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Material Selection Analysis for the Development of an Integrated Surface Vehicle System

Austin Pavlak
Student, austinpav@siu.edu

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A. Introduction

The basis of this project comes directly from my senior capstone design project as a graduating mechanical engineering student. The overall project itself is to develop an integrated surface vehicle system, or robot, for a Boeing competition. The robot's purpose is to be used for bomb disposal in military applications. This robot must meet certain requirements, including: a capture carry system that is able to pick up three objects of various sizes, the ability to detect and capture metal, the ability to move in various terrains, the ability to move over objects such as a log, stream live video, and a few other components. In order to fulfill as many of these requirements as possible, the robot frame design must be able to house all of the electrical circuits, motors, batteries, and other elements necessary for an operational robot. Thus, the frame must be made of a strong, rigid material that will not break under additional weight and can withhold additional stress at many different points on the frame. In working on this project, one of my subsystems involved the frame material selection and frame design that was used as the structural basis for the robot.

This report will include a researched analysis of the materials selected for the robot frame. In order to do this, a literary review will be conducted to give background on the different areas of the projects, including the different types of materials, the materials selection process, and finite element analysis (FEA). The goals and objectives of the project will then be laid out for further clarification. Next, the experimental methods will be discussed in order to clarify how the research and tests were conducted on the robot frame. The results and discussion will follow, outlining the findings of the experiment and the chosen materials. The conclusion will then reflect on the findings of the analysis as well as giving advice to future mechanical engineering students on how to go about working on a senior design project.

B. Literature Review

a. Materials Selection Process

The engineering process involves three different steps: selecting a suitable material, specifying a shape or design for the engineering problem, and determining the necessary manufacturing processes to create the design [1]. The engineering process thus begins with the material selection process.

The material selection process begins with identifying the desired attributes of the engineering problem, such as looking at the density, strength, or cost of the material for example. When looking at an engineering problem, certain design demands are required in order to fit the goals of the problem, such as a high strength material at low cost. After these attributes and demands are determined, the criterion will be compared with real life materials in order to find the best possible match. In order to keep an open mind, all materials are originally viewed as possible options for the engineering problem, which in this case is the robot frame. An overview of the materials selection process can be seen in Figure 1 on the left. The four major steps for material selection include translation, screening, ranking, and supporting information. The following paragraphs will outline each step individually within the materials selection process.

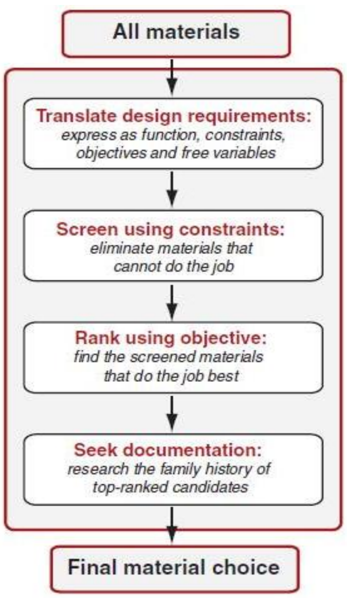

Figure 1: Materials Selection Process [2]

The first step involves translating the design requirements. This step involves taking the design requirements and translating the criterion into a material. The different components of the translation phase are seen in Figure 2. The first step in translation is deriving the function of the design. In this case, the function is the robot frame that must be sturdy enough to remain in one piece while housing all of the other components for the competition. The function of the material must then meet the given constraints of the design, such as the weight, dimensions, and other components. From here, the

objective of the design process can be determined. The objective involves what you are trying to maximize or minimize with the material choice, such as maximizing the strength of the material. In order to reach the objective of the design, there are normally certain variables that are open to interpretation and can change in order to better fit the objective. These variables are called free variables and could include allowing the thickness of a plate to vary in order to optimize the objective. The translation phase is crucial in determining what materials to select because it allows the designer to lay out all of the design requirements in order to optimize the material selection.

Function	What does component do?
Constraints*	What non-negotiable conditions must be met? What negotiable but desirable conditions . . . ?
Objective	What is to be maximized or minimized?
Free variables	What parameters of the problem is the designer free to change?

Figure 2: Translation Steps [2]

The second step in the materials selection process involves screening. In the screening phase, materials are eliminated that absolutely will not fit the engineering problem. The screening is done by looking at the constraints found in the translation phase. If a material does not meet the requirements of the design constraints, then the material is not suitable for this application. An example could be in that the constraints for a rod must meet a certain strength requirement. All of the materials that don't match this strength requirement are then eliminated from discussion because it will not fit the functionality of the design.

The next step in the material selection process involves ranking. Ranking looks at the materials that were approved during screening and see which ones best fit the objective of the engineering design. In order to do this, a material index must be derived in order to optimize the performance of the material. The material index is the best way to rank the materials that passed the screening step. The material index can reflect the performance of a single property or multiple properties depending on the design requirements and the objectives. Several examples of derived material indices can be seen in Figure 3. The first example in the figure shows a tie that has a given stiffness and wants to minimize weight. In order to rank the materials, the derived material index needs to be maximized so that the

Function, objective, and constraints	Index
Tie, minimum weight, stiffness prescribed	$\frac{E}{\rho}$
Beam, minimum weight, stiffness prescribed	$\frac{E^{1/2}}{\rho}$
Beam, minimum weight, strength prescribed	$\frac{\sigma_y^{2/3}}{\rho}$
Beam, minimum cost, stiffness prescribed	$\frac{E^{1/2}}{C_m \rho}$
Beam, minimum cost, strength prescribed	$\frac{\sigma_y^{2/3}}{C_m \rho}$
Column, minimum cost, buckling load prescribed	$\frac{E^{1/2}}{C_m \rho}$
Spring, minimum weight for given energy storage	$\frac{\sigma_y^2}{E \rho}$
Thermal Insulation, minimum cost, heat flux prescribed	$\frac{1}{\lambda C_p \rho}$
Electromagnet, maximum field, temperature rise prescribed	$\frac{C_p \rho}{\rho_e}$

Figure 3: Examples of Derived Material Indices [2]

best material can be selected. The material index maximizes the property groups for the required design and many can be derived depending on the situation. These indices provide excellent criterion that make it easier to rank materials that can work for the needed design.

The final step in the material selection process involves finding the proper supporting information. In this phase of the process, more research is conducted on the selected material to see if there is anything you need to know about the material before you select. This step looks to find the strengths and weaknesses of the material to make sure it is a good fit for the problem. An example of supporting information could involve finding out that wood is not a commonly used material choice in a heat sink but rather aluminum alloys are more commonly used [2]. Both materials meet the design requirements but it might be a smarter choice to select aluminum in this situation.

After going through these four steps in the Ashby material selection process, a proper material can be found to fit the need of the engineering problem. The next section will analyze the different types of materials and properties as well as commonly used material choices for robots already available in the industry.

b. Robot Materials and Properties

i. Material Properties and Material Families

Materials are categorized into several different families, including metals, polymers, ceramics, elastomers, glasses, and hybrids. Each material family is distinguishable by having different features or properties in common. As noted in the material selection process section, the properties of a material are what is desired, not the material itself [2]. This section will first start out by giving a background into the different types of properties used to distinguish materials and then will analyze each different type of material family.

Material properties can be divided into several different subsections, including mechanical, thermal, electrical, optical, environmental, general, and several other subsections, as can be seen in Figure 4. For the purpose of this report, only the general and mechanical properties will be discussed as these properties actually relate to the properties of a robot frame.

Figure 4: Material Properties [2]

Class	Property	Symbol and units	
General	Density	ρ	(kg/m^3 or Mg/m^3)
	Price	C_m	($/kg)
Mechanical	Elastic moduli (Young's, shear, bulk)	E, G, K	(GPa)
	Yield strength	σ_y	(MPa)
	Ultimate strength	σ_u	(MPa)
	Compressive strength	σ_c	(MPa)
	Failure strength	σ_f	(MPa)
	Hardness	H	(Vickers)
	Elongation	ε	(–)
	Fatigue endurance limit	σ_e	(MPa)
	Fracture toughness	K_{1C}	($MPa.m^{1/2}$)
	Toughness	G_{1C}	(kJ/m^2)
	Loss coefficient (damping capacity)	η	(–)
Thermal	Melting point	T_m	(C or K)
	Glass temperature	T_g	(C or K)
	Maximum service temperature	T_{max}	(C or K)
	Minimum service temperature	T_{max}	(C or K)
	Thermal conductivity	λ	(W/m.K)
	Specific heat	C_p	(J/kg.K)
	Thermal expansion coefficient	α	(K^{-1})
	Thermal shock resistance	ΔT_s	(C or K)
Electrical	Electrical resistivity	ρ_e	(Ω.m or $\mu\Omega$.cm)
	Dielectric constant	ε_d	(–)
	Breakdown potential	V_b	(10^6 V/m)
	Power factor	P	(–)
Optical	Optical, transparent, translucent, opaque	Yes/No	
	Refractive index	n	(–)
Eco-properties	Energy/kg to extract material	E_f	(MJ/kg)
	CO_2/kg to extract material	CO_2	(kg/kg)
Environmental resistance	Oxidation rates	Very low, low, average,	
	Corrosion rates	high, very high	
	Wear rate constant	K_A	MPa^{-1}

The first section of properties is the general properties that include density and price. The density of a material is the mass per unit volume of the material shape. Density can be

used when trying to determine the weight of a material. The price of a material is the cost per unit weight of the material. This property is fluctuates as the market and economy change for that given material and is looked at when the price is a constraint on the design material.

The other section to be discussed involves mechanical properties. The first property is the elastic modulus, which is the slope of the linear elastic line on the stress-strain curve and describes a materials response to compression or tension loads [2]. The elastic modulus, or Young's modulus, is important in knowing how much a material will deform. The next property is strength, which varies in definition depending upon the material. Strength is defined by looking at the stress, which is defined as the amount of force per surface area that the material can withhold. Strength can be looked at in various forms, such as fracture strength, compressive strength, ultimate strength, and failure strength. Another way to measure the strength is by looking at the hardness of the material, which is defined as the force used to indent the material over the projected area of the indent [2]. These mechanical properties are important in determining what type of material is needed to match the engineering design.

With the material properties in mind, it is now appropriate to discuss the different types of materials. As noted before, there are several different types of materials, including metals, polymers, ceramics, glasses, elastomers, and hybrids. The material families and some of their most common members are seen in Figure 5. Metals generally have a very high modulus of elasticity and can easily deform. In order to strengthen metals, alloying or heat treatment methods can be utilized. Metals are also rather ductile, thus making metals prone to fatigue and are also not very resistant to corrosion. Polymers are the opposites of metals in that they have a low modulus of elasticity while still being strong. Polymers will deflect, however, if under a constant load. Using polymers is significantly related to the surrounding environment temperature that the polymer will be in. Polymers are very useful in strength to weight situations and are very easy to work with in the industry. Ceramics are similar to

metals in that they have a high modulus of elasticity but are much more brittle. Ceramics have a small tolerance for stresses because ceramics have no ductility in comparison to metals. Thus, ceramics are not as strong as metals, but have benefits such as stiffness, hardness, and abrasion resistance. Glasses are non-crystalline or amorphous solids [2]. Glasses are very similar to ceramics in that they do not have a crystal structure, which reduces their plasticity. Therefore, glasses are very hard and brittle, but are susceptible to stress that can cause the glass to deform and break. The next material group involves elastomers, which are long chain polymers. Elastomers can have a very low modulus of elasticity and are very elastic. Elastomers have very unique properties and are very different than the other material families, making them difficult to test in comparison to other materials. The final material family includes hybrids, which are the combinations of different materials. Hybrids are created to maximize the necessary properties while minimizing the weaker properties of materials to make the perfect material. The biggest drawback to hybrids is that they are generally more expensive than other materials, which can leave the designer in a predicament in choosing the best material while at a reasonable cost.

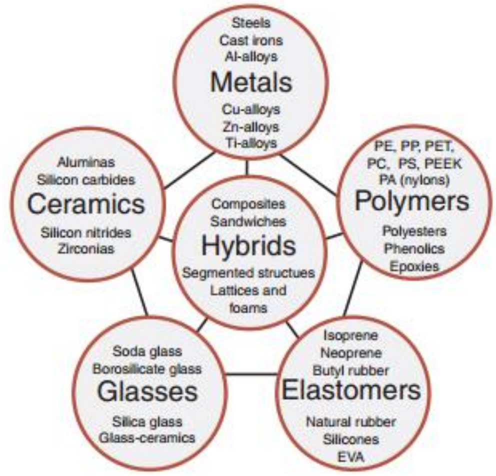

Figure 5: Material Families [2]

ii. Robot Frame Materials

Robotic frames are generally made out of four different types of materials: wood, plastic, metal or composites [3]. These different materials vary with the function, size, cost, and weight of the robot design requirements. Robots also come in various sizes as well, whether the body type is round, oval,

square, or other shapes. When choosing the frame materials, it is important to know how easy the material is to machine and shape into the frame.

The first robot frame material is wood. Wood is used mainly because it is relatively cheap and does not require special equipment. In general, hard woods such as ash or birch are used because of their strength while softer woods like pine and fir are avoided. Oak also isn't widely used because of its weight and difficulty to cut. The next robot frame material is plastic. Plastic robot frames are generally made more at manufacturing plants because it is easy to mold plastic into a desired shape. Injection molding is the most commonly used process for making plastic frames, but this process is not accessible to the do it yourself robot designers. For these robot makers, plastic sheets, bars, and rods are purchases and then worked on to make the frame. The most common plastics used for robot framework include acrylic, polycarbonate, PVC, urethane resin, and acetal resin [3]. Acrylic and polycarbonate do not have as much strength in comparison to these other plastics and are more difficult to work with. PVC, urethane resin, and acetal resin all are much stronger but do not have the same strength capabilities as most metals. Another robot frame material is your standard metal frame. Metal tends to be a little more expensive than the wood and plastic materials. Metal frames are most commonly used on battle bots as well as robots that are designed for outdoor use. The most common metal frames are aluminum and steel. Aluminum is a much softer metal and is easy to work with, but steel is a much stronger material. The final most common robot frame material includes composites. Composite frames can include laminated material, fiberglass and resin, and carbon or graphite materials. The laminated material generally combines wood, paper, plastic, or metal to allow the best properties to be brought out in order to increase the strength and rigidity [3]. A common laminate material would be foam. For fiberglass and resin, filler materials such as metals or carbon are added in order to increase the strength of the material. The final composites include carbon and graphite, which

increase the strength of the material and do not need to be matched with other material components. These common robot materials will be further analyzed throughout the report.

c. Finite Element Analysis (FEA)

Computer Aided Design (CAD) is a tool that facilitates a computer based engineering approach to the design and stress analysis of mechanical engineering systems [4]. The use of CAD programs is becoming more and more prevalent in the engineering profession. AutoCAD programs allow a designer to design a system or part and then test this system using finite element analysis, stress analysis, or computer geometric modeling. Engineering systems can then be created using machining centers, lathes, mills, or prototyping machines based on the AutoCAD drawings of the systems. The finite element analysis feature in Autodesk Inventor will be utilized in testing the materials and loads on the robot frame.

Finite element analysis (FEA) is a tool that provides basic stress analysis on a designed system [4]. FEA allows the designer to examine the effects of various applied forces and moments on the design using an AutoCAD program. The program gives the displacements, strains, and stresses in a part that can then be compared to various material properties, loads, and fixtures. The testing can be used to identify failure areas within the design, critical stress areas, safety factors, and various other features. FEA includes the analysis of the finite element method. The finite element method is a numerical method that calculates approximate solutions on a complex three dimensional drawing. In the finite element method, the complex system or part is modeled so that mathematical equations can be developed to describe the system.

C. Goals

The goal of this project is to select the proper material for the frame design of this senior design project. The frame material needs to be light weight and cost effective in order to allocate finances towards other aspects of the project. The frame must be smaller than 2 ft^3, have a high strength (preferably greater than 50 MPA), and corrosion resistant as well. The frame must be rigid and strong enough to withstand the loads applied from the capture carry system, batteries, motors, and control systems as well as the rigors of the terrain. Another main goal of this project is to learn about the material selection process and be able to utilize this knowledge when designing parts in the future. Project management skills will also be learned through working with a multi-disciplinary team of engineers with various skills and knowledge in regards to designing and building a functional integrated surface vehicle.

D. Experimental Methods

The experimental methods for this study starts with the materials selection process. Each phase of the materials selection process will be analyzed, starting with the translation phase. After the translation phase, screening, ranking, and gathering supporting information will be completed for the frame. The top choices for materials will not only be analyzed using the materials selection process, but also by using FEA in AutoCAD Inventor. The 3-D model of the robot frame will be made in Inventor and then undergo stress analysis for each material type. This stress analysis shows extra information in how the frame will withstand applied loads and stresses in a simulated environment. Once the FEA is completed, the final material will be selected for the robotic frame.

E. Results and Discussions

a. Translation

The translation phase in the materials selection process lays out the design requirements for the robot frame. The translation steps are seen in Table 1 below.

Table 1: Translation Phase

Translation Step	Explanation
Function:	Robot Frame
Constraints:	Must be smaller than 2 ft^3, high strength (greater than 50 MPa), corrosion resistant, cost effective
Objective:	Minimize cost and weight
Free Variables	Choice of material, material thickness

Now that the function, constraints, objective, and free variables are defined, the material indices for the frame can be derived. Figure 6 below outlines the equations used in deriving the material index for minimum mass and minimum cost with respect to the material strength. In looking at the robot frame, the frame was determined to be similar to a flat plate, making it easier to derive the material indices. Equations 1-4 are equations that correspond with both the mass and cost of the frame. Equation 1 is a simple mass equation that relates the cross sectional area of the plate, the length of the plate, and the density of the material. Equation 2 is a yield stress equation that relates the applied force on the plate, the length of the plate, the width of the plate and the thickness of the plate. Equation 3 is the moment of inertia for a flat plate while equation 4 recognizes the cross sectional area of the plate as width times thickness. In looking at the minimizing mass index, equation 5 rearranges

$$m = AL\rho = wtL\rho \ (1)$$

$$\sigma_y = \frac{Mt}{2I} = \frac{3FL}{wt^2} \ (2)$$

$$I = \frac{wt^3}{12} \ (3)$$

$$A = wt \ (4)$$

Minimum Mass:

$$t = \left(\frac{3FL}{\sigma_y w}\right)^{1/2} \ (5)$$

$$m = w\left(\frac{3FL}{\sigma_y w}\right)^{\frac{1}{2}} * L\rho \ (6)$$

$$m = (3Fw)^{\frac{1}{2}} * L^{\frac{3}{2}} * \left(\frac{\rho}{(\sigma_y)^{1/2}}\right) (7)$$

Material Index: $\frac{\sigma_y{}^{1/2}}{\rho}$

Minimum Cost:

$$t = \left(\frac{3FL}{\sigma_y w}\right)^{1/2} \ (8)$$

$$C = m * c_m = c_m \rho wtL \ (9)$$

$$C = c_m \rho wL \left(\frac{3FL}{\sigma_y w}\right)^{\frac{1}{2}} (10)$$

$$C = (3Fw)^{\frac{1}{2}} * L^{\frac{3}{2}} * \left(\frac{\rho c_m}{(\sigma_y)^{1/2}}\right) (11)$$

Material Index: $\frac{\sigma_y{}^{1/2}}{c_m \rho}$

Figure 6: Derivation of Material Indices

equation 2 in order to solve for the thickness since the thickness of the plate is a free variable. Equation 6 is the result of substituting equation 5 into equation 1 in order to eliminate the thickness term. Equation 7 is a simplified version of equation 6 that groups the material properties together in order to determine the material index. The material index for minimum weight is determined to be $\frac{\sigma_y{}^{1/2}}{\rho}$ and must be maximized in order to achieve the design requirements. In looking at the minimizing cost index, equation 8 is the same as equation 5 in that it solves for the thickness. Equation 9 shows the cost function as mass times the price (C_m). From here, equation 10 is the result of substituting equation 8 into equation 9 in order to eliminate the thickness term. Equation 11 is a simplified version of equation

10 that groups the material properties together in order to determine the material index. The material index for minimum cost is determined to be $\frac{\sigma_y^{1/2}}{c_m \rho}$ and must be maximized in order to select the proper material that achieves the design requirements.

b. Screening

Figures 7 and 8 below are material properties charts for mass and weight with respect to strength. These charts were chosen because they align with the desired material properties found in the material indices. The horizontal black line represents the 50 MPa requirement determined in the translation phase. All materials above this line in both charts would meet the strength requirements. The slanted line represents the material index for that chart. The farther to the left the line is, the stronger the material index will be. All of the materials on that line will have the same material index.

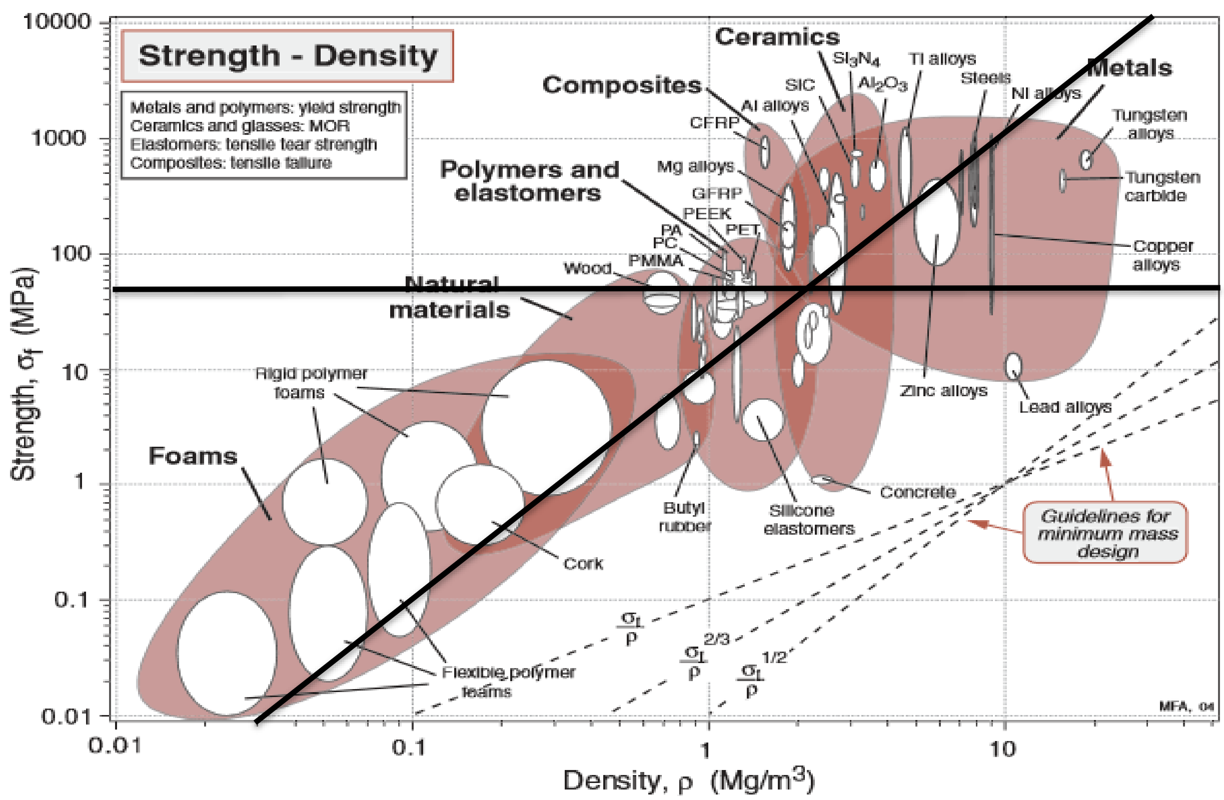

Figure 7: Strength vs. Density

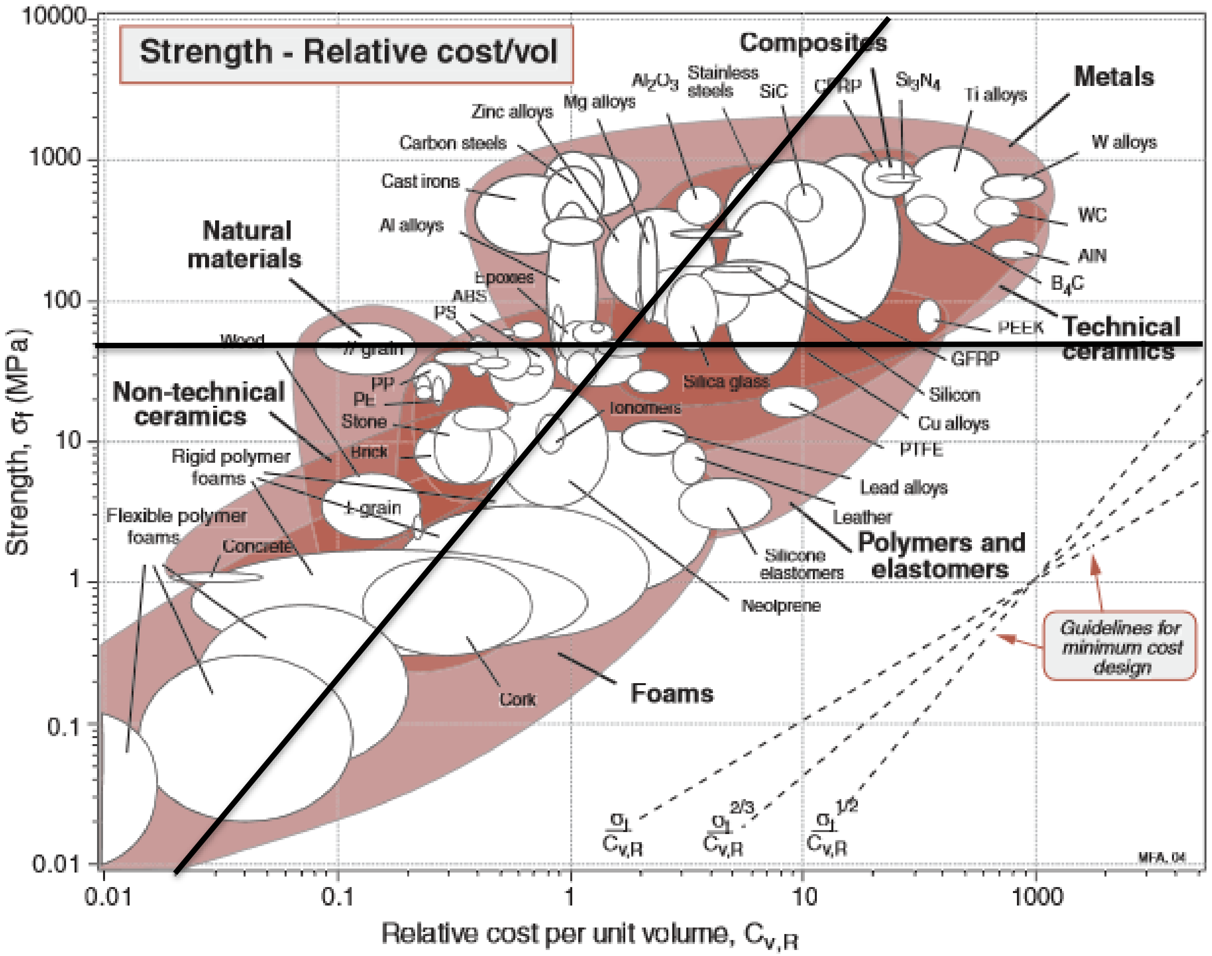

Figure 8: Strength vs. Relative cost/vol

Figure 9 below gives a representation of the usual cost per unit volume in regards to several different material families. This figure is helpful when distinguishing prices between materials within a specific material class or a between material classes.

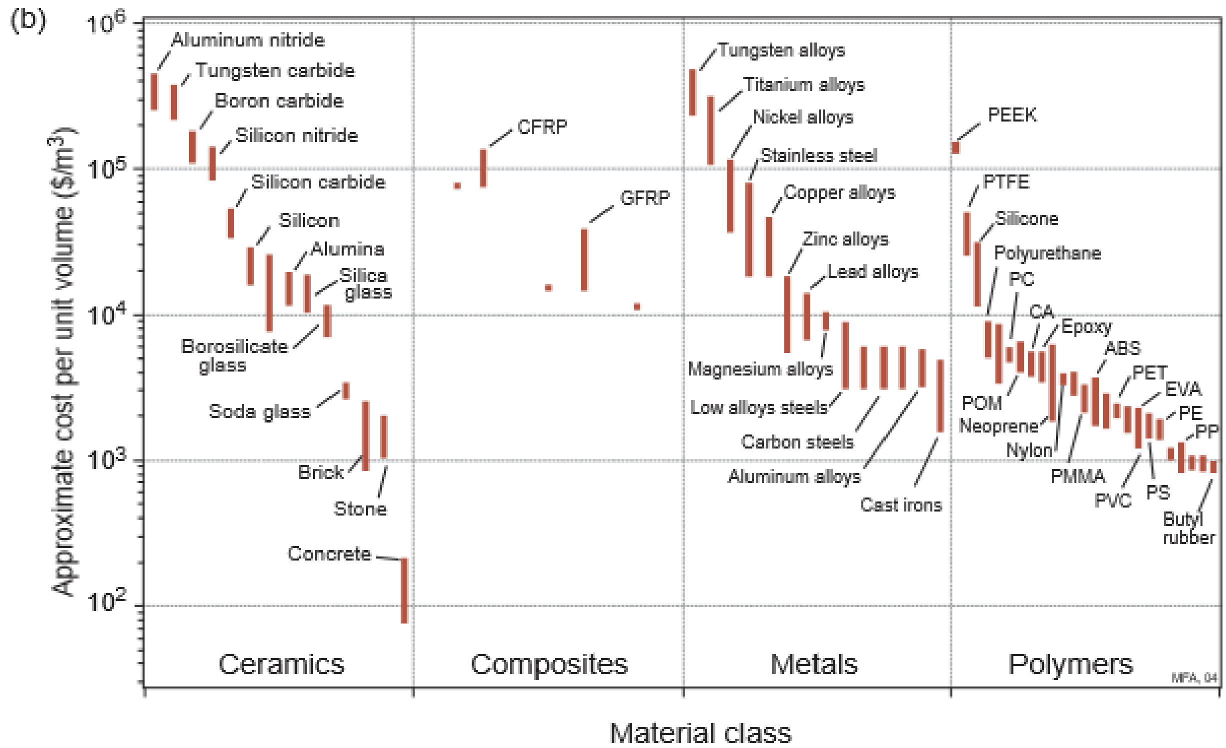

Figure 9: Cost/vol vs. Material Class

c. Ranking

In looking at the lines on Figure 8, it was determined that some of the suitable materials included wood, aluminum alloys, magnesium alloys, titanium alloys, CFRP, GFRP, steels, and a few others. All of these materials have the necessary strength while also being relatively lightweight. In looking at the lines located on Figure 9, it was determined that acceptable materials would include wood, cast iron, aluminum alloys, and carbon steels. These materials are all relatively low cost while still meeting the strength requirements for the robot. In order to meet the design requirements, a material that meets both the low cost and low weight requirements must be selected. The only materials that fit this description include wood, aluminum alloys, and steel. A ranking chart of these three materials is shown below in Table 2.

Table 2: Material Ranking

Wood	Aluminum Alloys	Steel
• Lightest weight • Strongest material index • Barely meets strength requirements • Slightly cheaper	• Light weight • More strength than wood • Good material index • Corrosion resistant • Relatively low cost	• Heaviest of the three materials • Strongest material • Good material index • About the same price as aluminum

d. Supporting Information

As noted in the literature review section, aluminum, steel, wood, and plastics are the most commonly used materials for robot frames. The materials selection verified all of these materials except for plastic. Most of the plastics did not meet at least one of the strength, weight, and cost requirements. If wood were to be selected, it would need to be a strong yet lightweight wood such as ash or birch. These woods have an excellent strength to weight ratio, but are on the more expensive side. If cheaper plywood was selected, the wood would be light and cheap, but might show fatigue and cracking when under stress or an applied load. Aluminum is a material used for rugged outdoor use robot frames. Aluminum is a soft metal and is very easy to work with. Aluminum can be bought at any local hardware store and is stronger than wood while also being more corrosion resistant. Steel is another material used for outdoor robots. Standard steel is a harder metal than aluminum and is also a stronger material. Sheet metal steel is very accessible and can be found at any local hardware store. Steel is also relatively cheap and is not a difficult material to work with in a machine shop. All three of these materials would be suitable for the robot frame.

e. FEA Simulation

Now that the robot frame material has been limited to three different materials, an FEA simulation will be conducted on each type of material. First, the constraints and forces will be described

to give a better idea of what the figures mean. The Von Mises stress is the three-dimensional stresses and strains built up on the model in various directions. The 1st principal stress is the value of the normal stress to the plane where there is no shear stress and represents the maximum tensile stress on the part [5]. The 3rd principal stress is the same as the 1st principal stress but differs in that the stress represents the maximum compressive stress instead. The displacement results show how much the part will deform from the original shape. Finally, the safety factor shows the different areas where the model could potentially fail under the given loads. There are a few different types of loads as well on the models. The loads on the bottom four legs represent the bearing loads from the axles holding the tread sprockets. The load on the front of the robot is the weight of the arm. The load in the middle is the gravitational load of the entire body while the load at the back of the robot is the weight of the battery. The bearing loads are 0.5 pounds, the load of the arm is 5 pounds, and the load from the battery is 5 pounds as well. The only constraints on the frame is on the underneath part of the side plate. In addition, it is important to note that the displacement images are over-emphasized in order to show the effects of the loads on the frame. The color scale also gives a visual representation of what is acceptable on the design. The blue colors represent very good elements in the design while red areas represent areas for improvement. FEA simulations are conducted for each material and are shown in the following sections. The final frame design is shown in the figure below.

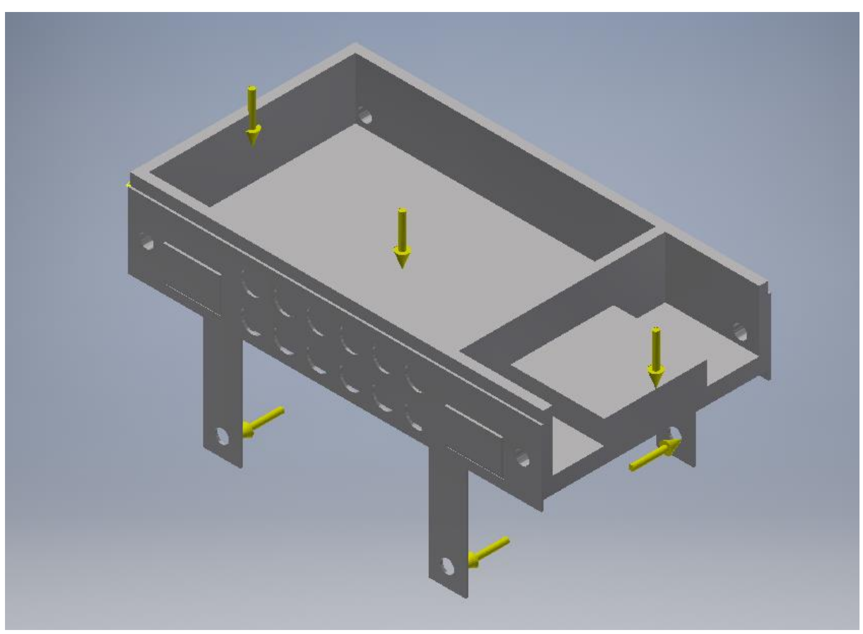

Figure 10: Final Frame Design

i. Steel Alloy

The following figures show the FEA simulations using steel alloy as the material.

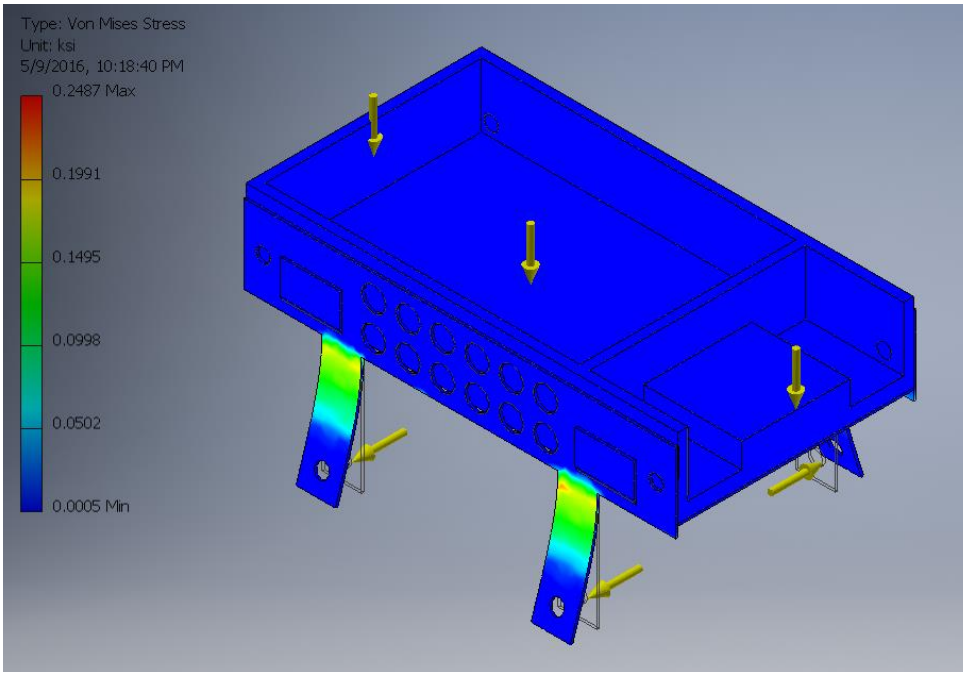

Figure 11: Von Mises Stress - Steel

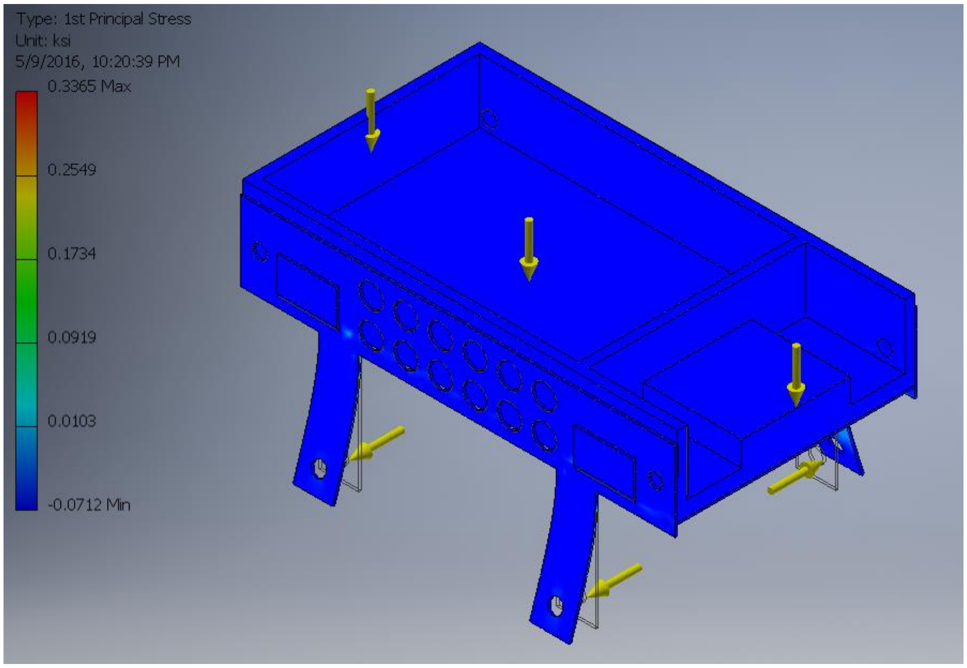

Figure 12: 1st Principal Stress - Steel

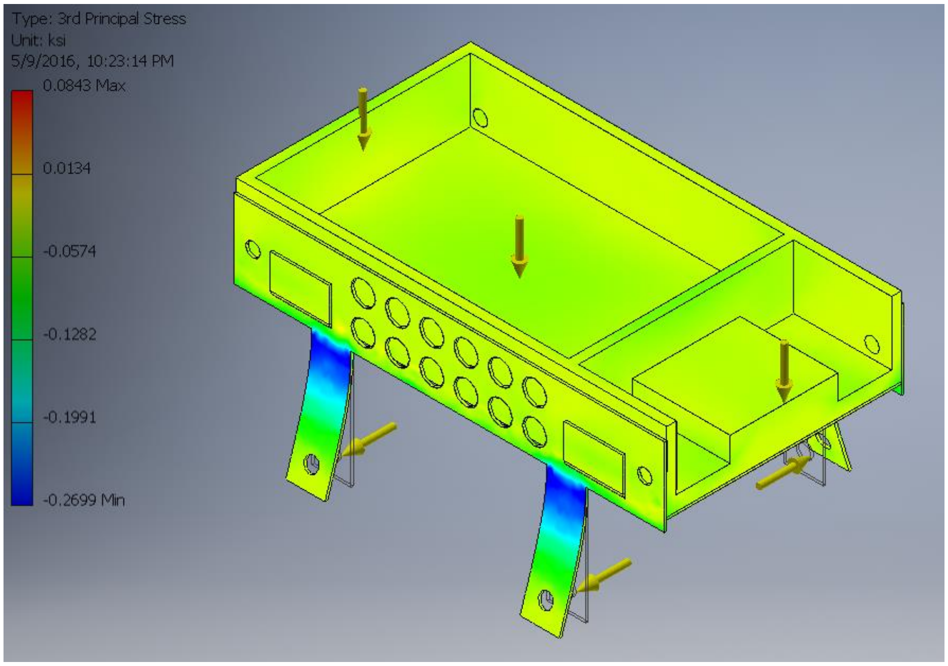

Figure 13: 3rd Principal Stress - Steel

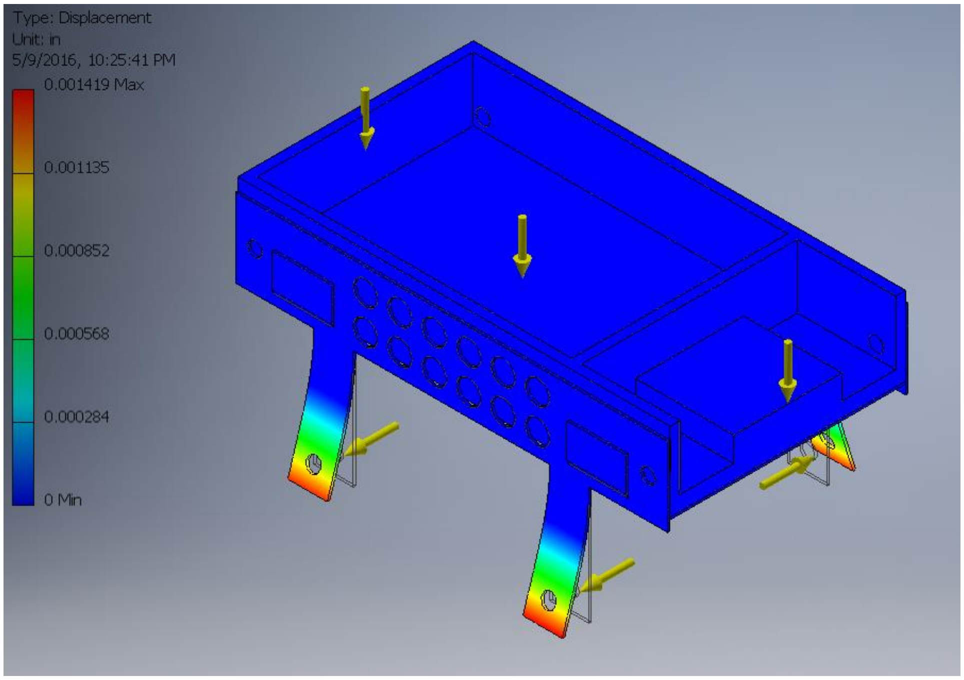

Figure 14: Displacement - Steel

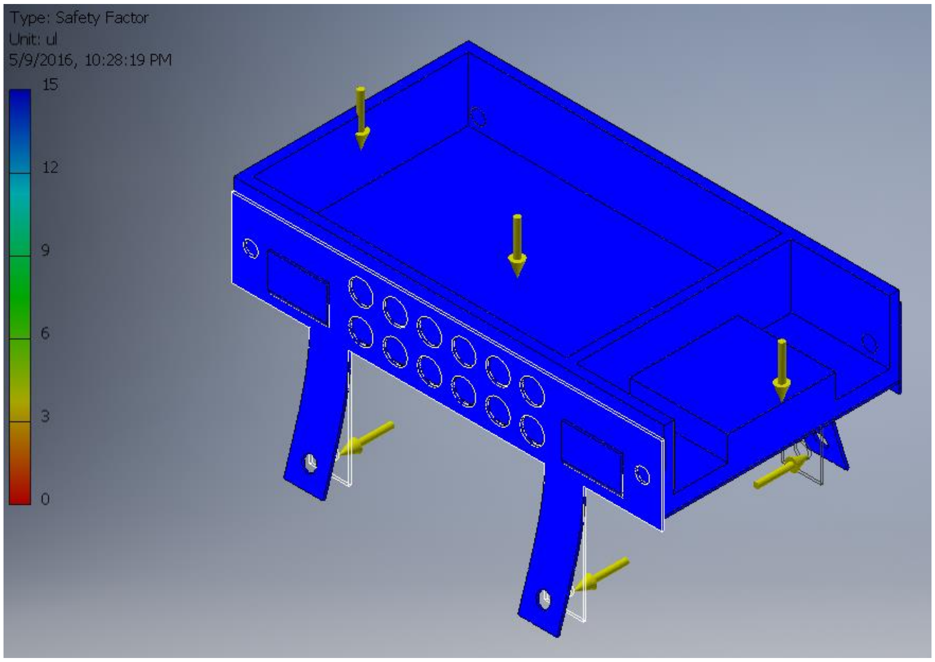

Figure 15: Safety Factor – Steel

Table 3: Steel Alloy Properties

Name	Steel, Alloy	
General	Mass Density	0.279264 lbmass/in^3
	Yield Strength	36259.4 psi
	Ultimate Tensile Strength	58015.1 psi
Stress	Young's Modulus	29732.7 ksi
	Poisson's Ratio	0.3 ul
	Shear Modulus	11435.7 ksi

ii. Aluminum 6061 Alloy

The following figures show the FEA simulations using aluminum 6061 alloy as the material.

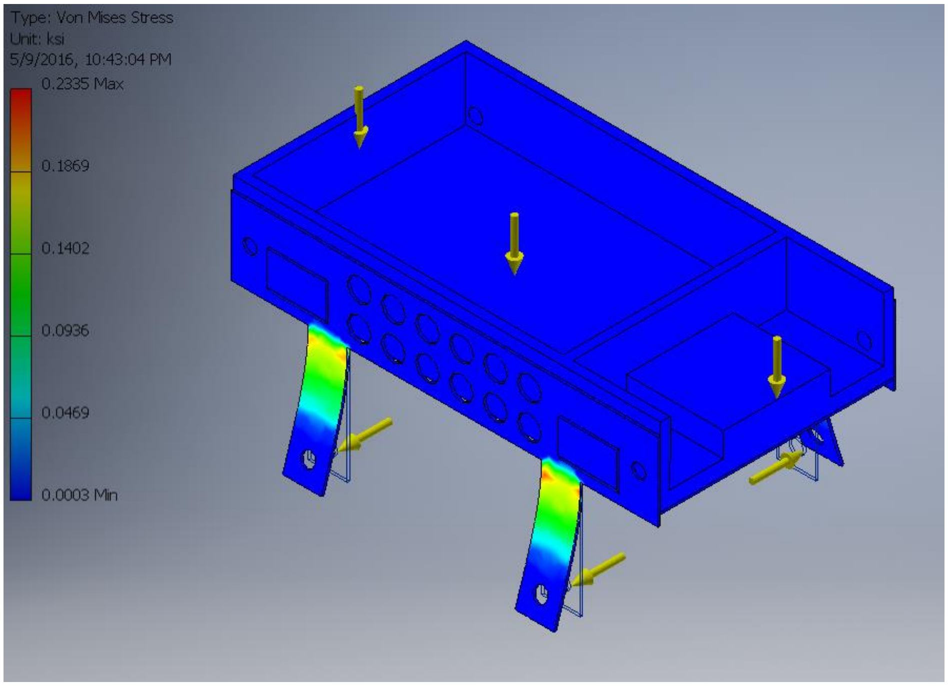

Figure 16: Von Mises Stress - Aluminum

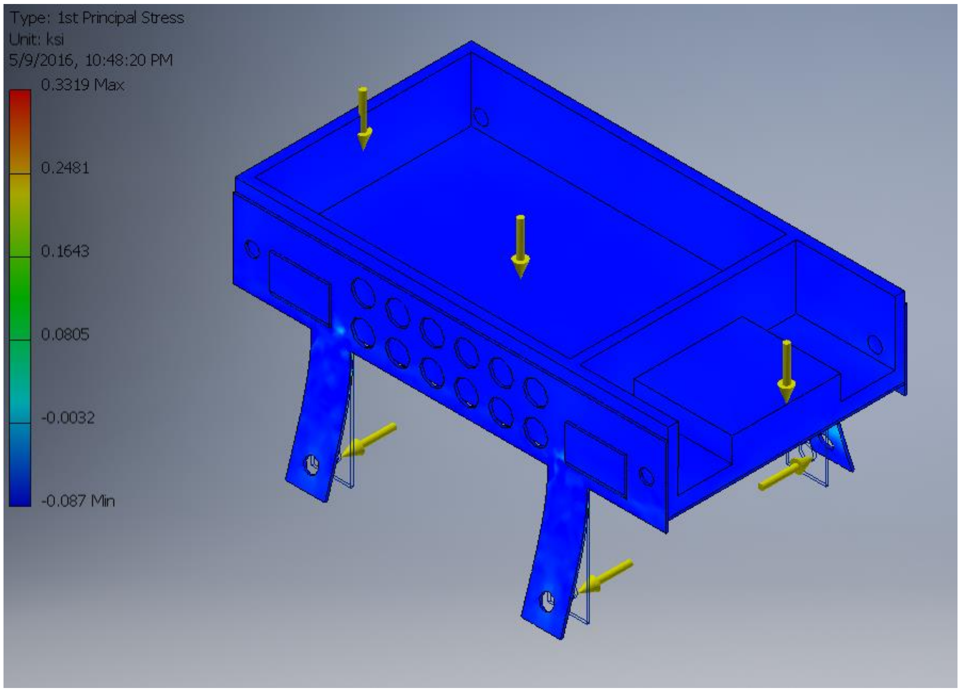

Figure 17: 1st Principal Stress – Aluminum

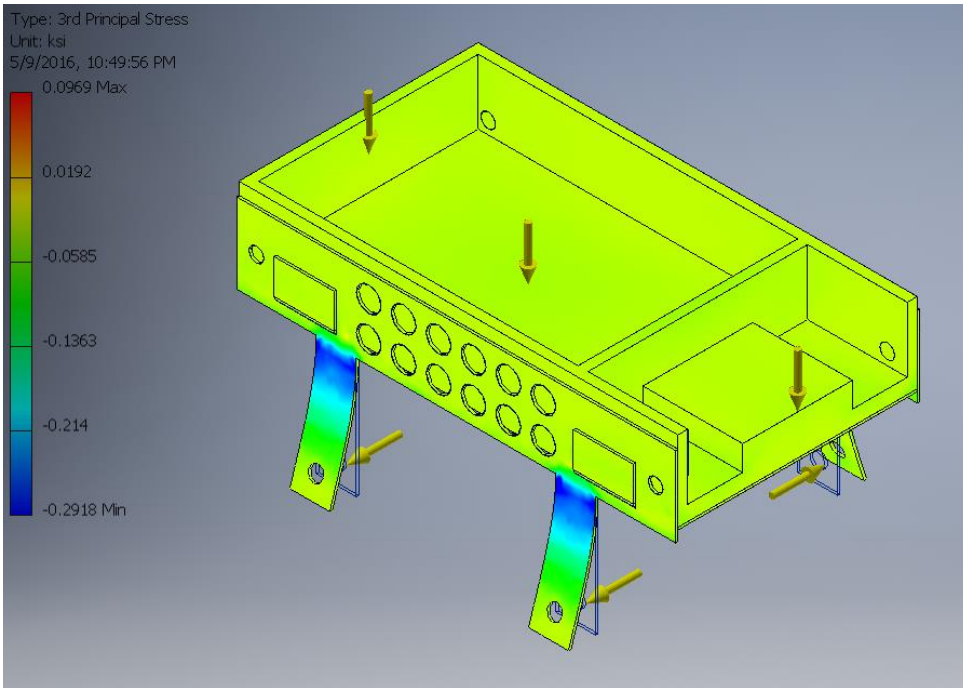

Figure 18: 3rd Principal Stress - Aluminum

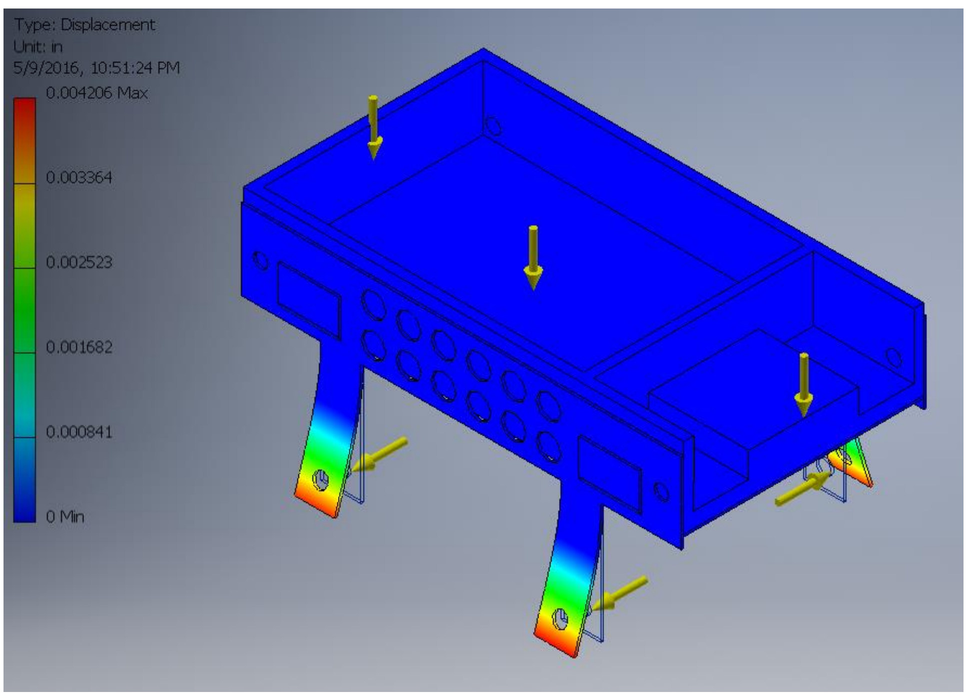

Figure 19: Displacement - Aluminum

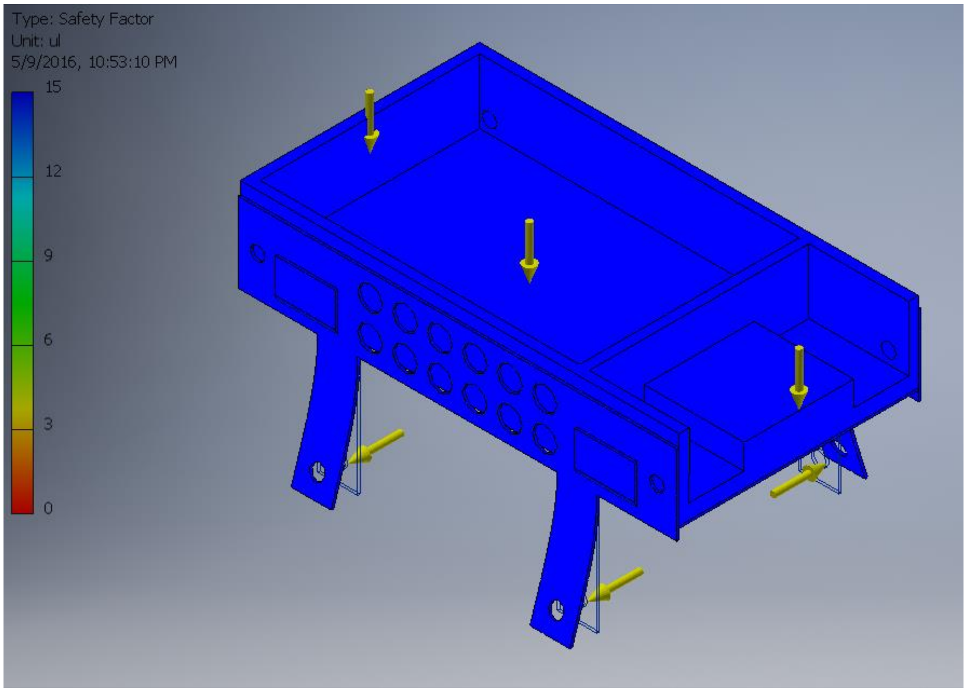

Figure 20: Safety Factor - Aluminum

Table 4: Aluminum 6061 Properties

Name	Aluminum 6061	
General	Mass Density	0.0975437 lbmass/in^3
	Yield Strength	39885.4 psi
	Ultimate Tensile Strength	44961.7 psi
Stress	Young's Modulus	9993.1 ksi
	Poisson's Ratio	0.33 ul
	Shear Modulus	3756.8 ksi

iii. Birch Wood

The following figures show the FEA simulations using birch wood as the material.

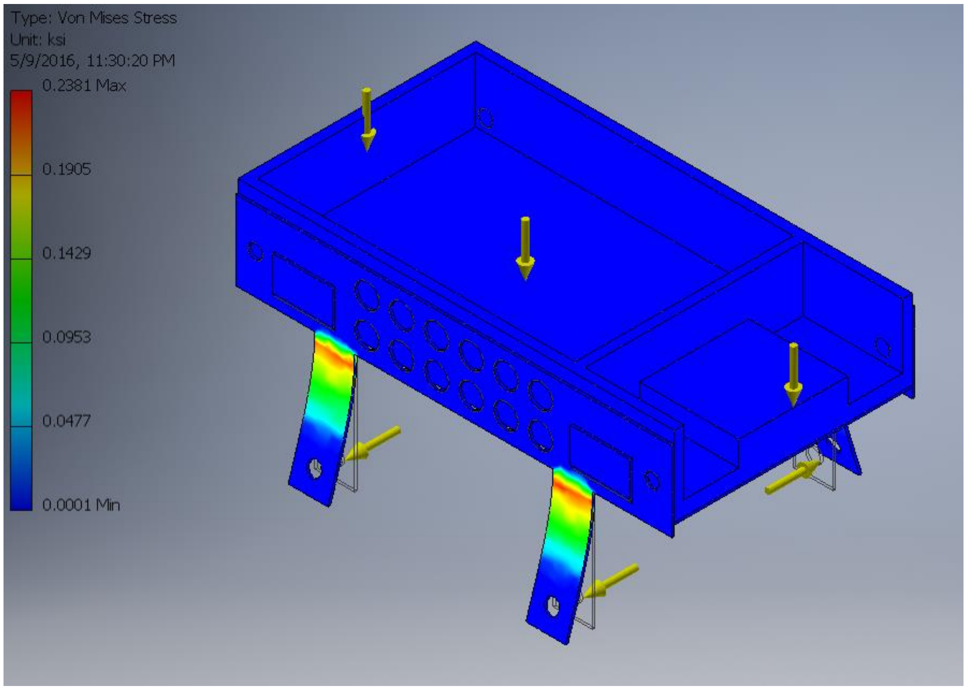

Figure 21: Von Mises Stress - Wood

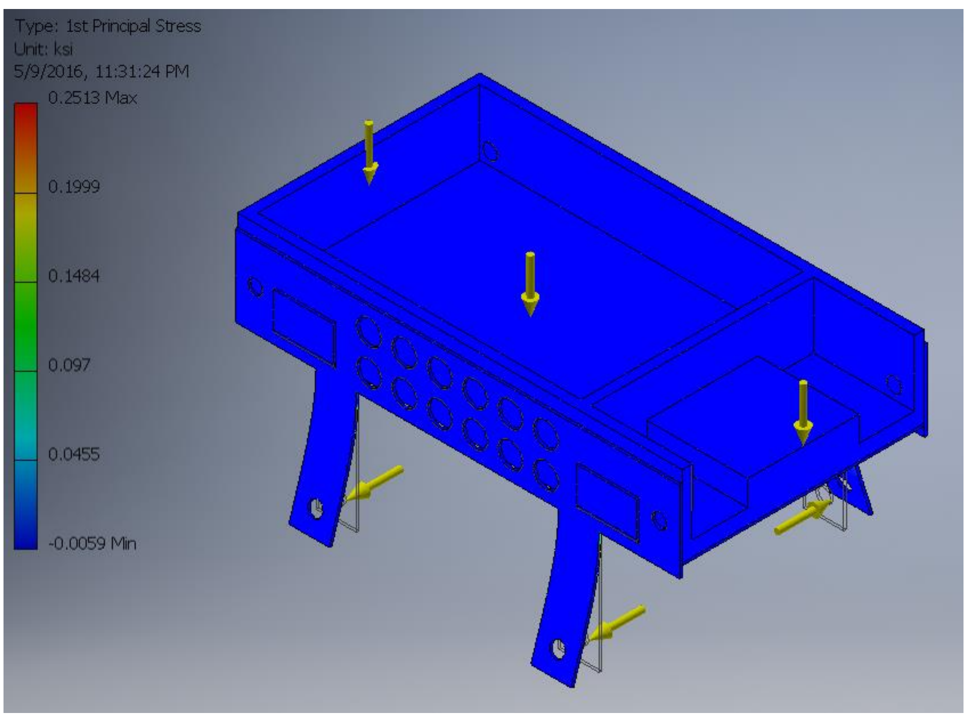

Figure 22: 1st Principal Stress - Wood

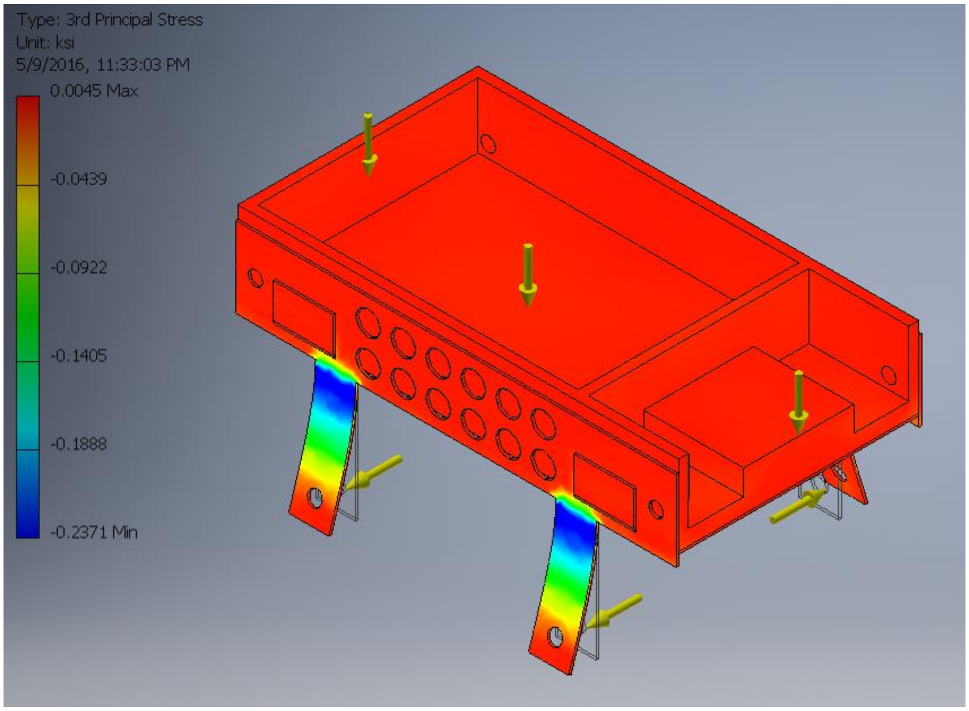

Figure 23: 3rd Principal Stress - Wood

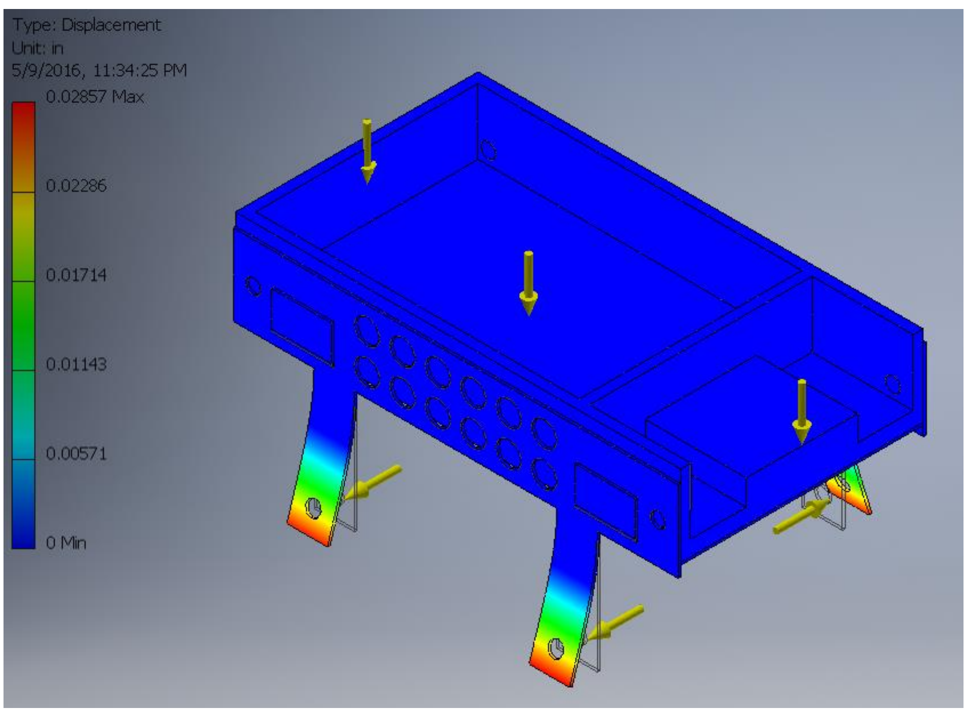

Figure 24: Displacement - Wood

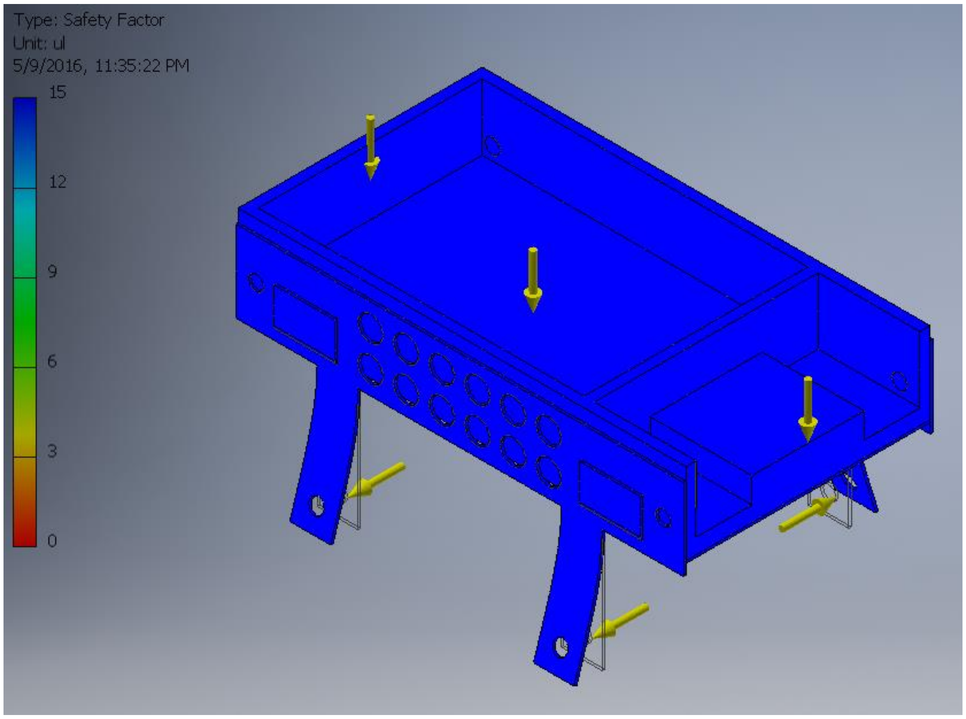

Figure 25: Safety Factor - Wood

Table 5: Birch Wood Properties

Name	Birch Wood	
General	Mass Density	0.0198698 lbmass/in^3
	Yield Strength	8166.67 psi
	Ultimate Tensile Strength	913.889 psi
Stress	Young's Modulus	1493.75 ksi
	Poisson's Ratio	0 ul
	Shear Modulus	746.875 ksi

f. Evaluation

Wood, aluminum, and steel are all suitable materials for the robot frame. All of these materials had very minor deformations in looking at the FEA simulations but all of them saw the most stress when looking at the compressive loads. In looking at the FEA simulations, it is determined that wood is not as suitable of a material. In the 3rd principal stress test for the birch wood, the compressive stresses were very high throughout the frame and thus could cause issues when the final frame is constructed. In

addition, both aluminum and steel have higher strengths and are more durable for the rugged terrain. Wood is slightly cheaper and less weight, but doesn't meet the corrosion requirements. In looking at the FEA simulations for aluminum and steel, the results are very similar. The main differences are that aluminum weighs less than steel but doesn't have as much strength. The cost of both aluminum 6061 and sheet metal steel are about the same, thus making these materials interchangeable for this design. It was decided that sheet metal steel would be selected for the frame because it was available free of charge. Although steel weighs more than aluminum, the free charge on the sheets made steel the overwhelming choice for the robot frame material.

F. Conclusion

In conclusion, standard steel sheet metal was selected as the material of choice for the robot frame. The steel frame has a very high strength, a very low cost, and is relatively light weight. The material selection process was crucial in selecting the right material for this frame. FEA simulations were also very beneficial in creating an environment that allowed the different materials to be tested on the same frame design without having to build each individual frame. Either wood, aluminum, or steel could have been a suitable material for the robot frame, but steel became the best choice for the desired parameters.

In working on this senior design project, there were several takeaways that should be passed on to future students. The first takeaway is to be organized from the start. It is very important to set deadlines individually and as a group and to stick to these deadlines. The sooner your team can start building your design, the better. This will allow for my time as a team to test the project and go through any troubleshooting that is required. The second big takeaway from working on a senior design project is to communicate effectively with your group. It is very difficult to keep everybody on the same page in the selected project. Some team members will work harder than others and it is important to recognize

which students you can trust to get the job done correctly. Communicating effectively with your teammates will improve how well you project performs at the final evaluations. With this advice, hopefully future students will be prepared for what to expect in working on their senior design project as a graduating engineering student.

G. Acknowledgements

I would like to thank the following people for their contributions throughout this project. Dr. Peter Filip was my research mentor and was very resourceful throughout the year. He helped me outline what I should put in this report while also masterfully teaching the material selection subject to me. I would also like to thank my senior design team, particularly Chris Attaway, for helping me select the materials for the project and supporting my pursuit of this honors thesis. Chris in particular was crucial in making the frame for the robot with me as well as helping me on other mechanical systems for the entire project.

H. References

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