection is AISI 1018 tubing with 1 inch diameter and 0.120 inch wall thickness. Instead of the standard tubing, the team selected AISI 4130 tubing with 1.25 inch diameter and 0.065 inch wall thickness to minimize weight. Four designs were considered for the final frame geometry. Each design was evaluated with the engineering objectives and the best design was chosen. Design two was selected as the final design as it is the lightest and is easy to manufacture. Gas metal arc welding was selected to manufacture the frame because it requires minimal setup and cleaning, and is very user friendly. Based on the team's current progress, the deadlines for final frame design selection and ordering material were unreasonable and have been moved. The team is still well on pace to finish the project on time by the end of the semester.

References

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[8] Everlast, "Arc Welding Pros and Cons," http://www.everlastgenerators.com/arc-welding-process.php, Oct. 2013.