EML 4905 Senior Design Project

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REQUIREMENT FOR THE DEGREE OF
BACHELOR OF SCIENCE
IN
MECHANICAL ENGINEERING

3G Panther Drone
Final Report: 100% Report

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Ethics Statement and Signatures

The work submitted in this B.S. thesis is solely prepared by a team consisting of DANIEL GONZALEZ, JORGE MAR, and EDUARDO VARGAS and it is original. Excerpts from others' work have been clearly identified, their work acknowledged within the text and listed in the list of references. All of the engineering drawings, computer programs, formulations, design work, prototype development and testing reported in this document are also original and prepared by the same team of students.

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Team Leader	Team Member	Team Member

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Abstract

The purpose of the project is to design, manufacture, and test a fully operating Unmanned Aerial Vehicle (UAV) with mobile Internet communication capabilities. Such UAV will be composed of four independent rotor blades and motors which will allow the device to steadily hover at a single location or move in any desired flight direction. The device will be equipped with multiple cameras in order to relay the gathered information back to a remote controller. The device will be controlled from a mobile device, such as a cell phone or tablet, located anywhere in the world provided that Internet access is available to both the device and controller.

The project will be divided into two main design parts: programming design and mechanical design. Programming design will incorporate the development of a communication link between the device and controller. This will include hardware selection, software selection, remote server application, and controller configuration. Mechanical design will incorporate the development of a stable, efficient, and durable flying device. Rotor blade selection, motor selection, and battery selection will all be important features of the project as minimal energy consumption will allow for a longer and more efficient flight. Material selection will also be a key feature as a durable and sturdy aerodynamic frame is desired. Hardware and equipment layout will be carefully analyzed as to create the most stable flight structure.

Upon completion of the final design the team will begin manufacturing the first prototype. The team will use the machine shop at Florida International University and other off campus locations to create and assemble all the necessary components. Once manufactured, the team will begin testing the device for possible upgrades. During this stage the team will focus in optimizing the design to increase the device’s flight time. The team will also focus on making the device as cheap as possible in order to make it more appealing to future clients. In order to reach a global client base, the team will develop user manuals in English, Spanish, and Japanese as well as work with SI units. Material research will also be carried out to analyze material availability in major economic areas of the world.

1. Introduction

1.1 Problem Statement

The project involved the development of an Unmanned Aerial Vehicle (UAV) with mobile Internet communication capabilities. The UAV was to be controlled from any mobile device, such as a tablet or phone, allowing the controller to be anywhere in the world while still maintaining full control of the UAV. Two cameras were to be placed in the body of the craft as to relay the visual data back to the controller. The team was free to create any other restrictions/limitations in order to make this a worthwhile project. The team felt that portability, weight, and an emergency recovery flight path, in case internet connection was lost, were three necessary restrictions/limitations.

1.2 Motivation

Natural disasters, such as hurricanes or tornadoes, can often leave trails of destruction leaving loved ones unaccounted for. It is then the job of firefighters, soldiers, police officers, or volunteers to enter a dangerous environment, risking their own lives, for the sole purpose of finding any trapped survivors. The team developed this UAV as a way to give these service men and women an extra tool that would enable them to perform their duty without risking their own lives.

As unfortunate as it sounds, war is and will always be an aspect of human nature. The team developed this UAV as a way to provide soldiers with a risk free way of gathering intelligence data. The UAV only requires direct human interaction at the point of deployment leaving all other command operations to an operator far from any danger.

1.3 Literature Survey

The application and concept of unmanned aerial vehicles has been part of aviation history since mid-1800. The first use of this concept was in the American Civil War, where explosive devices were attached to balloons that would fall into enemy's territory. A similar method was also used during World War II by the Japanese to send incendiary and other explosives to The United States. Apparently, both ideas were not effective. During World War II the United State created a prototype UAV called Operation Aphrodite which was an operation to convert manned vehicles to unmanned configuration. However, the US did not possess the technology in order to carry this operation to launch or control the aircraft. The unmanned vehicles used only for spying and reconnaissance were developed by the US in 1960s. The first drone was called the "Firebee" drone, a jet propelled engine made by the Ryan Aeronautical Company. Firebee was heavily used in communist countries such as China in the 1960s. The drones were used widely in reconnaissance and combat roles in the Vietnam War for the first time. The Firebee drones were launched for simple day reconnaissance activities with simple integrated cameras. The devices were equipped with night photo communication and electronics intelligence was integrated afterward.

Figure 1 : Firebee [1]

The desired structural condition of a UAV varies depending upon its application such as reconnaissance missions, surveillance services, or weather analysis.[2] The controlled features, such as, flight path and stability control are monitored using a remote control or pre-programmed computer software by an operator. Some UAVs have autonomous flight capabilities as their additional feature. This characteristic reduces the human task to command and navigate the device.

The United States and Israel are the current leaders in UAV systems. In March 2011 *The New York Times* reported that United State begun sending drones into Mexican territory to gather intelligence to help locate major drug trafficking rings. This aircraft is capable of peering deep into Mexico and tracking criminal's communications and movements. In similar manner, the 2001 edition of *Time Magazine* stated that counter narcotics officials were able to obtain sufficient evidence from UAVs to confirm that a suspect was indeed trafficking drugs.[3] Also, *Popular Science* magazine stated that nearly one in three American military aircraft is a drone, according to a congressional report, a 40-fold increase in the drone army from just a few years ago.[4] The US government is looking into using UAVs for surveillance over high crime areas in order to prevent crime and preserve harmony. UAVs could also be used to control 'hot spots', where violence takes place habitually.[5]

UAVs are finding use in the following industrial fields, based on information from table 1 below:

Table 1 : UAV Applications [1]

Industry	Use of UAVs
Agricultural industry	UAVs equipped with fertilizer and pesticide dispersing equipment can be used to spray over large fields.
Crop monitoring	Right now, only over 10% of the crops in the US are being monitored by aircraft. Use of UAVs would greatly increase the region or area under surveillance.
Environmental control / weather research	Weather balloons are being used to monitor the weather on the ground.
Mineral exploration	UAVs are being used in aerial survey and ground survey to find minerals on desolate and hard-to-reach regions.
Coast watch	UAVs are being used by the coast guard for monitoring coastlines.
Telecommunications	UAVs are finding use in telecommunications applications as mobile relay platforms, as well as in disaster zones for emergency telecommunications
News broadcasting	UAVs are finding use in providing aerial video feeds for news events where reporters cannot get to in time.

Remote sensing of marine resources	Marine labs are using UAVs to detect the presence of resources under the sea that are inaccessible to humans.
Unexploded artillery detection	UAVs are now being developed that can detect unexploded artillery, especially dangerous mines.
Air Traffic Control	UAVs can be used to monitor air traffic over busy airports.
Ground traffic control	UAVs are beginning to be used to monitor traffic and accidents over major state highways.

2. Conceptual Design

Due to the lack of constraints found in this project, the team needed to research several similar designs as a way of selecting the best platform from where to begin the design process. The first design that the team came across was the General Atomics MQ-1 Predator, found in Figure 2, which is a UAV used by the United Sates Air Force. Originally designed as a reconnaissance aircraft, the predator later evolved into an offensive aircraft used in several conflicts worldwide.

Figure 2: MQ-1 Predator [5]

Although the Predator has proven to be an excellent tool for The Unites States, the team has decided against the use of such platform for the design process. If such platform were used in this project several additional problems would arise. First, the predator's inability to remain static while in flight would pose a great challenge to the operator if internet connection was lost. Second, the predator requires runways for landings and take offs. Lastly, the predator serves as an offensive weapon which is not what the team is trying to accomplish.

The second UAV the team came across was the Northrop Grumman MQ-8 Fire Scout found in Figure 3. The MQ-8 is an autonomous helicopter designed for reconnaissance, situational awareness, and precision targeting support for ground forces.

Figure 3: MQ-8 [5]

Although the MQ-8 did prove to be a viable platform for the team's design, the team decided against the use of such platform for the design process for one particular reason. Forward, backward, and lateral movement of such a platform would require extensive research of highly complex and very expensive gear systems, making this platform too expensive and too complex for our initial constraints.

The third UAV the team came across was the Aeryon Scout found in Figure 4. The Aeron Scout is a remote controlled miniature UAV primarily designed for surveillance and reconnaissance missions. The team took deep interests in this design platform as it delivers all the essential qualities that the tem was looking for. The only reason that the team did not select this platform was because the team was able to find a better platform from where to begin the design process.

Figure 4: Aeryon Scout [6]

The fourth and final platform the team looked at was the AR. Drone Parrot found in Figure 5. The AR. Drone is a remote controlled quadcopter strictly used for recreational purposes. The AR. Drone is controlled from a mobile device, such as an iPad, through a local wireless internet connection crated by the drone. The AR. Drone is a very stable platform capable of hovering in place or moving to any desired location making it the perfect platform from where the team can begin the design process.

Figure 5: AR. Drone [7]

3. Proposed Design and Major Components

The proposed design consists of two main components: mechanical design and software design which are described as follows:

3.1 Design Characteristics

From a list of conceptual designs of working UAVs the team was able to accommodate the best features and learn from what was missing on most of these designs, thus the team decide to develop a quad-copter. A quad-copter is a device with four rotors and capable of flying. The main focus of the team design will be the design of the frame and its interaction with the rotors as to obtain the best efficiency and most lift. Additionally, the use of lightweight and durable materials such as Aerogels and composite materials will also increase the device's efficiency.

A Quad-copter similar to Parrot, A.R. Drone will be designed, tested and manufactured which will be able to fly using a battery and four fully independent motors and rotors.

Figure 6 : AR. Drone [7]

The Proposed device will consist of the following features:

- Four independent rotors and motors
- GPS
- 3G Mobile Internet Access

- On board computer with Linux OS
- 2 onboard video cameras
- Altitude sensors (Sonar sensors)
- Lightweight frame
- Rigid structure (Aluminum structure)
- Cellphone Controller (Android Smartphone or tablet)
- Access to device worldwide with internet connection
- Gyros and Accelerometers
- Highest possible efficiency

Such design was chosen based on several different objectives and limitations from all other devices. Loss of Internet connection is of high importance considering the device will be using Mobile Internet access using a 3G-network connection. In the case of Internet loss, the contact with the device will be lost, thus it is required to have an emergency recovery application on the device. Using a quad-copter gives the opportunity to have the device hovering for a period of time in case of limited or no connection to the device or to have the device return to the original starting point using GPS coordinates. If the battery is determined to be low enough an emergency landing can be conducted, thus allowing the team to retrieve the device using the last known GPS coordinates.

Additionally, as the device is oriented towards military use and surveillance missions, having four smaller motors instead of one gives the opportunity to use lower power motors, thus producing lower noise, and a lower change of being spotted. Lastly, using a Quad-copter allows users with little flying experience to control de device, as most of the controls and stability for the device will be embedded on the software. In case of severe weather or other natural obstructions the user will only be required to specify the direction and the altitude of flight; all other decision will be made by the device.

3.2 Software Characteristics

In order to operate the software, several electronic components must be selected. These components include onboard motherboard, motor controls, communications servers, controller, and 3G network access. Some other components have not yet been selected as they can only be discussed after some other design elements have been fully completed. These include motors and batteries.

3.2.1 Motherboard

The internal motherboard has to be a powerful yet portable device capable of handling all decision making processes. After several hours of research the team has decided to use a Beagle board; this is a small motherboard capable of running Linux OS. The board measures 8 cm x 8 cm, provides multi thread capabilities, contains an on-board USB port, and processes data at a high rate. These features make this board a perfect fit for the device as it is able to stream video and communicate with the controller.

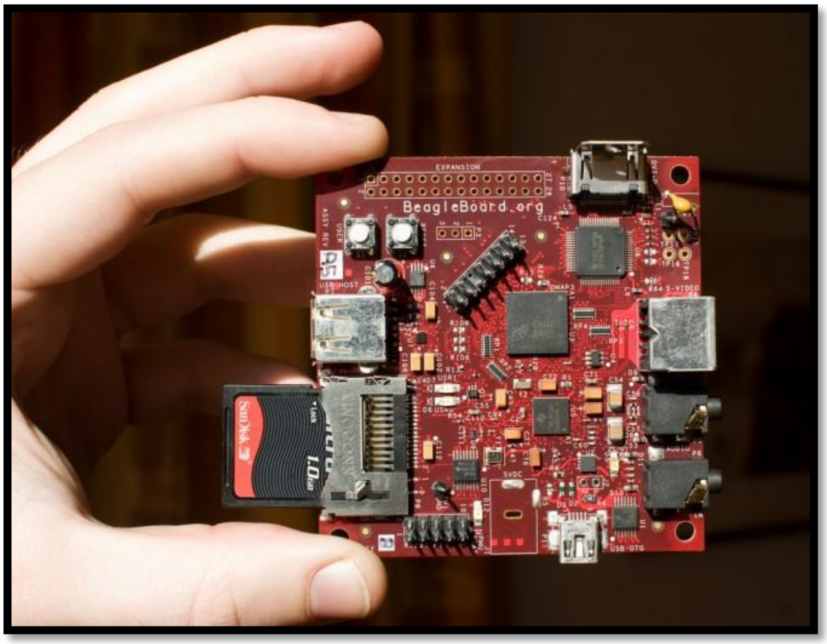


Figure 7: Beagle Board [8]

3.2.2 Servers

The team will be using two or three servers physically located in central Florida, these servers will allow for an excellent communication between the device and the controller. Additionally the servers provide a static IP address (Internet Protocol), which allows a connection between the device and the controller from virtually anywhere with an Internet connection. The chosen servers have the following characteristics and features:

- Dual Intel Xenon Quad-core Processor
- 8GB RAM
- Static IP Address
- Windows or Linux OS
- Physical Security (Firewall)
- 1GPS Internet Connectivity (no Restrictions)
- 10ms data transmission delay to South Florida
- Scalability Available (Virtually unlimited access to servers)

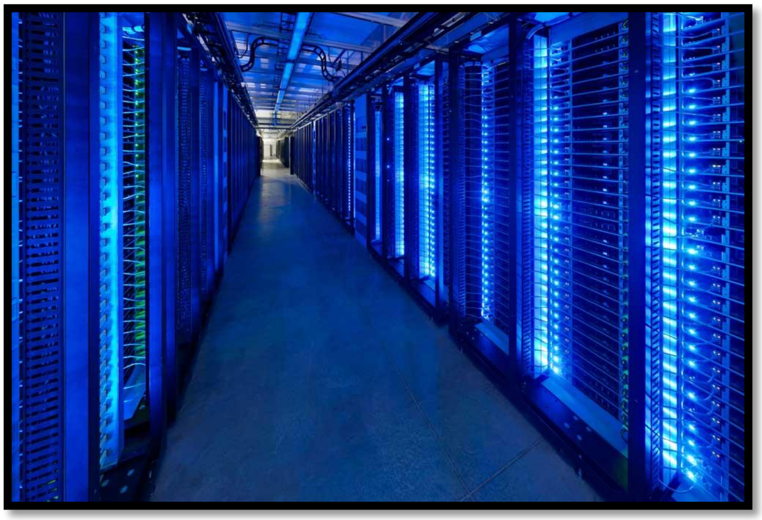


Figure 8: Servers in Data Center [9]

3.2.3 Controller

For the controller, the team has decided to use an Android powered cellphone or tablet. Android gives the great stability of Google, while allowing for free programming. Additionally Google provides several open source projects, which will make an easy integration between the cellphone, the controller, and the server. Some open source projects include but are not limited to virtual joysticks, accelerometer control, network communication, and video streaming.

Figure 9: AR. Drone Control Software [10]

3.2.4 Motor Drivers

TB6612FNG Dual Motor Driver Carrier is a small device that will allow the team to individually control up to two independent motors. For this reason the team will be required to use two of these small devices in order to operate the four motors required for the project.

Figure 10: TB6612FNG Motor Driver [11]

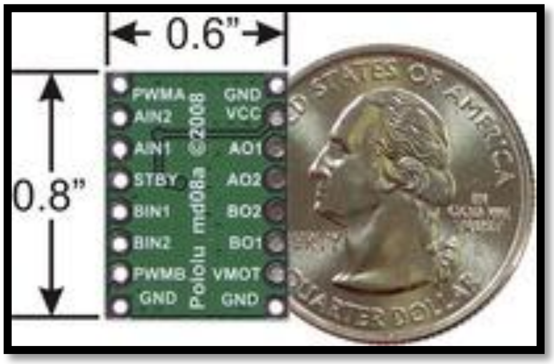


Figure 11: TB6612FNG Motor Driver Vs US Quarter Coin [11]

3.2.5 Flight Controls

The team will be using AeroQuad Mini Kit in order to have proper control of the device while in flight; this small electronic device created to work with Arduino systems is a great option to have control over a quad-copter. The device includes the following:

- Gyro
- Accelerometer

- Built in Battery monitor
- Ready for camera Stabilization System
- Ready for Ultrasonic Distance Sensors

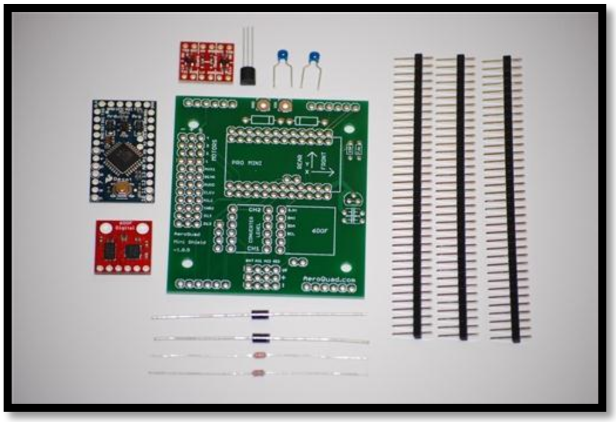


Figure 12: AeroQuad Mini Kit [12]

3.2.6 3G Connectivity and GPS

The Telit GM862-GPS, is a Small device, which allows the use of a 3G network by inserting a SIM card. This small device already comes equipped with a GPS, and Internet access. The device can be controlled from the previously descried Beagle Board which makes it an ideal fit for the project. This device will allow the UAV to connect to the Internet, send video streaming, send flight status, as well as receive controls from the controller trough the servers. Additionally, this device will allow for the usage of a built in GPS.

Figure 13: Telit GM862-GPS [13]

3.3 Additional Components

Some additional components have not yet been determined, due to some selection criteria and constraints to choose them, these devices such as motors, propellers and materials will be chosen later.

4. Final Prototype Design

The following is a list of the components selected for the construction of the first prototype. Software components will be presented first, followed by the mechanical components. Please note that some components differ from the original proposed design.

4.1 Motherboard

The new motherboard selection is the Raspberry PI motherboard. It has a 256MB RAM, a 10/100 Ethernet controller, and is capable of running Linux. The board is also capable of playing high definition video with the aid of a 700 MHz processor. The board also allows for on board memory storage through an SD card slot. This board is also smaller than the original selection with a total area of 8.5cm by 5.3 cm. This board is a great fit for the 3G panther drone as it provides all the software capabilities; it meets the size requirements, and is very reasonably priced.

Figure 14: Raspberry PI Motherboard

4.2 Servers

The final prototype uses the same servers as those originally selected for the proposed design. Below is a summary of the selected servers.

- Dual Intel Xenon Quad-core Processor
- 8GB RAM
- Static IP Address
- Windows or Linux OS
- Physical Security (Firewall)

- 1GPS Internet Connectivity (no Restrictions)
- 10ms data transmission delay to South Florida

Figure 15: Servers in Data Center

4.3 Controller

The final prototype uses the same controller as the one originally selected for the proposed design. The controller is to be an Android powered cell phone or tablet as it provides great Google stability while allowing for free programming tools. Some free tools include but are not limited to, open source projects for virtual joysticks and video streaming.

Figure 16: AR. Drone Control Software

4.4 Motor/Motor Drivers

To power the 3G panther drone the team selected to use four CF 2822 motors. Each motor is capable of lifting up to 800 grams providing a total lift force of 314 Newtons. The motors have three different speed settings: 35,000 RPM, 70,000 RPM, and 210,000 RPM. Each motor weighs around 39 grams and each motor is capable of working with different size propellers. In order to control the motors the team selected to use four Skywalker- 20A motor drivers. The proposed design originally called for two TB6612FNG Dual Motor Drivers to control the motors. Although the Skywalker-20A drivers can only control one motor at a time, these drivers proved to cheaper and lighter than the original selection.

Figure 17: CF 2822 Motor and Skywalker-20A Controller

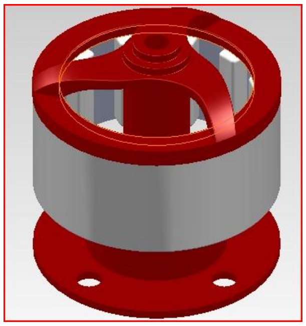


Figure 18: SolidWorks Motor Modeling

4.5 Flight Controls

The final prototype uses the same flight controls as the original proposed design. The team will be using AeroQuad Mini Kit in order to have proper control of the device while in flight; this small electronic device created to work with Arduino systems is a great option to have control over a quad-copter. The device includes the following:

- Gyro
- Accelerometer
- Built in Battery monitor
- Ready for camera Stabilization System
- Ready for Ultrasonic Distance Sensors

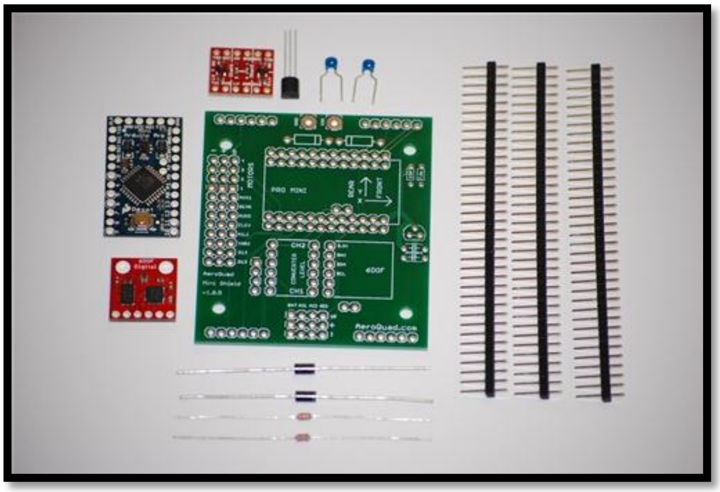


Figure 19: AeroQuad Mini Kit

4.6 3G Connectivity and GPS

The Telit GM862-GPS, is a Small device, which allows the use of a 3G network by inserting a SIM card. This small device already comes equipped with a GPS, and Internet access. The device can be controlled from the previously descried Beagle Board which makes it an ideal fit for the project. This device will allow the UAV to connect to the Internet, send video streaming, send flight status, as well as receive controls from the controller trough the servers. Additionally, this device will allow for the usage of a built in GPS.

Figure 20: Telit GM862-GPS

4.7 Battery

When the team came up with the original proposed design, the team was not able to reach a decision on the type of battery that should be used. For the final prototype the team selected to use a KDS 11.1V Lipo battery. This is a rechargeable lithium polymer battery weighing around 175 grams. The battery has a capacity of 62 Amps, however; for a short power burst it can provide up to 93 amps. The battery is relatively small with a total volume of $81cm^3$.

Figure 21: KDS 11.1V Lipo Battery

4.8 Propellers

For the final prototype design the team has decided to use four 9” x 4.7 propellers, two counter-clock wise and two clockwise. The number 9 refers to the diameter of the propeller in inches. The 4.7 refers to the pitch of the propeller which is the distance that the propeller would move forward with one rotation. The higher the pitch, the more the propeller would move, and the faster the 3G panther drone would fly. The 3G panther drone requires two sets of opposing spin propellers in order to balance out the torques created by the rotation of the propellers. Once the propeller is tested and flown, the team will exchange these propellers for carbon-reinforced propellers of the same exact size.

Figure 22: 9” x 4.7 propellers

Figure 23: Carbon Reinforced 9” x 4.7 propellers

4.9 Base

For the final prototype design, the team selected to use aluminum 6061 for the material of the base. This type of aluminum is widely available and easy to mill. The base was designed to serve as the structural starting point of the drone. For this reason, the team wanted to make it as rigid and sturdy as possible. However, the team was also looking to minimize the weight and volume of the base. Based on those considerations the team selected to use “cross” like shape for the base.

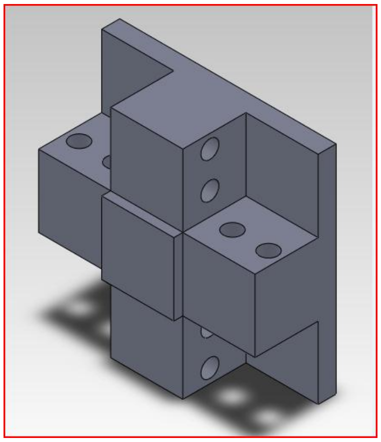


Figure 24: Base

4.10 Base/Motor extension

For the final prototype design the team selected to use aluminum 6061 for the material of the base/motor extension. The base/motor extension is basically a C-channel that will be cut to the necessary dimensions. The C-channel design gives the drone the necessary rigidity to withstand the torque created by the spinning of the propellers. The C-channel and base are to be connected through the use of a screw and nut.

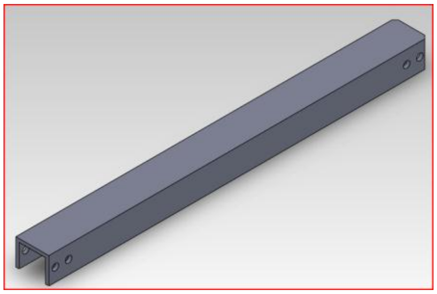


Figure 25: Base/Motor Extension

4.11 Motor Supports

For the final prototype design the team selected to use aluminum 6061 for the material of the motor support. The motor support design was meant to be as light and small as possible yet strong enough to prevent any "give" or slight movement when the motor was turned on. If any "give" or movement was to be present at the time of flight, the propeller would not be properly centered and cause a rather unfortunate event. The motor support was also designed to prevent any deflection from the heat dissipated from the motors.

The motor support is to be connected through a screw and nut to the base/motor extension.

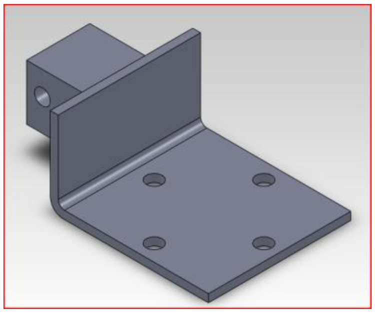


Figure 26: Motor Support

4.12 Shell

For the final prototype the team has already developed the shell geometry; however, the team is still researching ways into manufacturing and molding the shell. The team is also debating whether to use fiber glass or carbon fiber as the material of the shell. The team is also researching ways on how to attach the shell to the structure of the drone in the safest way possible. The complete development of the shell is the team's next priority.

Figure 27: Shell

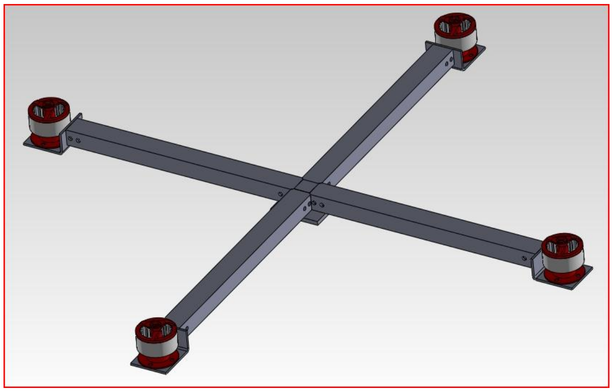
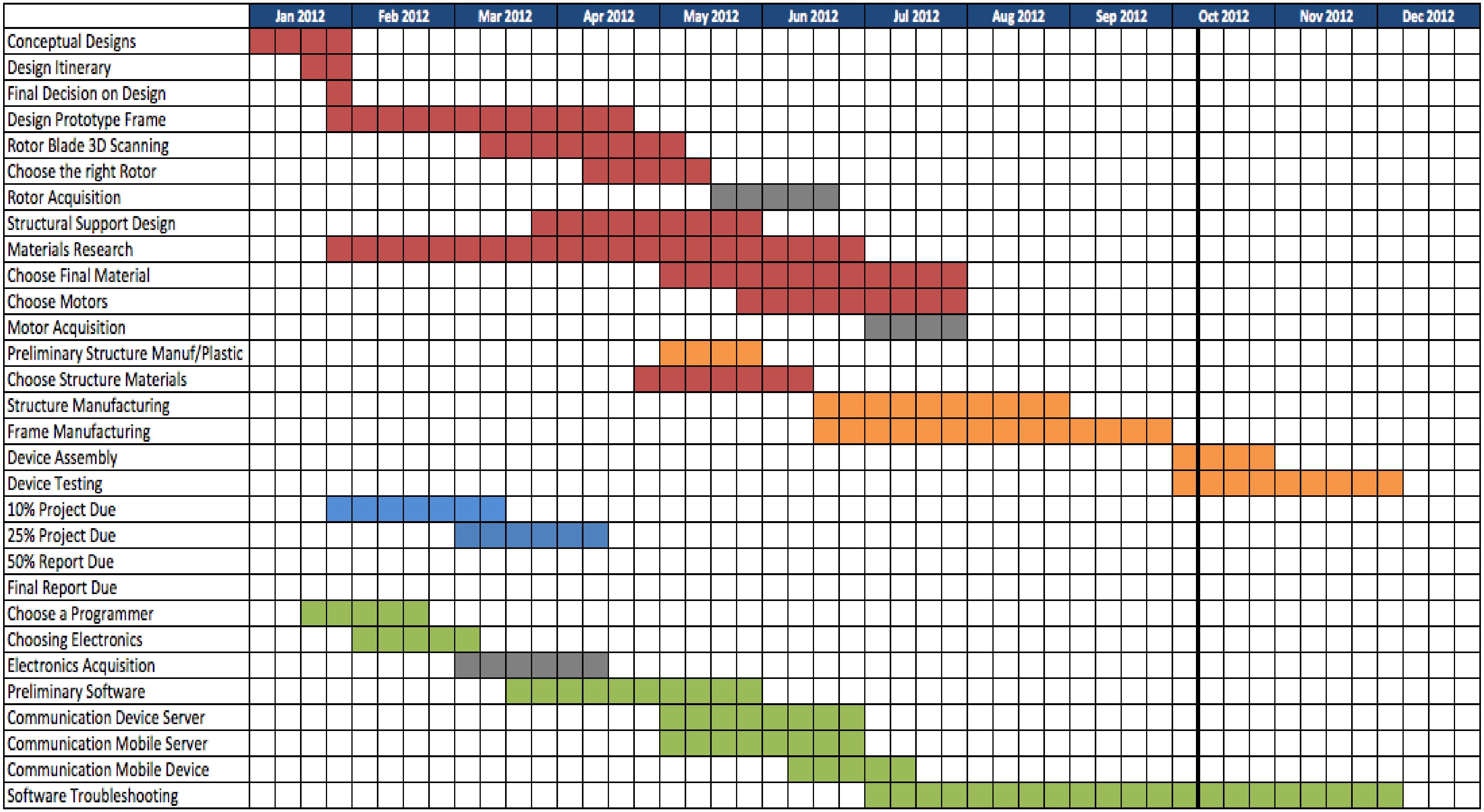


Figure 28: Mechanical Component Assembly

5. Time Line

5.1 Tasks in Time



	Jan 2012				Feb 2012				Mar 2012				Apr 2012				May 2012				Jun 2012				Jul 2012				Aug 2012				Sep 2012				Oct 2012				Nov 2012				Dec 2012			
Conceptual Designs	🟥	🟥	🟥	🟥																																												
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Table 2: Time Line

5.2 Time Distribution and Task Distribution

The time line is divided in four main aspects: written work, design, manufacturing, and computer programming. These tasks are distributed among the team members, and are spread through the duration of the project.

The team has divided the tasks to accommodate for areas of expertise for each member; however, work on each task is not limited to that member alone. Table 2, found in Appendix B, describes the team member in charge of each area of the project, as described on the time line schedule.

6 Analytical Analysis

6.1 Analysis via CAD software

In order to analyze the most efficient structure and proper material for this project numerous software trials must be conducted. The CAD software is useful in monitoring the behavior of the structure under a specified condition material. Solid Works offers great variety of critical stress analysis and deflection analysis tools. The aim of performing the structural analysis and deflection analysis is to determine the best design at the lowest cost possible.

6.2 Stress Analysis

Due to the nature of the design, the team has decided to simulate the stress that occurs in the motor/base connection. The results of the analysis will determine the optimal material and geometry of the motor base connection. The team began by determining the optimal material followed by selecting the proper shape. The team assumed the C-Channel geometry in order to test for material selection. The motor/base extension was loaded with an upward force of 900 grams in order to simulate the lift created by each motor. The team looked into aluminum 6061, ASTM A36 steel, and titanium. Table 3 shows the results of the simulation. For a detailed look at the actual simulation please refer to the appendix section of the report.

Table 3: Stress Simulation by Material

Stress simulation		
Material	Tensile Yield Strength (MPA)	Acual Stress (MPA)
Aluminum 6061	276	1.548
ASTM A36 Steel	551	1.553
Titanium (Annealed)	880	1.562

The simulation results revealed that the stress present at the motor/base extension varies very little with material and the stress present is insignificant compared to the material properties. Thus, based on the stress simulation the team decided to select the material based on the availability and price. However, before making a final decision the team must take into consideration the results of the stress simulation on the motor/base geometry. The team looked into three different geometries: the C-Channel, the I-beam, and the T-beam. Figures 29 through 31 show the profile of each of the geometries.

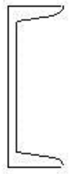


Figure 29: C-Channel Geometry

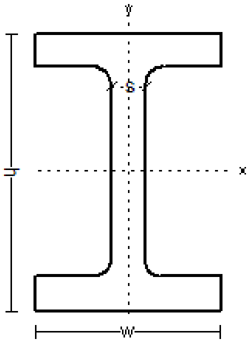


Figure 30: I-Beam Geometry

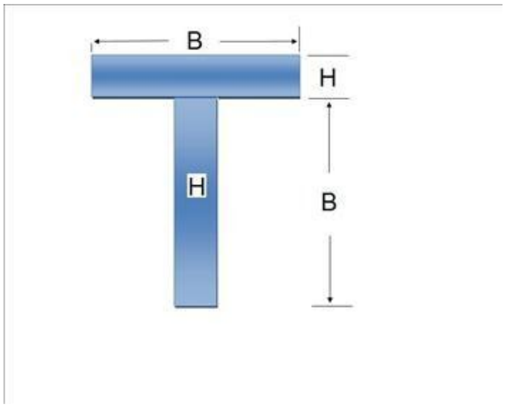


Figure 31: T-Beam Geometry

The motor/base extension was loaded with an upward force of 900 grams in order to simulate the lift created by each motor. Based on the results of Table 3, the team selected aluminum 6061 as the standard material for all three geometry simulations. Table 4 shows the results of the simulation. For a detailed look at the actual simulation please refer to the appendix section of the report.

Table 4: Stress Simulation by Geometry

Stress simulation		
Geometry	Tensile Yield Strength (MPA)	Acual Stress (MPA)
C-Channel	276	1.548
I-Beam	551	1.086
T-Beam	880	1.901

The simulation results show that the I-Beam geometry configuration is the geometry that experiences the least stress. However, results reveal that the stress present at the motor/base extension varies very little with geometry and the stress present is insignificant compared to the material properties. Thus, the team decided to select the geometry based on the availability and price.

After careful analysis of the stress simulation of the motor base/extension, the team has decided that the optimal configuration would be a C-Channel made out of aluminum 6061. The decision was mostly price driven as all three materials and all three configurations would be more than suitable for the expected stress levels.

6.3 Deflection Analysis

It is also important to look at the deflection that the motor/base extension will experience during flight. It is very important to keep the propeller as centered as possible in order to maintain a stable and steady flight. Just as with the stress analysis, the team was testing to determine the optimal geometry and material. The team began by determining the optimal material followed by selecting the proper shape. The team assumed the C-Channel geometry in order to test for material selection. The motor/base extension was loaded with an upward force of 900 grams in order to simulate the lift created by each motor. The team looked into aluminum 6061, ASTM A36 steel, and titanium. Table 5 shows the results of the simulation. For a detailed look at the actual simulation please refer to the appendix section of the report.

Table 5: Deflection Simulation by Material

Defelction simulation	
Material	Maximum Actual Deflection (mm)
Aluminum 6061	2.81E-02
ASTM A36 Steel	9.71E-03
Titanium (Annealed)	1.84E-02

The simulation results revealed that the ASTM A36 Steel experienced the least amount of deflection. However, it is also important to keep in mind that all three deflection results are very small compared to the scale of the motor/base extension. Ideally the team would select the ASTM A36 Steel as the final material for the motor /base extension; however, before making a final decision the team must take into consideration the results of the deflection simulation on the motor/base geometry. The team looked into three different geometries: the C-Channel, the I-beam, and the T-beam. The motor/base extension was loaded with an upward force of 900 grams in order to simulate the lift created by each motor. Based on the results of Table 5, the team selected aluminum 6061 as the standard material for all three geometry simulations. Table 6 shows the results of the simulation. For a detailed look at the actual simulation please refer to the appendix section of the report.

Table 6: Deflection Simulation by Geometry

Defelction simulation	
Geometry	Maximum Actual Deflection (mm)
C-Channel	2.81E-02
I-Beam	2.32E-02
T-Beam	3.26E-02

The simulation results revealed that the I-Beam geometry experienced the least amount of deflection. However, it is also important to keep in mind that all three deflection results are very small compared to the scale of the motor/base extension. Ideally the team would select the I-Beam geometry as the final geometry for the motor /base extension; however, due to lack of availability in an aluminum 6061 setting the team decided to use the second best geometry: the C-Channel geometry.

After careful analysis of the deflection simulation of the motor base/extension, the team has decided that the optimal configuration would be a C-Channel made out of aluminum 6061. The decision was mostly price driven as all three materials and all three configurations would be more than suitable for the expected stress levels.

Since deflection plays a very important role in the success or failure of the project, the team decided to conduct another defection analysis using the singularity method. Once again the team tested for the material and geometry of the motor base extension. Figure 32, found below, shows the results of the analysis. For a detailed look at the calculation procedure please refer to the appendix section of the report.

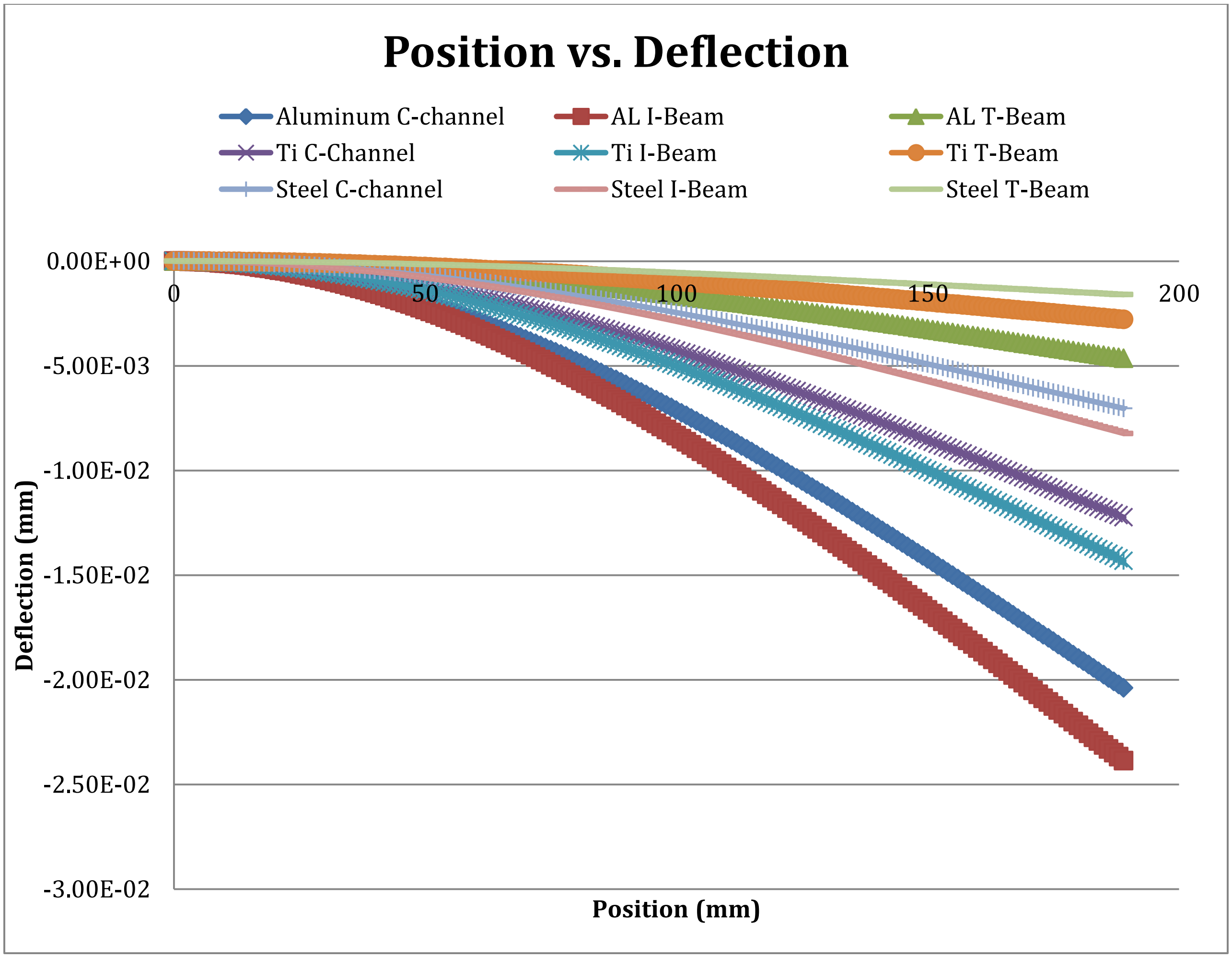


Figure 32: Deflection Analysis for Singularity Method

It can be concluded form figure 32 that the best combination of material and geometry for the motor/base extension is the T-Beam configuration made out of ASTM A36 Steel. This analysis is slightly different form results given by the SolidWorks simulation. Table 7, found below, shows the defection analysis conclusions for both the singularity method and for the SolidWorks simulation.

Table 7 : Deflection Analysis Comparison

Deflection Analysis Comparison		
Simulation Method	**Optimal Metrial**	**Optimal Geometry**
SolidWorks	ASTM A36 Steel	I-Beam
Singularity Method	ASTM A36 Steel	T-Beam

It is evident from table 7 that ASTM A36 Steel is the optimal material for the design of the motor base extension. However the simulation methods do not agree on the optimal geometry of the motor/base extension. The conflicting results lead the team to use the results of the stress analysis as the final material selection and geometry configuration for the motor/base extension. The results from the stress analysis determined that optimal configuration would be a C-Channel made out of aluminum 6061. The decision was mostly price driven as all three materials and all three configurations would be more than suitable for the expected stress levels.

7. Cost Analysis

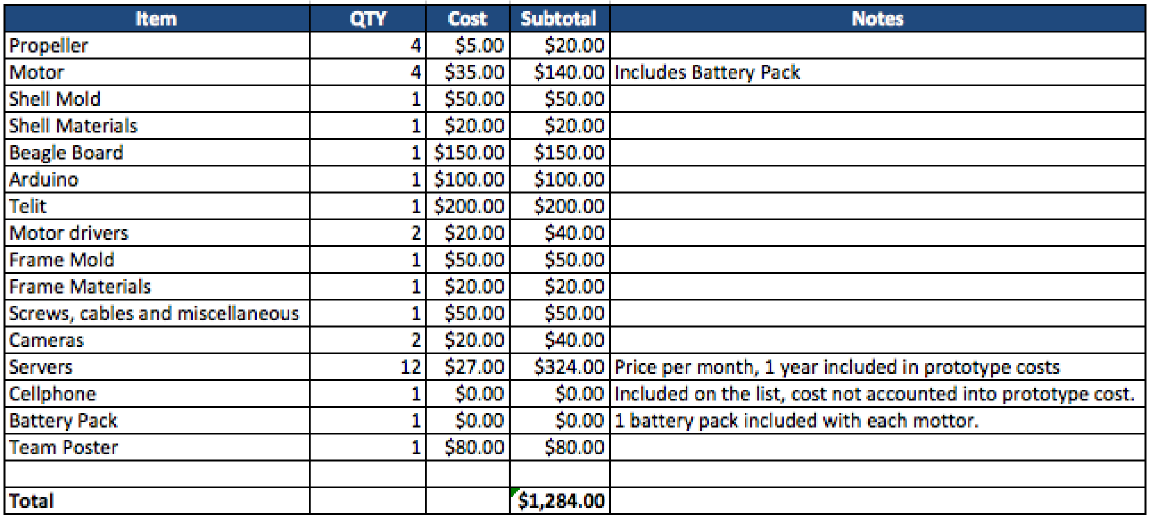
The project will be financed mostly by the team members of the project; however, the team sponsor will provide some small contributions. The team has set a monetary budget of $1,000.00 and 1000 Engineering hours; however this is a tentative budget and 20% difference from this budget is accepted.

The monetary budget for the project has been designated to cover the main components for the production of the prototype and materials required for presentations such as a required team poster. The sponsor will provide the team with a set of servers designated for the communication between the UAV and the controller, as well as access to both an Android Tablet and an Android Cellphone.

8. Prototype Cost Analysis

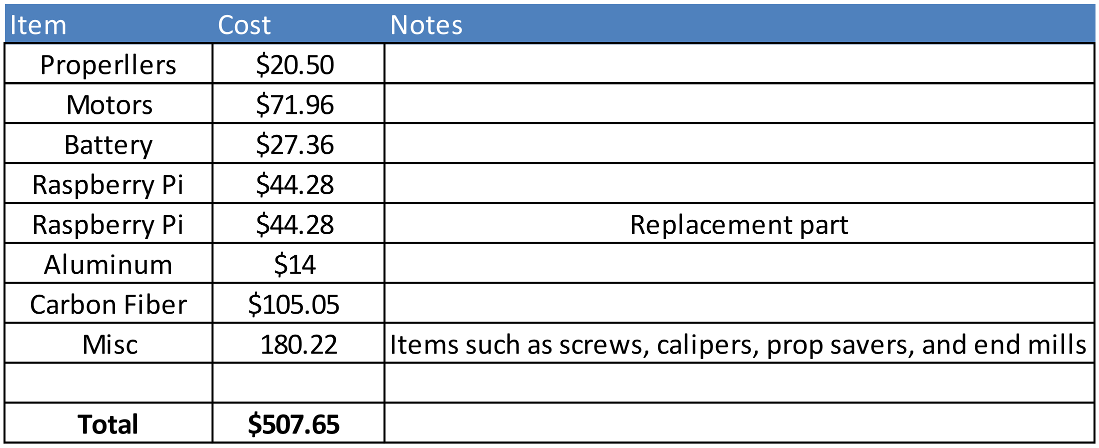
The monetary budget for the project has been distributed as described on table 8. The sponsor contributions will be accounted for the prototype analysis, but will not count against the designated budged described on table 8. The contributions include a server with VM Ware OS, and this is a recursive monthly cost estimated to be $27.00/month [14]. Additionally the provided cellphone for the controller will not be taken into account, as this is a normal electronic gadget easily accessible for most Americans. According to a research about 46% of Americans have a smartphone in 2012 [15].

Table 8: Project Budget



Item	QTY	Cost	Subtotal	Notes
Propeller	4	$5.00	$20.00	
Motor	4	$35.00	$140.00	Includes Battery Pack
Shell Mold	1	$50.00	$50.00	
Shell Materials	1	$20.00	$20.00	
Beagle Board	1	$150.00	$150.00	
Arduino	1	$100.00	$100.00	
Telit	1	$200.00	$200.00	
Motor drivers	2	$20.00	$40.00	
Frame Mold	1	$50.00	$50.00	
Frame Materials	1	$20.00	$20.00	
Screws, cables and miscellaneous	1	$50.00	$50.00	
Cameras	2	$20.00	$40.00	
Servers	12	$27.00	$324.00	Price per month, 1 year included in prototype costs
Cellphone	1	$0.00	$0.00	Included on the list, cost not accounted into prototype cost.
Battery Pack	1	$0.00	$0.00	1 battery pack included with each mottor.
Team Poster	1	$80.00	$80.00	
Total			**$1,284.00**	

Table 9: Updated Project Budget

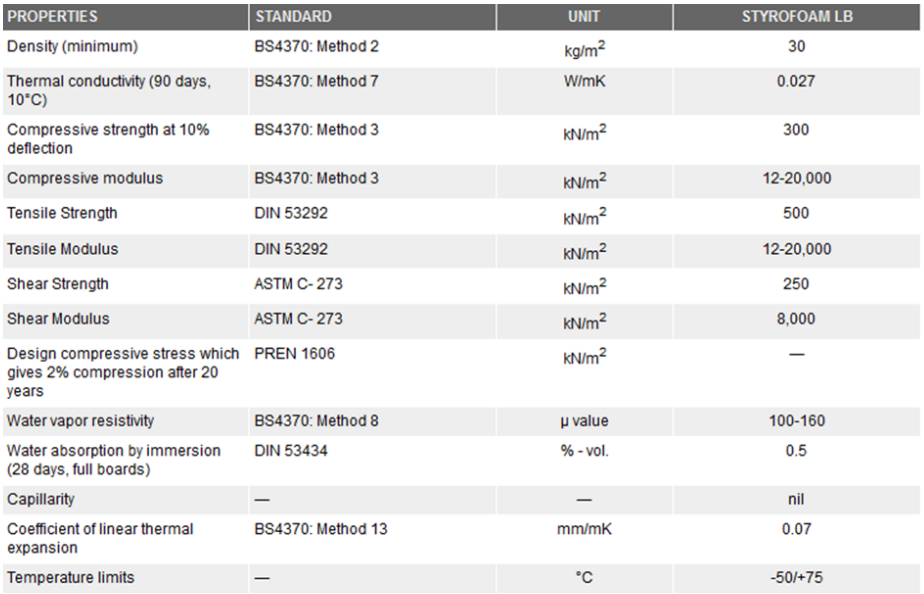


Item	Cost	Notes
Properllers	$20.50	
Motors	$71.96	
Battery	$27.36	
Raspberry Pi	$44.28	
Raspberry Pi	$44.28	Replacement part
Aluminum	$14	
Carbon Fiber	$105.05	
Misc	180.22	Items such as screws, calipers, prop savers, and end mills
Total	**$507.65**	

8 Prototype System Description

The main goal of the system prototype is to test if the original design is able to meet the basic restrictions/limitations once all the analysis is complete. The first developed prototype is to have nine main components: shell, frame, propeller, motor, battery, electronics, servers, camera, and controller. The shell is to be made out of Styrofoam, also known as polystyrene, as it is readily available and easy to work with. Please refer to table 10 for material properties. The frame found in is to be made out of two fiber glass rods, both perpendicular to each other, which will support the entire weight of the UAV. Four BM2806CD-KV1200 motors and four 9 x 5 propellers will be attached to the UAV at the ends of the frame. In order to power the four motors four 3 cell-Lipo max batteries will be placed at the center of the UAV. All other electronics such as the beagle board, Arduino board, motor drivers, and Telit GM862-GPS will also be placed in the center of the UAV. Please refer to figure 33 for a detailed look at the complete UAV assembly. Servers, located in Ocala, FL, will serve as the communication link between the UAV and controller. The team has decided to incorporate a T-Mobile Sensation 4g cell phone as the first controller. A minimum of two cameras will be placed in the UAV; one camera will be facing the ground and the other will be facing a specified flight direction.

Table 10: Shell Material Properties



PROPERTIES	STANDARD	UNIT	STYROFOAM LB
Density (minimum)	BS4370: Method 2	kg/m^2	30
Thermal conductivity (90 days, 10°C)	BS4370: Method 7	W/mK	0.027
Compressive strength at 10% deflection	BS4370: Method 3	kN/m^2	300
Compressive modulus	BS4370: Method 3	kN/m^2	12-20,000
Tensile Strength	DIN 53292	kN/m^2	500
Tensile Modulus	DIN 53292	kN/m^2	12-20,000
Shear Strength	ASTM C- 273	kN/m^2	250
Shear Modulus	ASTM C- 273	kN/m^2	8,000
Design compressive stress which gives 2% compression after 20 years	PREN 1606	kN/m^2	—
Water vapor resistivity	BS4370: Method 8	μ value	100-160
Water absorption by immersion (28 days, full boards)	DIN 53434	% - vol.	0.5
Capillarity	—	—	nil
Coefficient of linear thermal expansion	BS4370: Method 13	mm/mK	0.07
Temperature limits	—	°C	-50/+75

Figure 33- Final Assembly

9 Plans for Prototype Testing

The team plans to break up the prototype testing into several different stages. First, the team will test the communication link between the server and any random computer. Once the communication link is established the team will replace the random computer with the specified controller, a T-Mobile Sensation 4G cellphone, and again test the communication capabilities. Second, the team will test the communication link between the controller and the actual UAV with several dry runs. Once a steady and healthy communication link is established between the controller and the UAV the team will begin the indoor flight test of the UAV. At this point the team does not have a specific testing procedure for the UAV as this phase of the project is months away. However, the team expects to perform multiple hovering trials in order to fully calibrate and adjust any necessary mechanical or electronic components. Following the calibration stage the team plans to test the UAV for maximum weight capacity, maximum flight time, handling, and the emergency recovery flight path feature. The emergency recovery flight path feature will allow the UAV to return to the original deployment location in case of a loss in Internet connection. Once all of the indoor testing is done the team will move the UAV to an outdoor location and repeat all of the tests.

11 Manufacturing

Having completed the final prototype design, the team moved on to the manufacturing phase of the project. The team took full advantage of the student shop, located at FIU's engineering center, as it provided the team with the necessary tools and equipment to carry out the manufacturing phase. At this point the team would like to thank Mr. Zicarelli, co-director of the engineering manufacturing center, for all the help and guidance he provided the team during the manufacturing phase. In order to manufacture the design, the team mainly used the following tools: the knee mill, the horizontal band saw, and the sander.

Figure 34: Bridgeport Knee Mill [1]

Figure 35: Carolina Horizontal Band Saw [2]

Figure 36: Sander

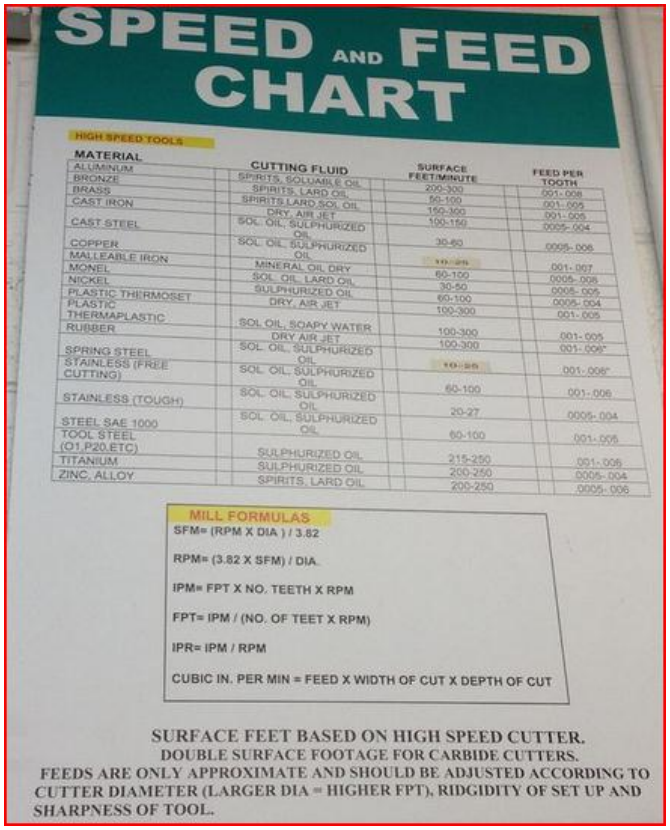
11.1 Base

The base was the first piece to be manufactured as it served as the linking point for much of the design. As mentioned in section 4.9 of the report, the base was to be constructed of aluminum 6061 as it is readily available, easy to work with, and meets the required structural load for the design. The team purchased a 2’’x 10’’x 1’’ piece of aluminum 6061 from River Recycling. This piece of aluminum was to suffice for the manufacturing of the base and motor holders. The team began by using the horizontal band saw to cut the original 2’’x10’’x1’’ block into a 2’’x1.75’’x1’’ block. It is with the highest importance to mention that all knee mill and horizontal band saw operations were carried out with the help of a lubricant.

Figure 37: Horizontal Band Saw

Once the 2’’x1.75’’x1’’ block was cut, it was placed in the knee mill to further get it down to the desired dimension of 1.5’’x1.5’’x0.63’’. However, before using the knee mill it is important to select the proper mill bit and desired bit speed. The student shop provides a wide range bits, thus it is important to select the proper bit to prevent damage to the part or equipment. The student shop also provides a chart to help students select the proper bit and speed.

Figure 38: Mill Bits



SPEED AND FEED CHART

HIGH SPEED TOOLS

MATERIAL	CUTTING FLUID	SURFACE FEET/MINUTE	FEED PER TOOTH
ALUMINUM	SPIRITS, SOLUABLE OIL	200-300	001-008
BRONZE	SPIRITS, LARD OIL	50-100	001-005
BRASS	SPIRITS LARD SOL OIL	150-300	001-005
CAST IRON	DRY, AIR JET	100-150	0005-004
CAST STEEL	SOL. OIL, SULPHURIZED OIL	30-60	0005-006
COPPER	SOL. OIL, SULPHURIZED OIL	10-25	001-007
MALLEABLE IRON	MINERAL OIL DRY	60-100	0005-008
MONEL	SOL. OIL, LARD OIL	30-50	0005-005
NICKEL	SULPHURIZED OIL	60-100	0005-004
PLASTIC THERMOSET	DRY, AIR JET	100-300	001-005
PLASTIC THERMAPLASTIC	SOL OIL, SOAPY WATER	100-300	001-005
RUBBER	DRY AIR JET	100-300	001-006*
SPRING STEEL	SOL. OIL, SULPHURIZED OIL	10-25	001-006*
STAINLESS (FREE CUTTING)	SOL. OIL, SULPHURIZED OIL	60-100	001-006
STAINLESS (TOUGH)	SOL. OIL, SULPHURIZED OIL	20-27	0005-004
STEEL SAE 1000	SOL. OIL, SULPHURIZED OIL	60-100	001-005
TOOL STEEL (O1,P20,ETC)	SULPHURIZED OIL	215-250	001-006
TITANIUM	SULPHURIZED OIL	200-250	0005-004
ZINC, ALLOY	SPIRITS, LARD OIL	200-250	0005-006

MILL FORMULAS

SFM= (RPM X DIA) / 3.82

RPM= (3.82 X SFM) / DIA.

IPM= FPT X NO. TEETH X RPM

FPT= IPM / (NO. OF TEET X RPM)

IPR= IPM / RPM

CUBIC IN. PER MIN = FEED X WIDTH OF CUT X DEPTH OF CUT

SURFACE FEET BASED ON HIGH SPEED CUTTER.
DOUBLE SURFACE FOOTAGE FOR CARBIDE CUTTERS.
FEEDS ARE ONLY APPROXIMATE AND SHOULD BE ADJUSTED ACCORDING TO CUTTER DIAMETER (LARGER DIA = HIGHER FPT), RIDGIDITY OF SET UP AND SHARPNESS OF TOOL.

Figure 39: Speed and Feed Chart

Based on the Speed and Feed Chart the team decided to use 3/4 inch bit at around 2000 RPM. However, as the current knee mill does not provide an accurate way of setting the RPM, the team had to use a trial and error method to determine the proper speed setting.

Figure 40: Improper Bit Selection

Figure 41: Proper Bit Selection

Once the bit and speed had been selected, the team began to mill the 2’’x1.75’’x1’’ block to get it to the desired dimension of 1.5’’x1.5’’x0.63’’**.** It is important to note that before beginning to mill it is necessary to set the “Zero” in all three directions. The knee mill allows the user to control the movement of the piece in all three directions: x, y, and z. Thus, to properly mill a piece it is necessary to locate a starting point or “Zero” for all three directions. Once the three directions are zeroed out the user can manipulate one of these directions to get the desired cut. After getting the 2’’x1.75’’x1’’ block to 1.5’’x1.5’’x0.63’’, the team uses to the sander to remove any remaining sharp pieces of aluminum still attached to the edges of the 1.5’’x1.5’’x0.63’’ block.

Figure 42: Use of the Sander

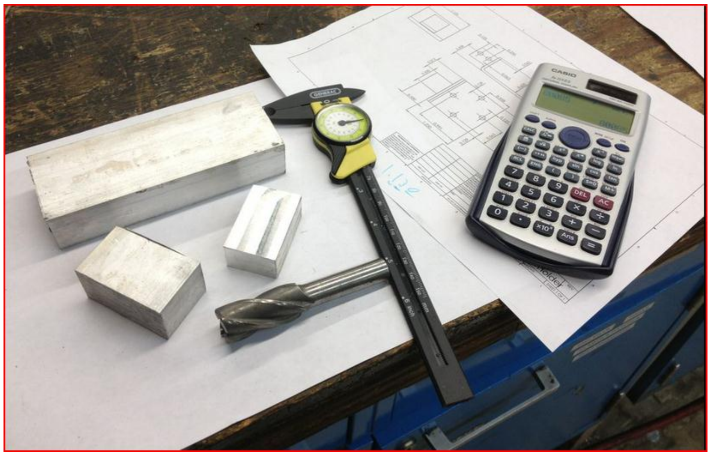


Figure 43: Transformation from 2’’x 1’’x 10’’ to 1.5’’x1.5’’x0.63’’

Once the 1.5’’x1.5’’x0.63’’ block is free of any sharp aluminum edges, the team places the block back in the knee mill to give it its final shape.

Figure 44: Construction of Base

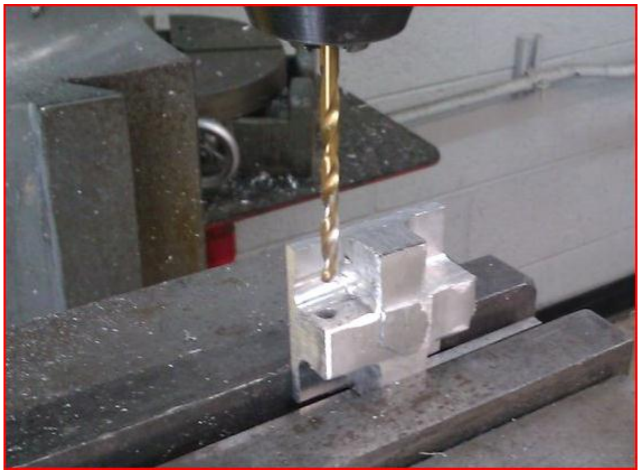


Figure 45: Final Base

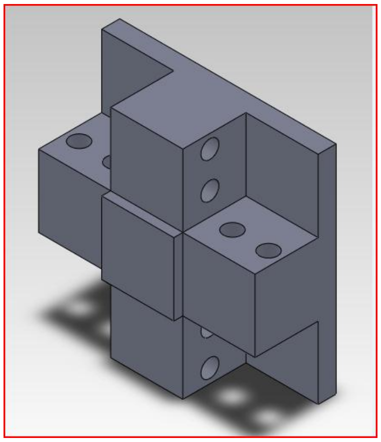


Figure 46: Final Prototype Base

The final base and final prototype base look very similar with one slight difference. The final prototype base was designed to have two holes in each arm. However, the actual final base only has one hole per arm. Originally, the team had designed each arm with two holes in order to prevent any “give” or “wobble” in the base/motor extension. However, after manufacturing the team realized that one hole was sufficient enough to prevent this “give” or “wobble”.

11.2 Base/Motor extension

The base/motor extensions were selected as the second part to be manufactured. As mentioned in section 4.10 of the report, the base/motor extension is to be made out of aluminum 6061 as it is readily available, easy to work with, and meets the required structural load for the design. The team purchased one 0.63”x ½”x96’’ C-channel made of aluminum 6061 from the local Home Depot. In order to get the 0.63”x ½”x96’’ c-channel to the 0.63’’x.50’’x7.19’’, the team utilized the horizontal band saw.

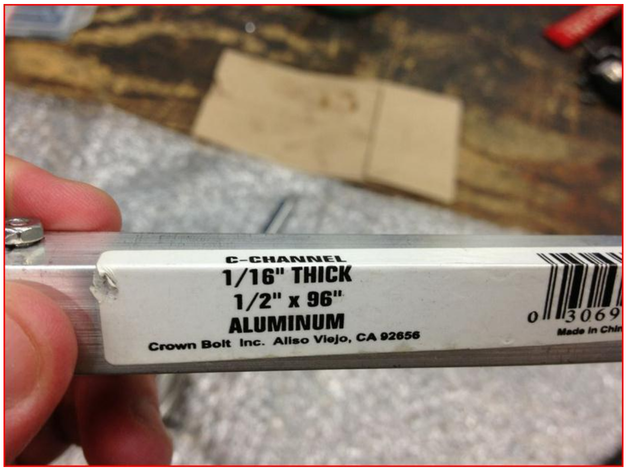


Figure 47: Purchased C-Channel

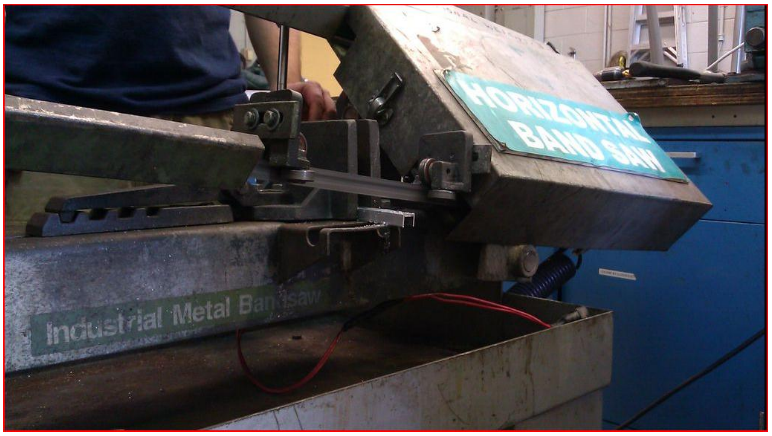


Figure 48: C-Channel in Horizontal Band Saw

Once the c-channel is cut to the 0.63’’x.50’’x7.19’**,** the team utilizes the sander to smooth out any rough edges or corners. The sanding process has to be done carefully as the team does not want to alter the cross sectional dimension of the c-channel. Once the c-channel is fully sanded, it is then inserted into one of the base’s arm to check for a proper fit. This process is repeated for all four c-channels.

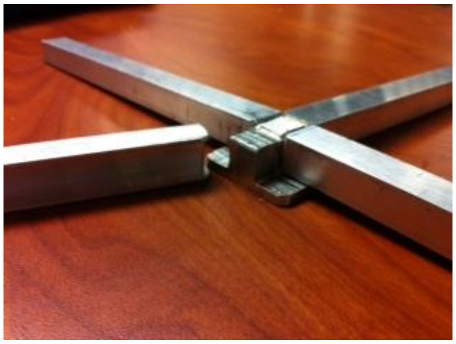


Figure 49: C-Channel Fitting

Figure 50: C-Channel Fitting

After checking for proper fit the team uses the knee mill to drill the holes that will later be used for assembly. Just as with the base, the team selects the proper drill bit and functional speed, as well as zeroing out the part before any drilling is done. Once the drilling is done the transformation from a 0.63”x ½”x96’’ c-channel to a complete motor/base extension is finished.

Figure 51: Final Motor/Base Extension

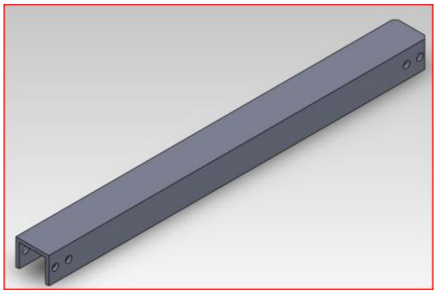


Figure 52: Final Prototype Motor/Base Extension

It is important to note that there is a slight difference between the final prototype motor/base extension and final motor/base extension. Originally, the team had designed each motor/base extension with two holes in order to prevent any “give” or “wobble” in the motor supports. However, after manufacturing the team realized that one hole was sufficient enough to prevent this “give” or “wobble”.

11.3 Motor Supports

The motor holders were the third part to be selected for manufacturing. As mentioned in section 4.11, the motor supports are to be manufactured out of aluminum 6061 as it is readily available, easy to work with, and meets the required structural load for the design. The team purchased a 2’’x 1’’x 10’’ piece of aluminum 6061 from River Recycling**.** The team began by using the horizontal band saw to cut the original 2’’x1’’x10’’ block into a 2’’x1’’x1.75’’ block.

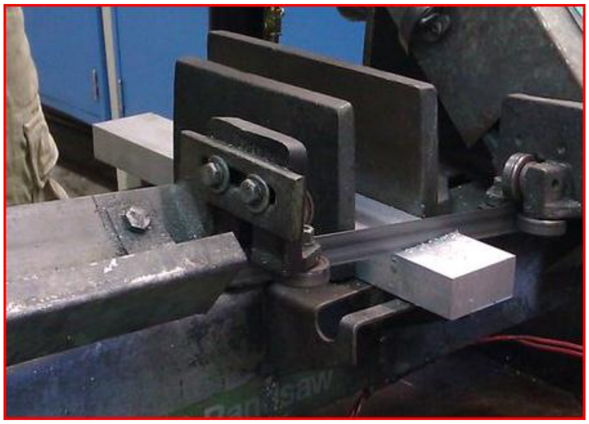


Figure 53: Horizontal Band Saw Cutting

Following the horizontal band cutting, the team places the 2’’x1’’x1.75’’ block in the knee mill to further refine the dimension of 1.13’’x0.69’’x1.75’’**.** Please note that the team follows the procedure outlined in section 10.1 for the knee mill operations. Once the 1.13’’x0.69’’x1.75’’ is complete, the team uses the sander to smooth out any rough edges or corners. Following the sander, the team places the 1.13’’x0.69’’x1.75’’ back in the knee mill to give it the final shape.

Figure 54: Machining Motor Support

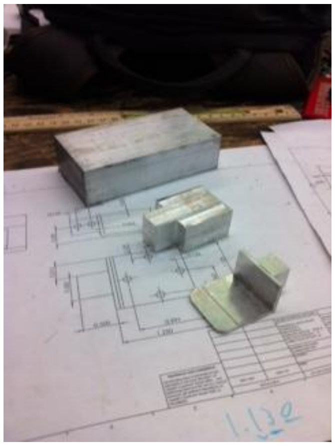


Figure 55: Motor Support Transformation

Once the final shape of the motor support is achieved the team places the motor support back in the knee mill to drill the assembly holes.

Figure 56: Motor Support Drilling

Figure 57: Final Motor Support

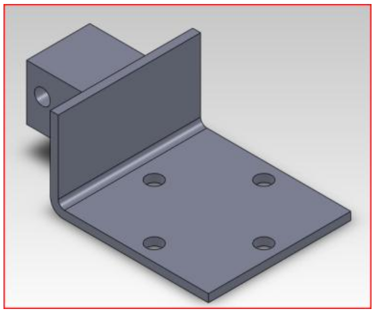


Figure 58: Final Prototype Motor Support

It is important to note that there is a slight difference between the final motor support and the final prototype motor support. The final prototype motor support has the assembly hole drilled parallel to the ground and the final motor support has the assembly hole drilled perpendicular to the ground. The team had intended to have the assembly hole parallel to the ground, but due to a broken mill bit obstructing the parallel path, the team had no choice but to go perpendicular to the ground. Two of the four motor supports have the assembly hole parallel to the ground and the other two have it perpendicular to the ground.

11.4 Final Mechanical Assembly

Once the base, base/motor extension, and motor supports were manufactured they were assembled together through the assembly holes. All connections were fastened with a zinc machine screw # 3 and zinc nut # 3. Please note that zinc corrodes very quickly; thus, for continuous use of the drone the team would recommend stainless steel screws and nuts. Prior to inserting the screw in the assembly holes the team had to use a screw tap to embed the inverted screw profile into the assembly hole.

Figure 59: Final Mechanical Assembly

11.5 Shell Manufacturing

After completing the manufacturing of the structural components the team began to manufacture the shell. The team had originally planned on making the shell out of Styrofoam; however, the team decided to manufacture the shell out of fiber glass or carbon fiber. The only reason that the team would select fiber glass over carbon fiber is due to the high price of carbon fiber. At this point, the shell has not been manufactured; however, the team has manufactured the mold that will produce the shell. With the help of the SOA (School of Architecture) and Professor Peterson, model shop manager, the team was able to manufacture the mold. The team began by building the actual shell on SolidWorks and then transferring the data to a STL file and using Mastercam CAD software to create a G-code. Once the G-code was created the team handed the code to Professor Peterson, who used a CNC to manufacture the mold. The team, with guidance from Professor Peterson, selected to use polyisocyanurate, polyiso, as the mold material. Polyiso is a plastic that is most commonly used as thermal insulation; however, it is also widely used as a mold material for several applications such as roofing decorations. Once the polyiso was purchased and the code developed, the team went to the model shop and manufactured the mold.

Figure 60: Polyisocyanurate (Polyiso)

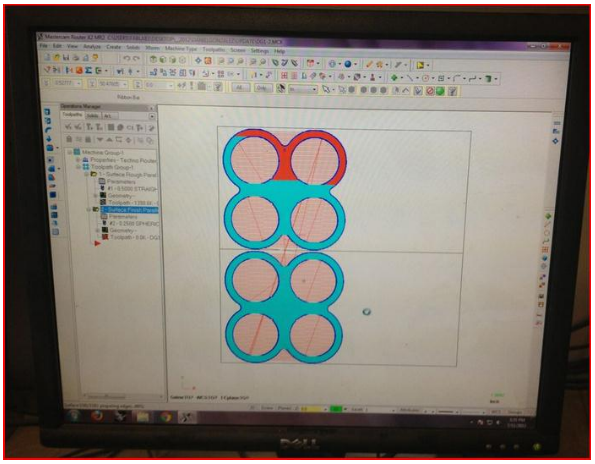


Figure 61: CAD Mold Manufacturing

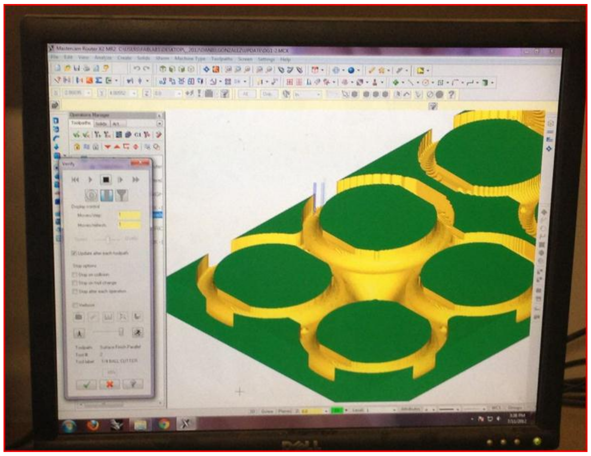


Figure 62: CAD Mold Manufacturing

Figure 63: Mold Manufacturing

Figure 64: Complete Mold Manufacturing

Testing

After successful manufacturing of the 3G panther Drone, the team begins the testing phase of the project. The testing phase will be broken down into two main steps. The first step will be to join the manufactured drone with the electrical components to ensure proper electrical and mechanical behavior. The second step will be to test the drone in stages to ensure an airworthy vessel.

Testing Part I

Part I of the testing requires for the successful union of mechanical components and electrical components. This will be the first time that both components will be joined together. The first stage of this testing part is to place the engines in the motor holders. Once the motors are in place, it is then necessary to attach the motor controllers to the motor/base extension. The motor controllers are to be placed equidistant from the base of the drone to ensure stability. Figure 65 shows the progress up to this point.

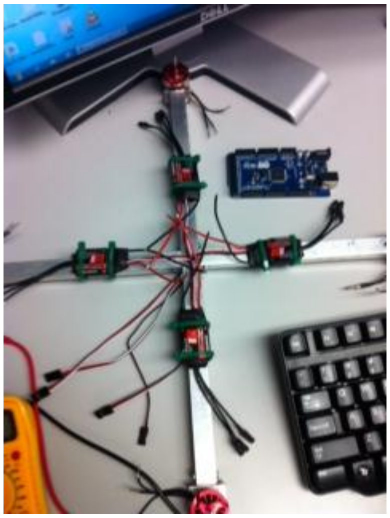


Figure 65: Early Testing Part I

After attaching both the motors and controllers it is then necessary to wire the system. The team began by wiring the motors to the controllers and the controllers to the battery. The controllers are also wired to the Arduino. The Arduino is then also wired to the battery and to the motherboard. These connections ensure that the battery will supply the power to the Arduino board which can handle the 20 volts form the battery. From the Arduino board the motherboard receives the required 5 volts to operate safely. Once fully wired the team installs the propellers and tie wraps the battery, motherboard, and Arduino board. Figure 66 shows the progress up to this point. Please note that in figure 66 the Arduino board is not attached to the drone.

Figure 66 : Fully wired Drone

Once the drone is fully wired it is the necessary to begin testing the electrical components. Since no internet connection has been established, the drone is to be controlled from a computer. The computer code was written in “Arduino” language which is a combination of C and Java. For a look at the complete code please refer to the appendix section of the report. The code was written in a way that the user is able to directly control the amount of power supplied to the motors. Based on the power input to each motor, the drone is able to move in different directions. The team decided to use the first flight to determine the amount of power required for the drone to lift off and stabilize. Figure 67 found below shows the first flight test. The drone only required a 35% of motor power to successfully lift off the ground.

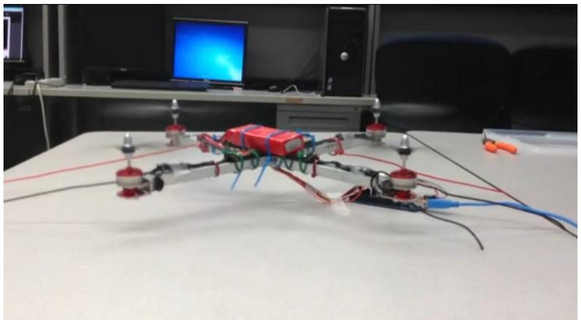


Figure 67 : First Flight at 35% power

Testing Part II

Part II of the testing phase requires the drone to fly through a series of movements. These movements include stable flight in all three coordinate planes. The team is currently in this testing phase. More data to come ahead.

12 Conclusion

To conclude this project, the team had the opportunity to learn several aspects of the development process of a new project, from obtaining the idea to developing the preliminary designs to manufacturing, testing, and debugging. The main goal of the project was to design, manufacture, and test a fully operational UAV with mobile Internet capabilities. At the current time, the team concludes that the main goal of the project has been accomplished; however, some areas require further study

The team began with an idea to create an UAV that would be useful in several fields such as, but not limited to: the emergency sector, the military sector, and the private sector. The UAV was to be designed after the quad-copter design which incorporates four separate motors to create a steady, cheap, and useful design. The UAV was to be controlled from a mobile device located anywhere in the world provided that Internet access is available to both the controller and UAV.

After two semesters of work the team was able to design and manufacture a fully functional quad-copter; however, some areas require more work. The extreme complexity of programing the device to stabilize has been a huge obstacle. The team is still in the second testing phase trying to control the UAV in all three coordinate planes. The UAV is still using the serial communication to communicate to the controller. However, once the quad-copter is fully operational the transition to a 3G network connection should be a simple step. Camera installation should come after the 3G network connection is set up, as there is no need for cameras at the moment.

The milestones achieved in this project include, but are not limited to: the design of a quad-copter frame and shell, the development of CAD and analytical simulations, the manufacturing the quad-copter based on simulations, the proper electronic and mechanical component testing, the development of a proprietary flight control code, the successful flight at 35 % power, and the development of a life-long learning collaboration between the mechanical department and the Discovery Lab.

The team would like to thank Professor Dulikravich for his continuous and diligent support. The team would also like to thank the Mr. Zicarelli and Eric Peterson for guiding the team during the manufacturing stage. Finally the team would like to thank Dr. Kim and the Discovery Lab.

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14. Appendices

Appendix A. Engineering Drawings

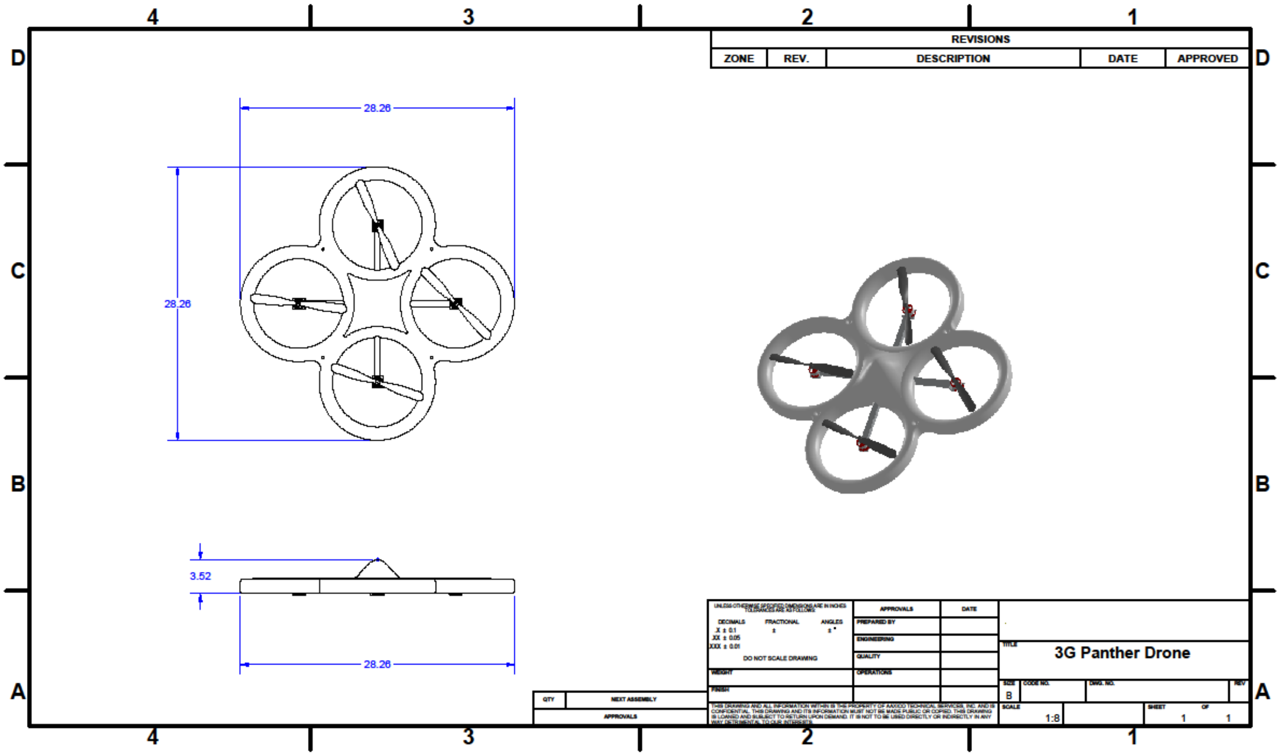

Figure 68: Complete Assembly

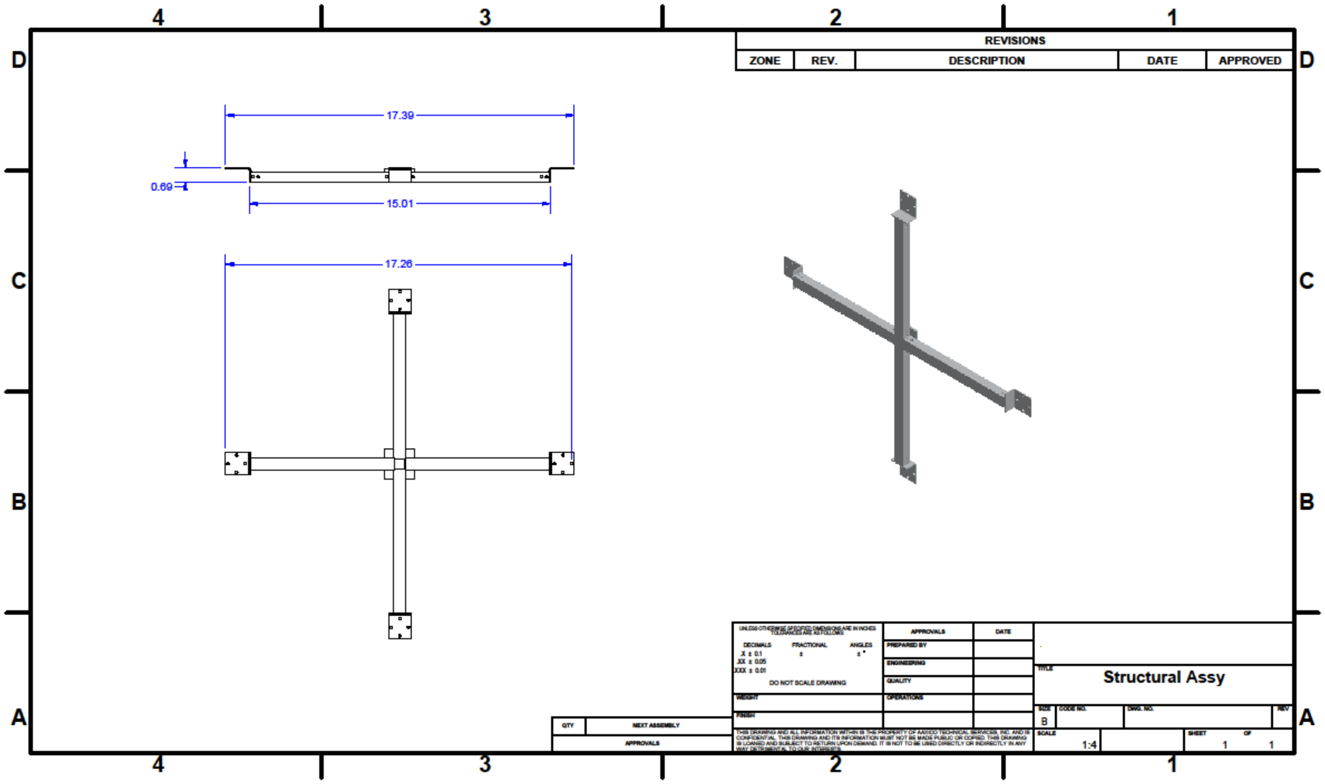

Figure 69: Frame

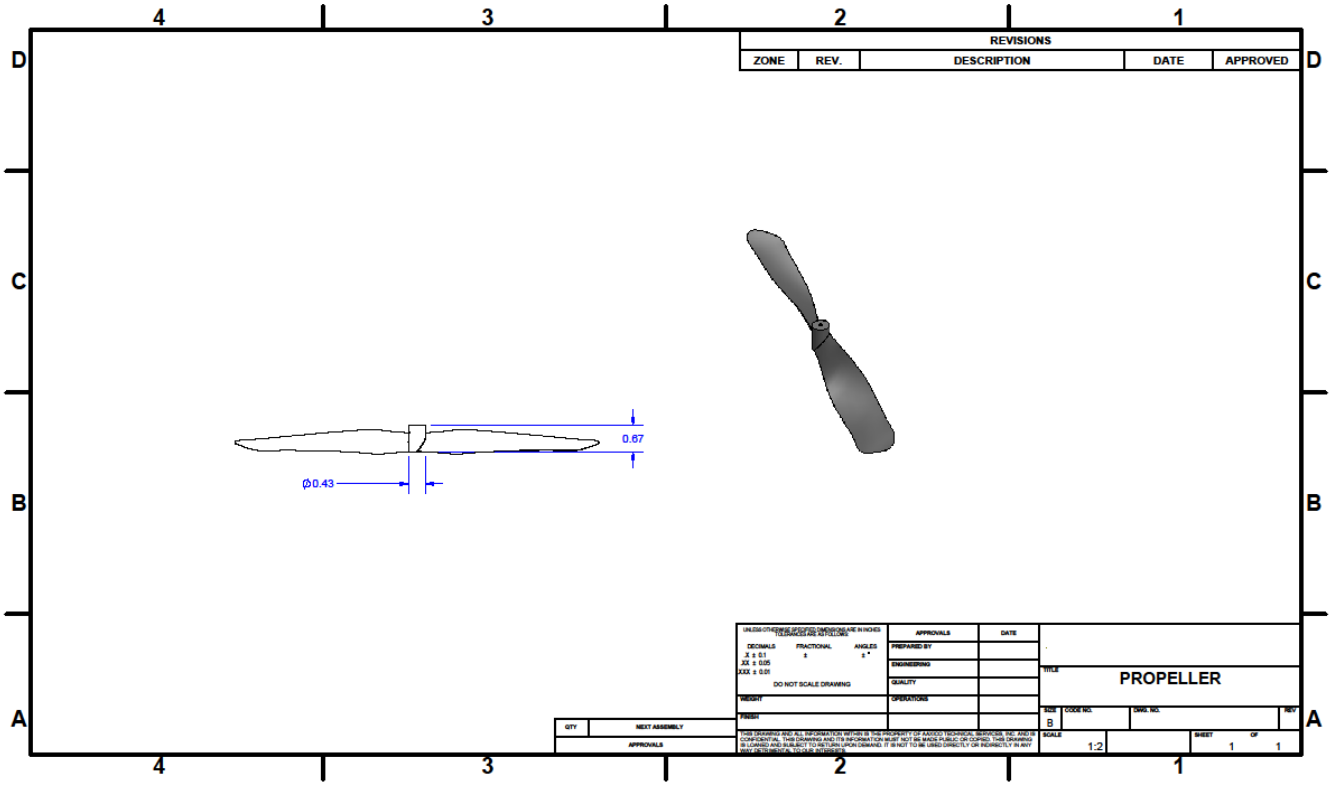

Figure 70: Propeller

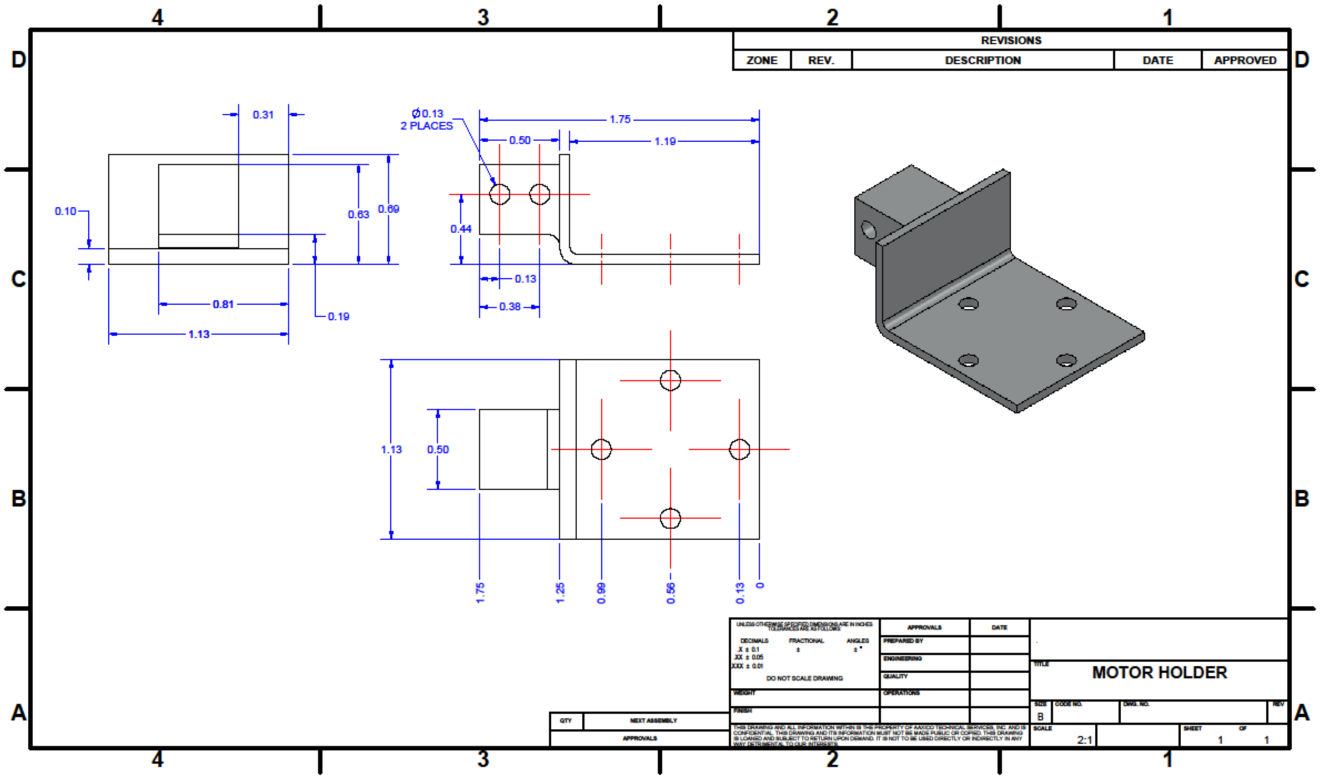

Figure 71: Motor Holder

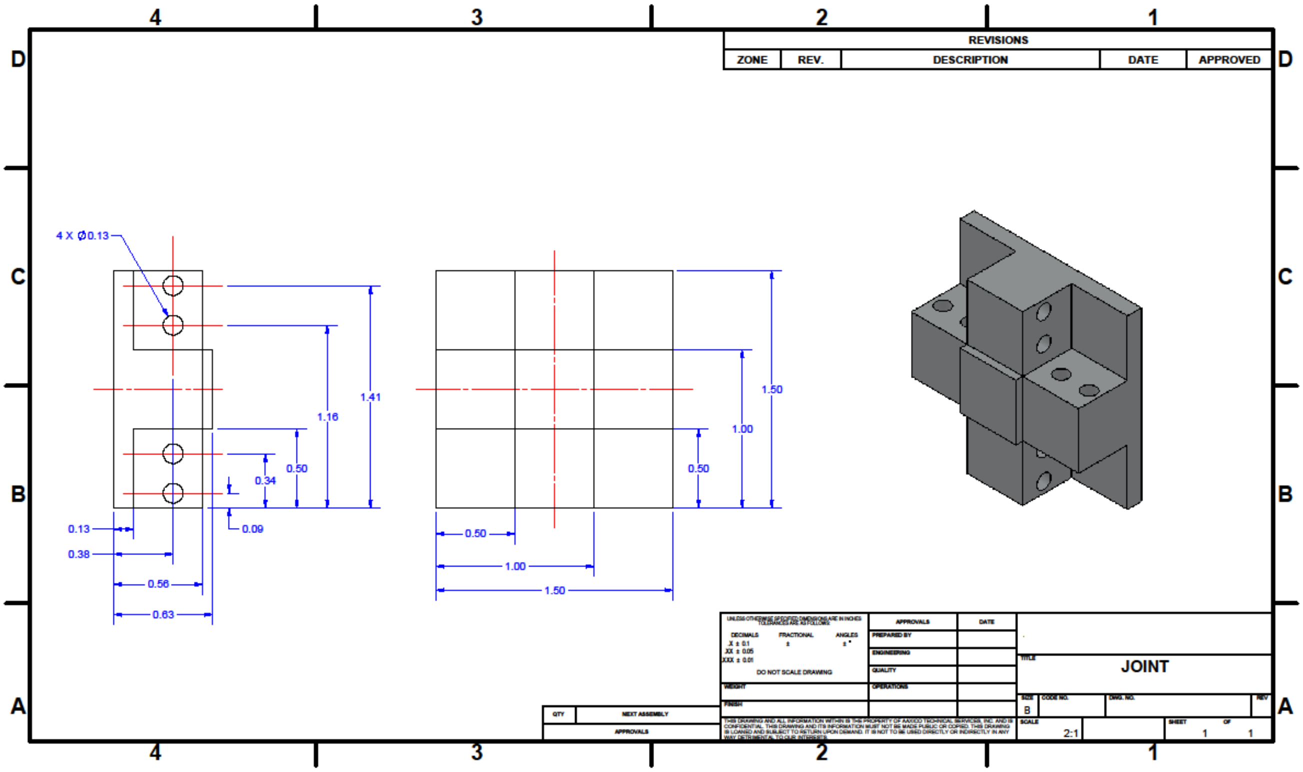

Figure 72: Base

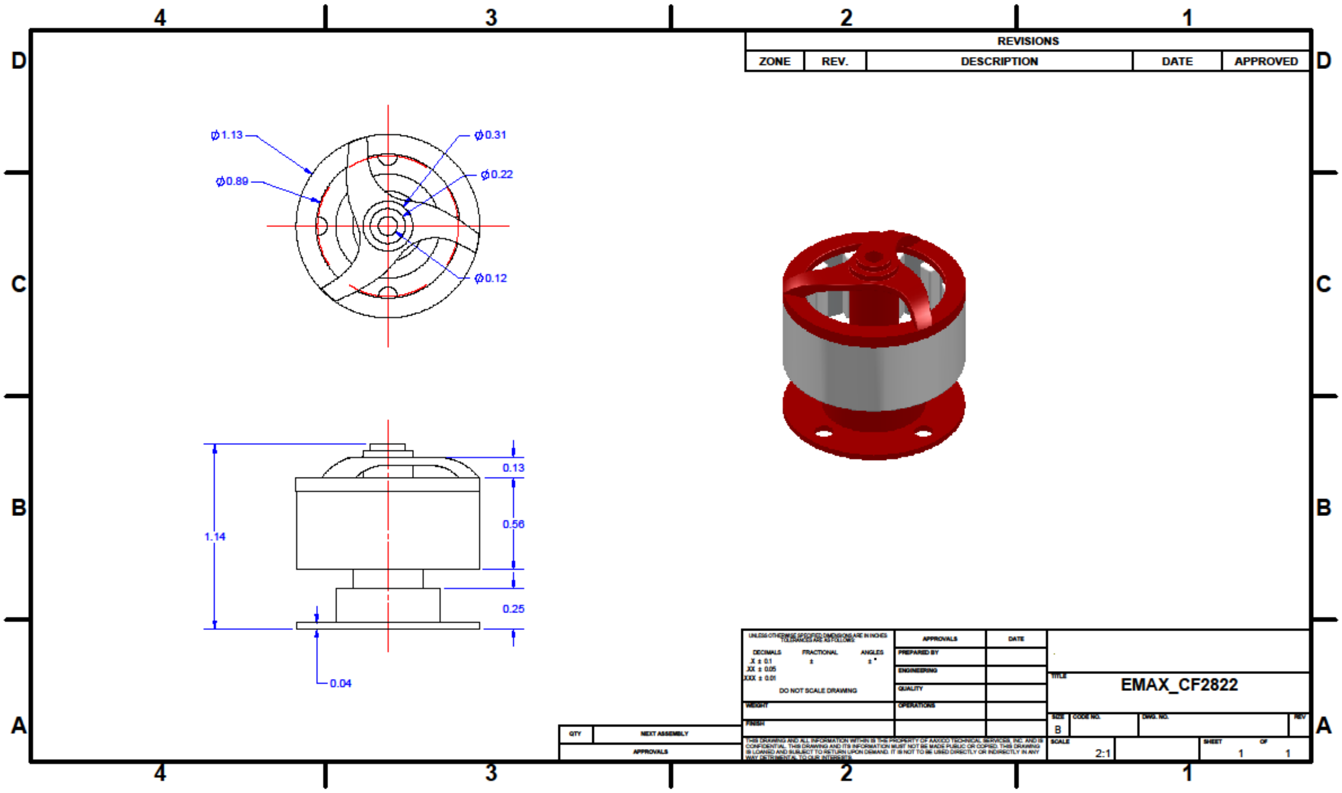

Figure 73: Motor

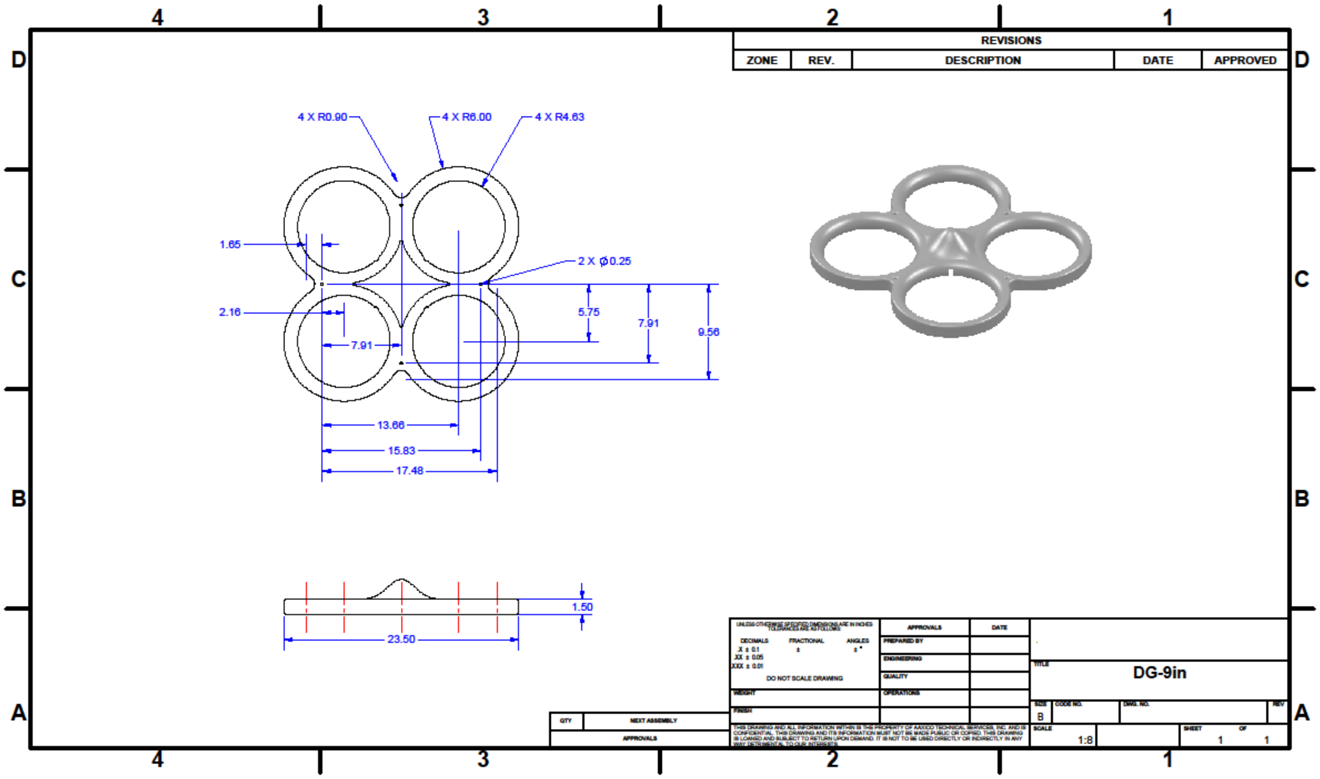

Figure 74: Shell

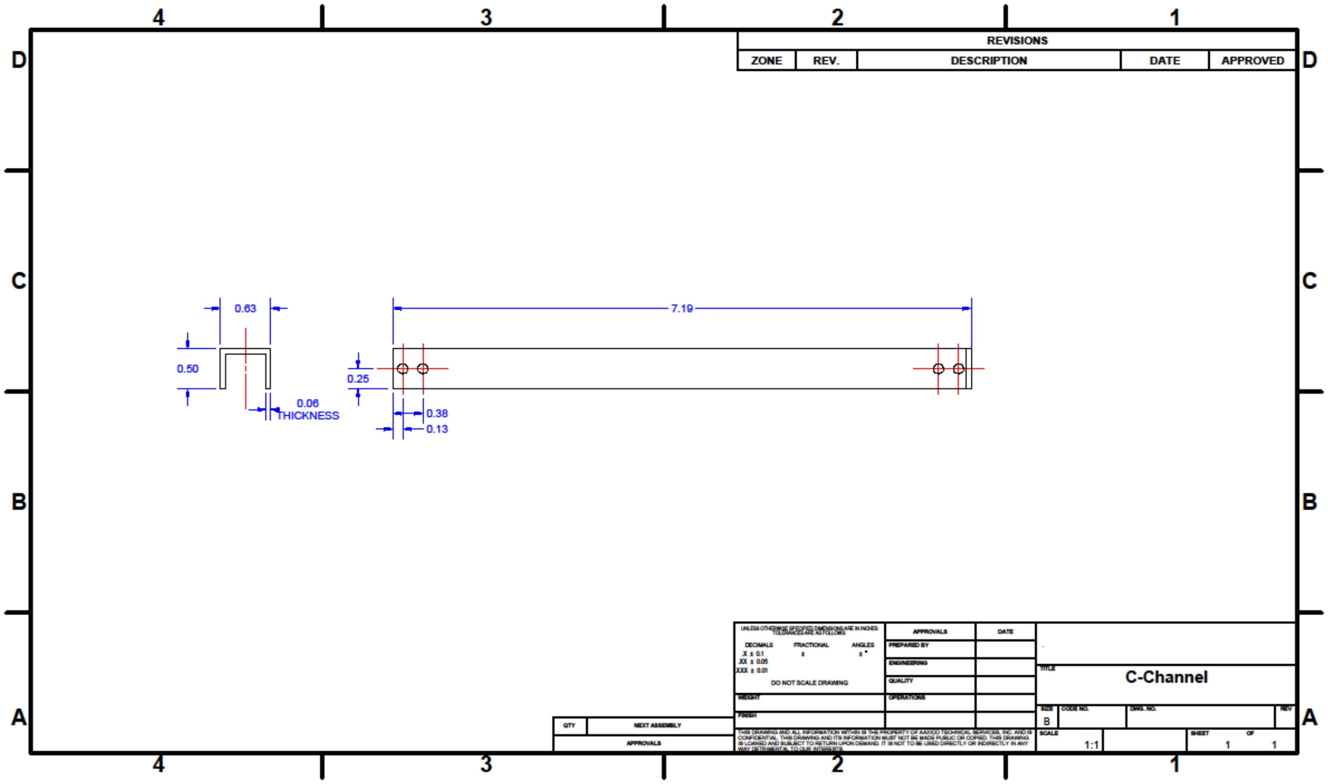

Figure 75: Base/Motor Extension

Appendix B. Simulations

The following simulations pertain to the stress testing mentioned in section 6.2.

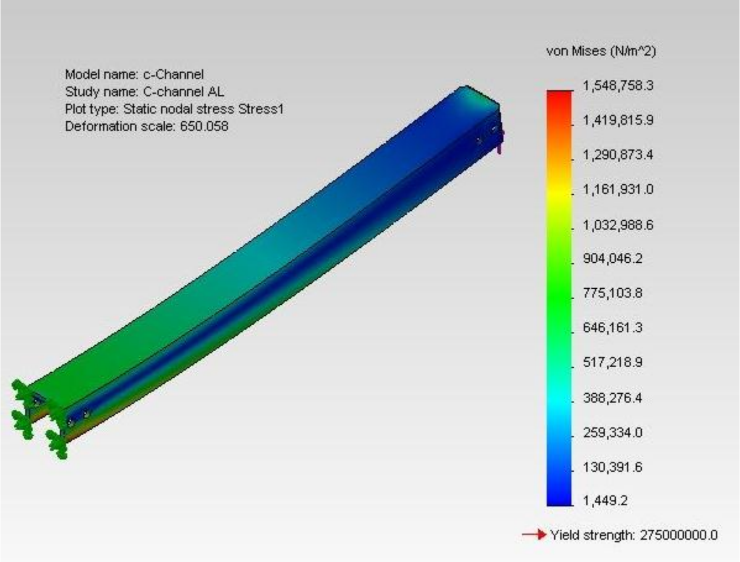

Figure 76: Stress Test Aluminum C-Channel

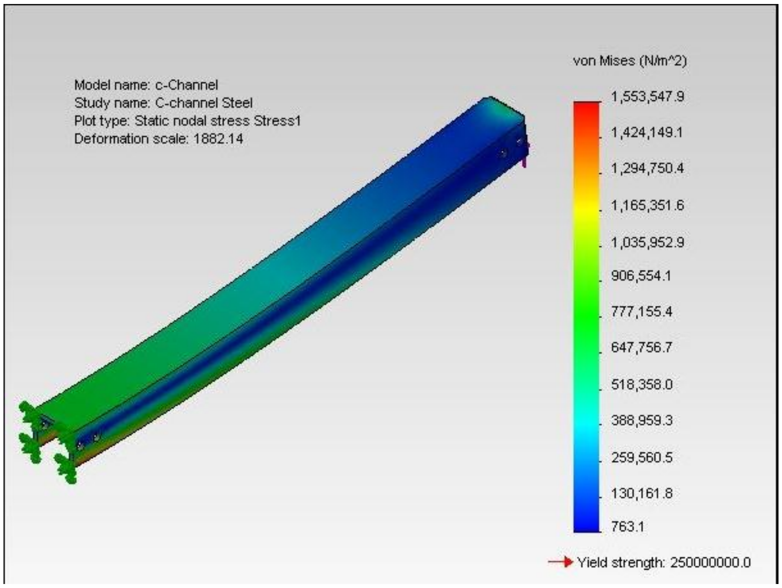

Figure 77: Stress Test Steel C-Channel

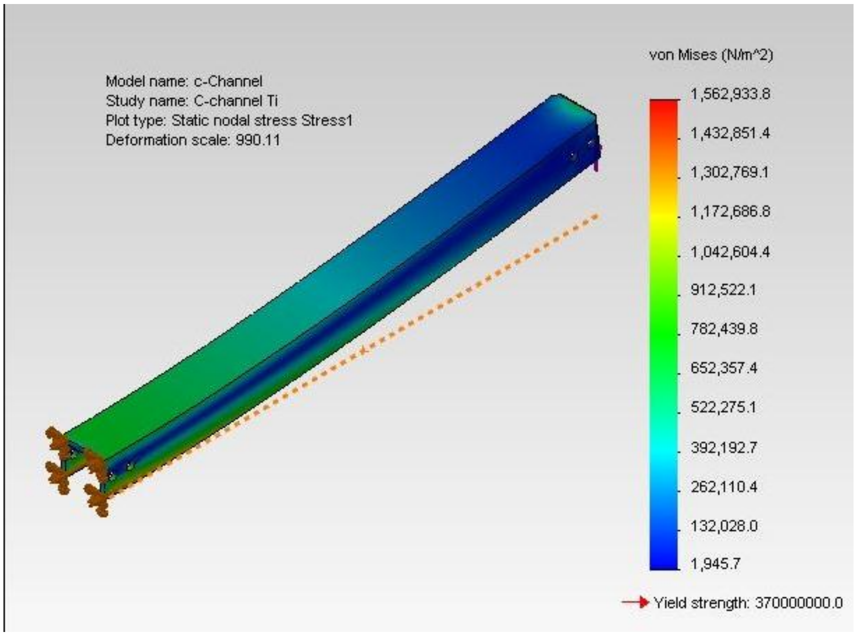

Figure 78: Stress Test Titanium C-Channel

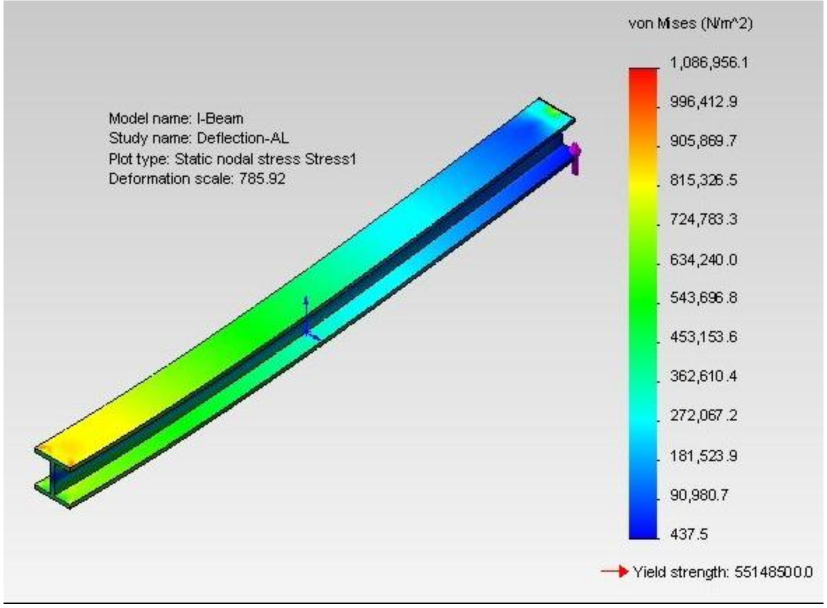

Figure 79: Stress Test Aluminum- I-beam

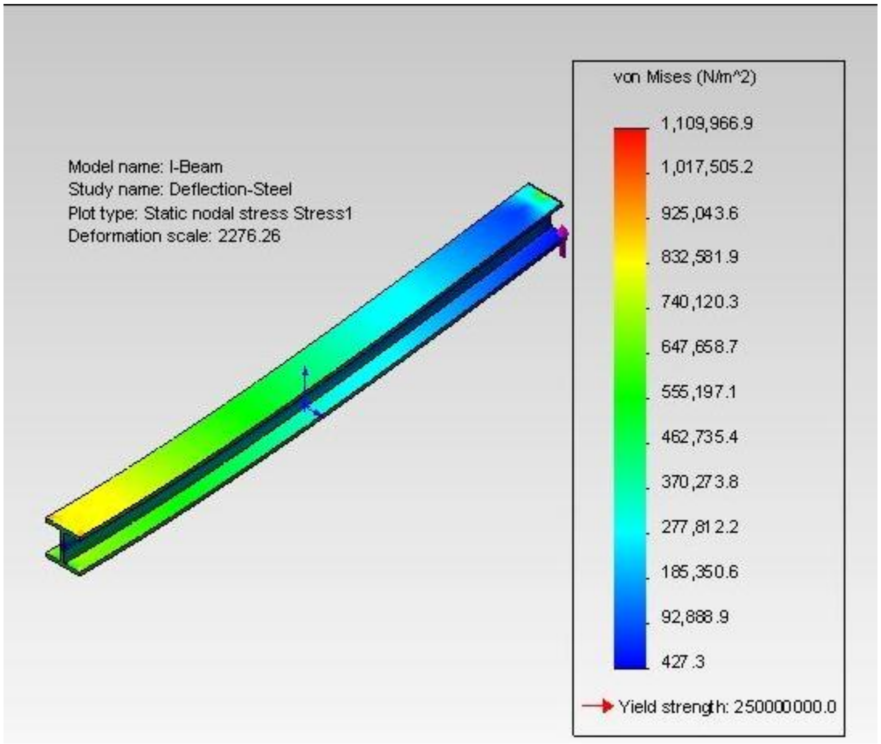

Figure 80: Stress Test Steel- I-beam

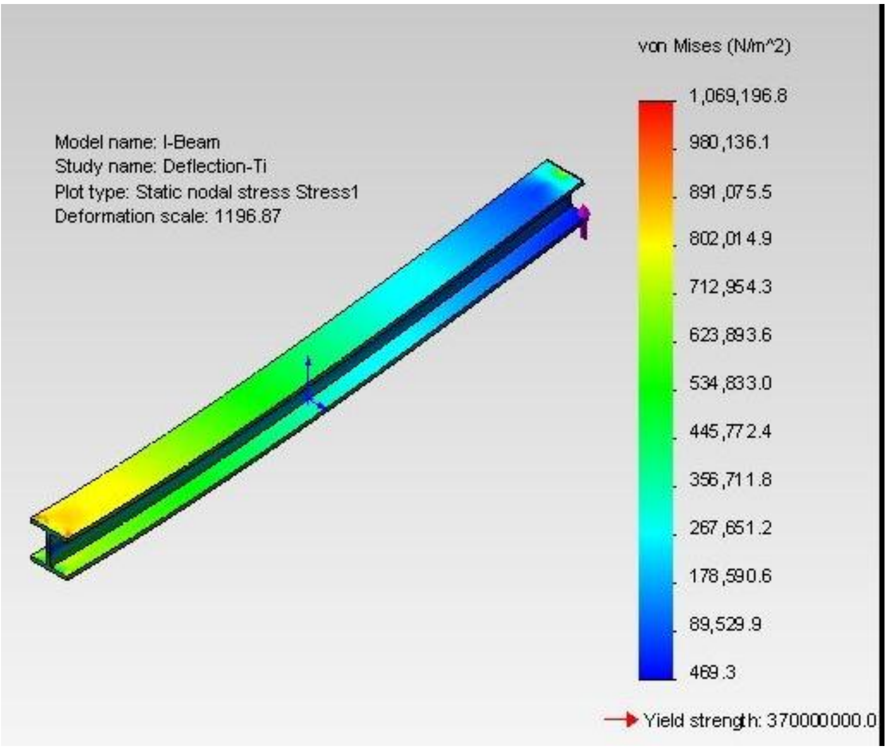

Figure 81: Stress Test Titanium- I-beam

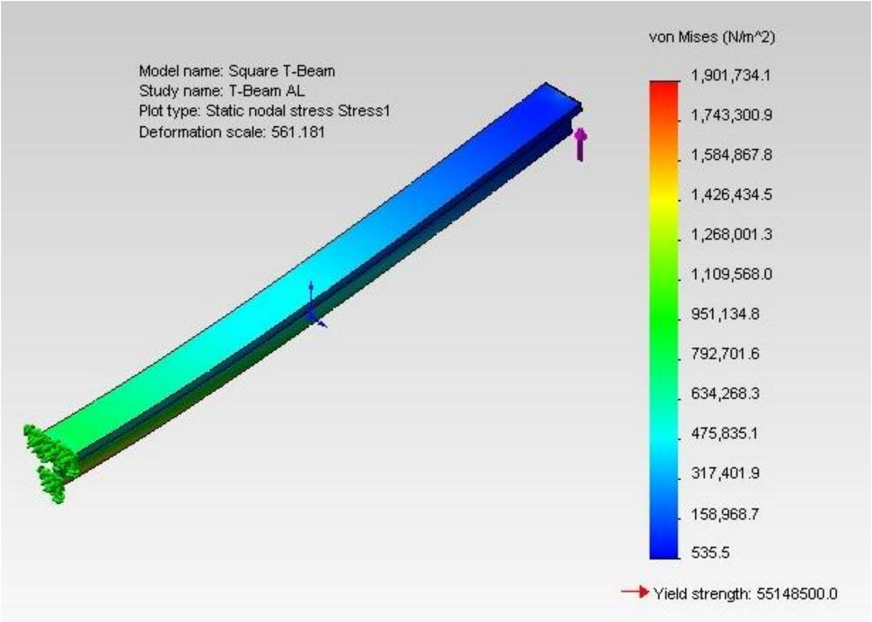

Figure 82: Stress Test Aluminum- T-beam

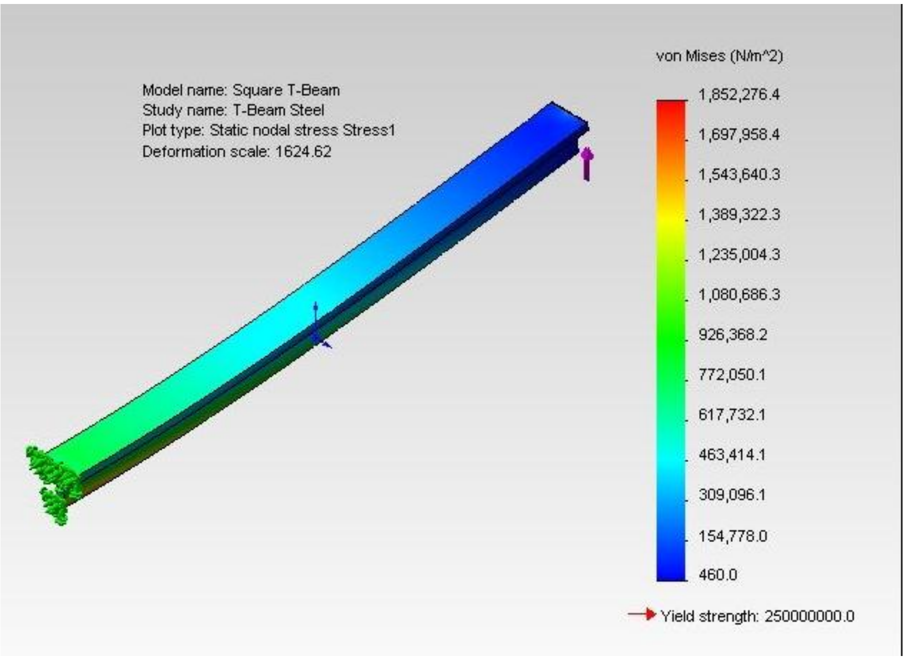

Figure 83: Stress Test Steel- T-beam

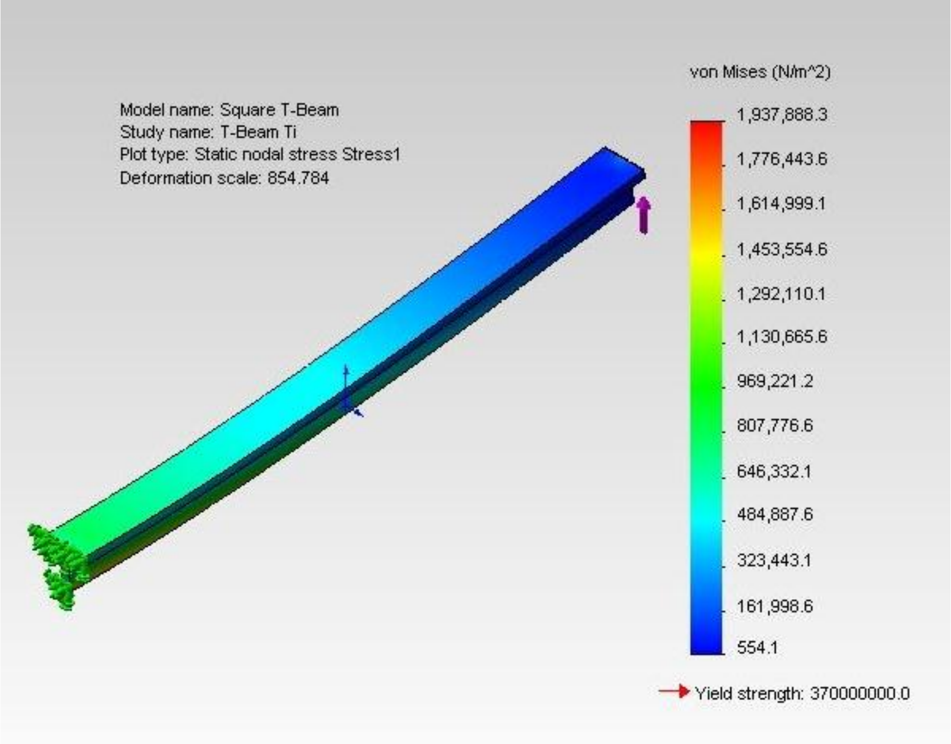

Figure 84: Stress Test Titanium- T-beam

The following simulations pertain to the deflection testing mentioned in section 6.3.

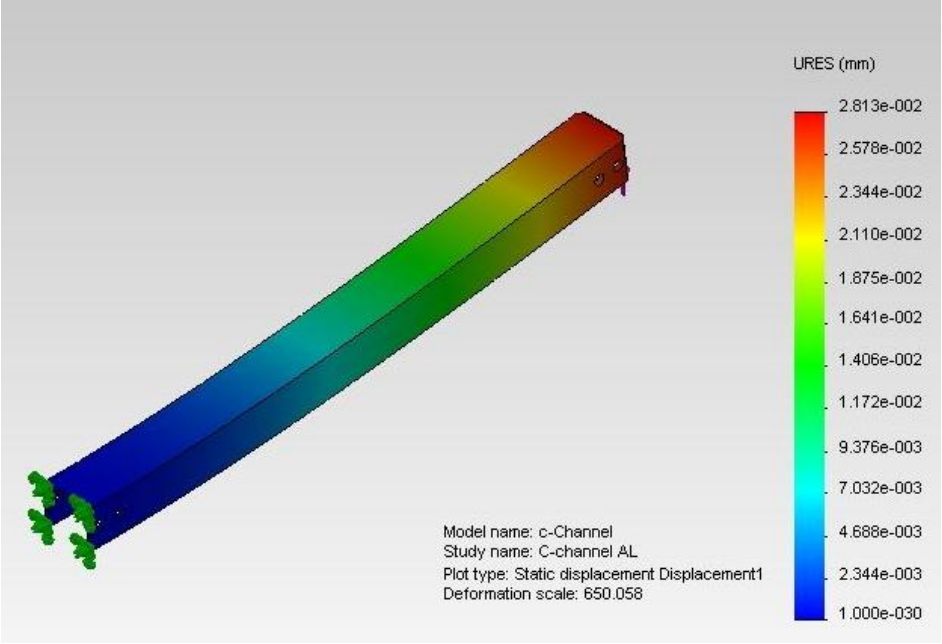

Figure 85: Deflection Test Aluminum-C-Channel

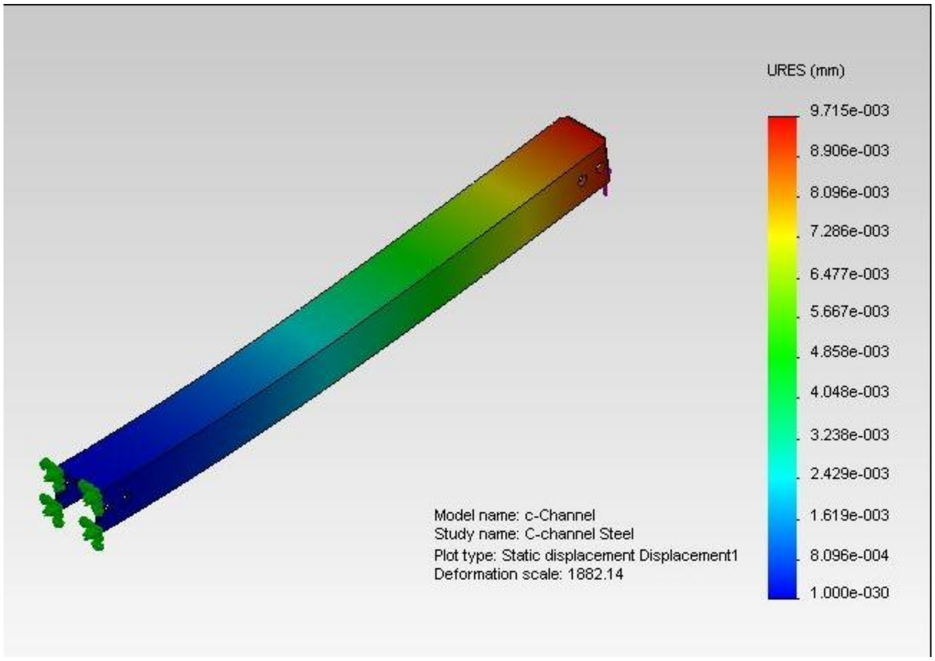

Figure 86: Deflection Test Steel-C-Channel

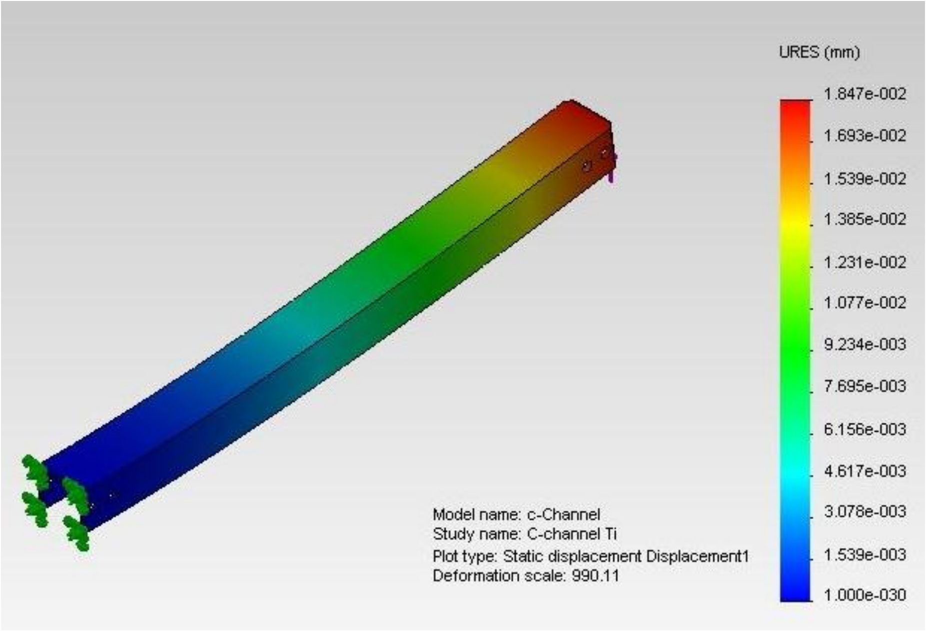

Figure 87: Deflection Test Titanium-C-Channel

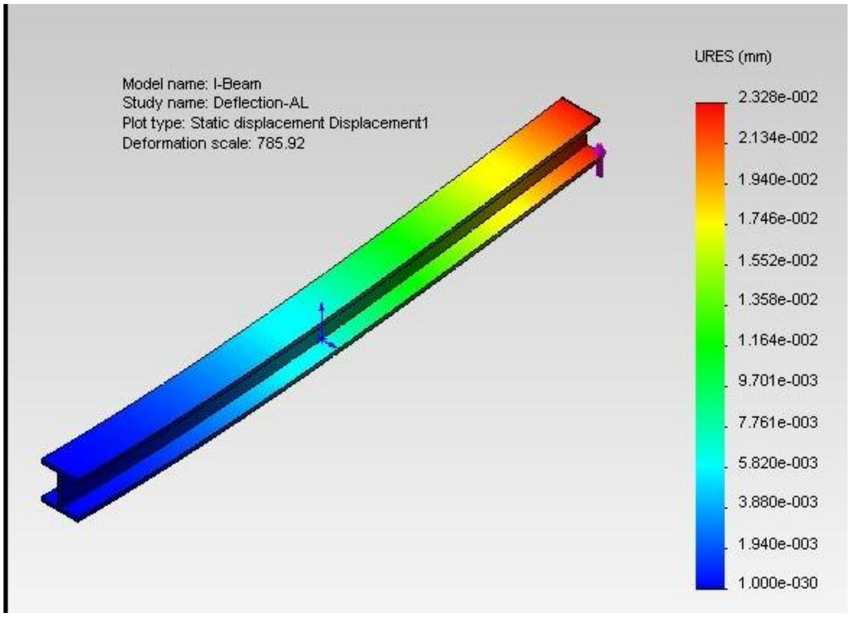

Figure 88: Deflection Test Aluminum-I-beam

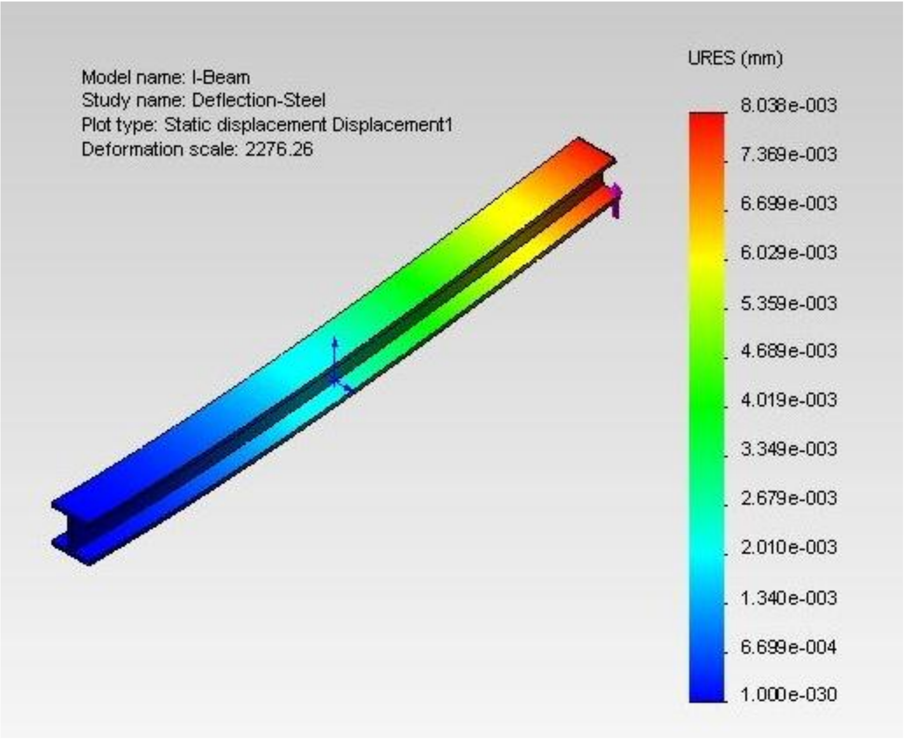

Figure 89: Deflection Test Steel-I-beam

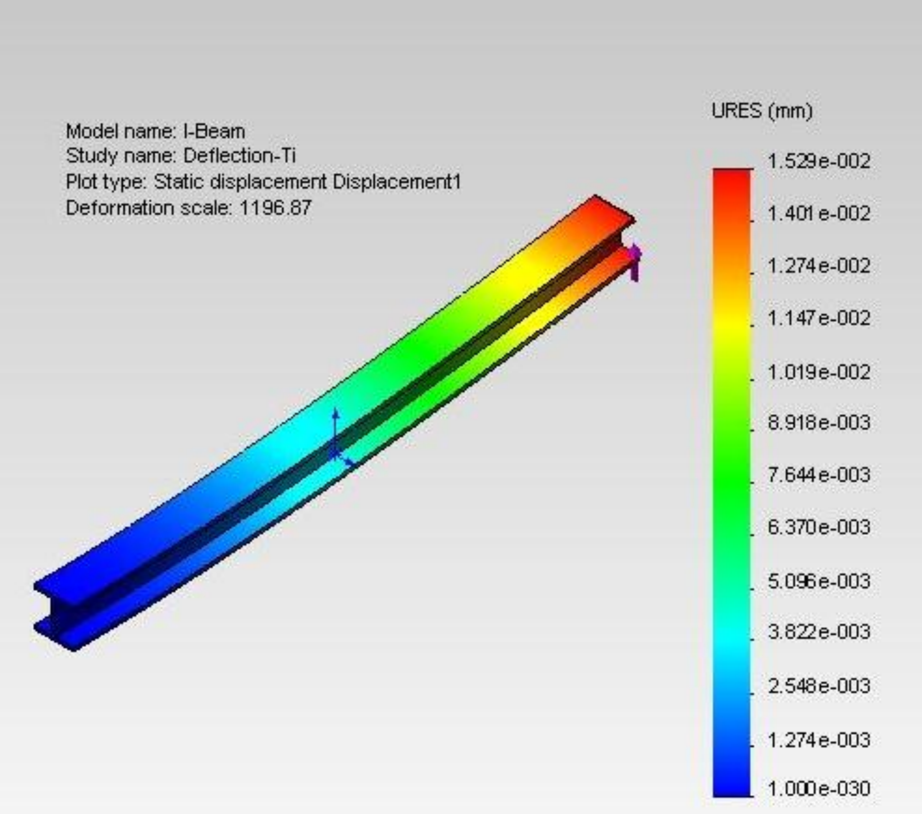

Figure 90: Deflection Test Titanium-I-beam

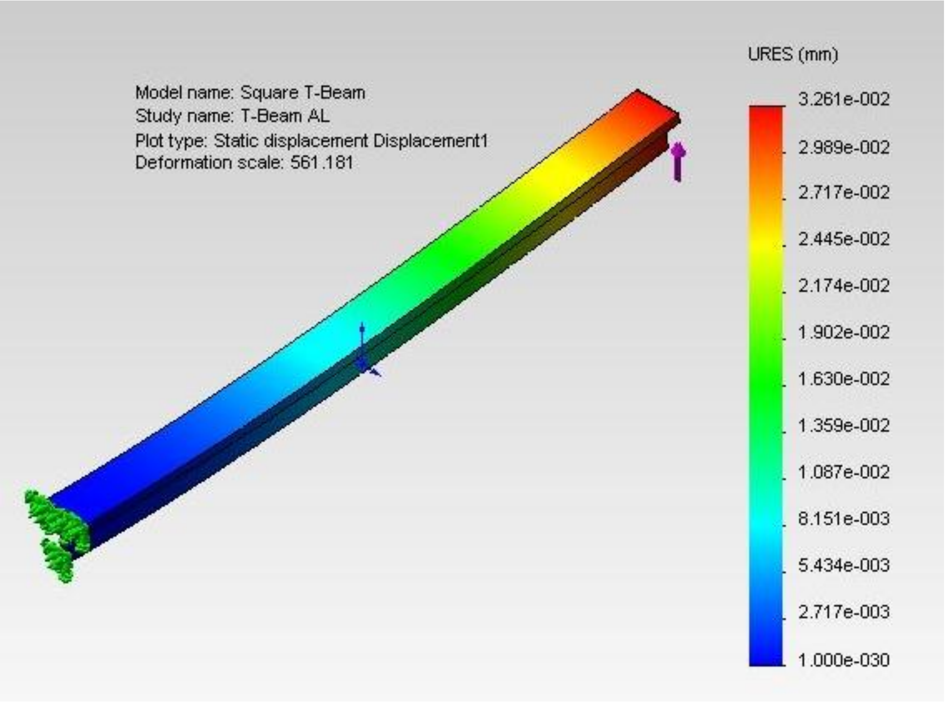

Figure 91: Deflection Test Aluminum-T-beam

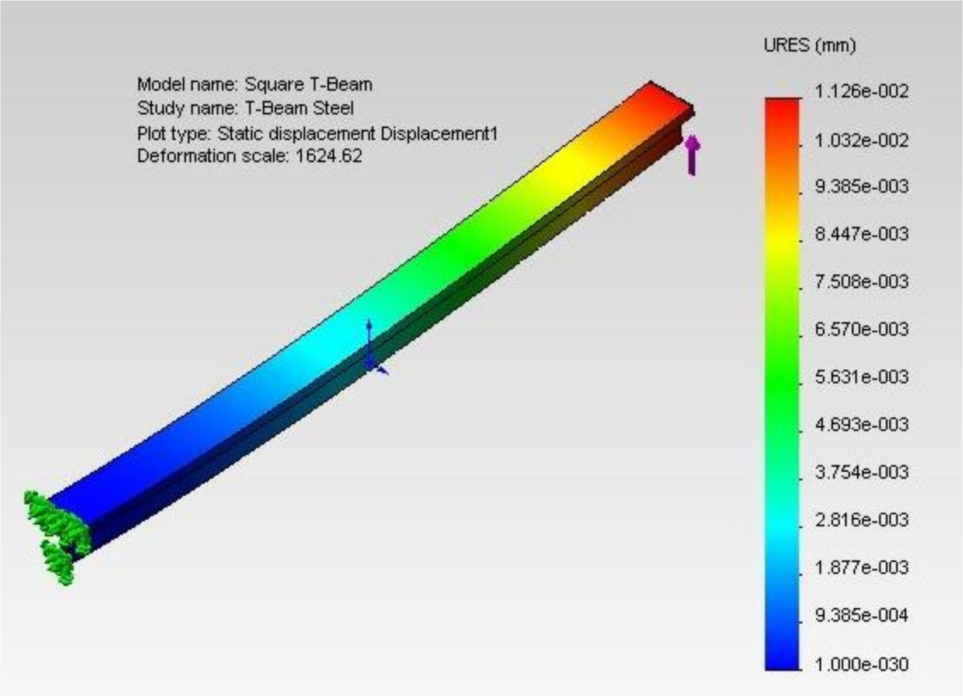

Figure 92: Deflection Test Steel-T-beam

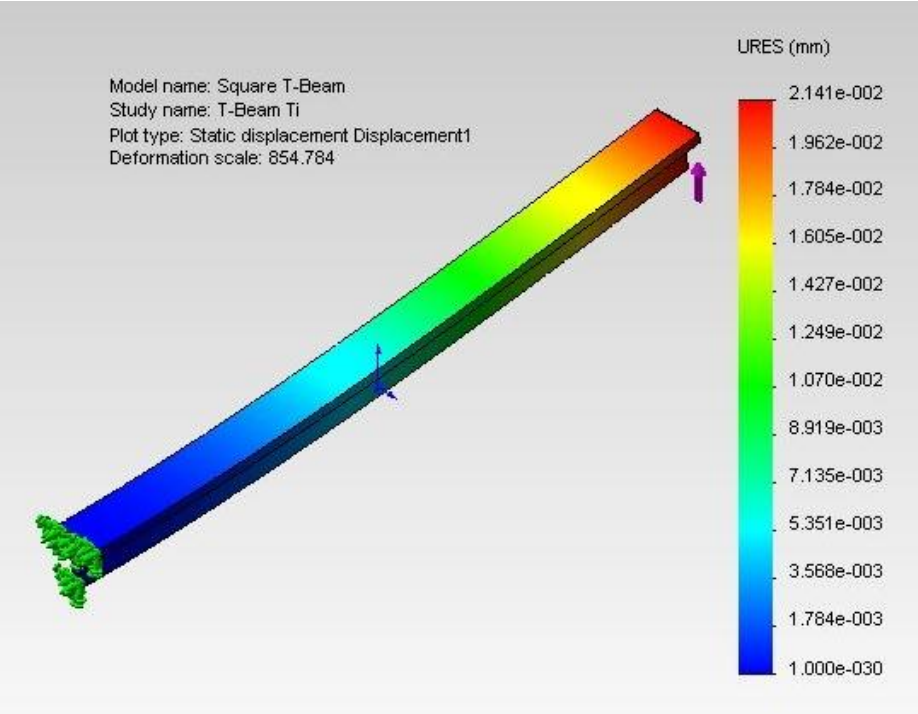

Figure 93: Deflection Test Titanium-T-beam

The following analysis pertains to the deflection testing mentioned in section 6.3 using the singularity method.

Table 11: Singularity Method- Material Properties

Constand material properties:			
Material	Young Modulus (Pa)	Ultimate Tensile Stregth (Pa)	Yield Strength (Pa)
Aluminum 6000's series	6.90E+10	1.10E+08	9.50E+07
Titanium	1.15E+11	9.00E+08	7.30E+08
Steel, ASTM-A36	2.00E+11	4.00E+08	2.50E+08

Table 12: Singularity Method- C-Channel

C-channel Profiles:	Value	Unit
b=	12.7	mm
d=	12.7	mm
s=	1.5875	mm
t=	1.5875	mm
h=	9.525	mm
Cx =	4.834659091	mm
Cy=	6.35	mm
Area =	55.4434375	mm^2
I_{xc} =	1367.62238	mm^4
I_{yc} =	859.238688	mm^4
J_{zc} =	2226.861068	mm^4

Table 13: Singularity Method- I-beam

I-Beam Profiles:	Value	Unit
b=	12.7	mm
d=	12.7	mm
s=	1.27	mm
t=	1.27	mm
h=	10.16	mm
Cx =	6.35	mm
Cy=	6.35	mm
Area =	45.1612	mm2
Ixc =	1168.916587	mm4
Iyc =	1741.234797	mm4
Jzc =	2910.151384	mm4

Table 14: Singularity Method- T-beam

Square T-Beam:	Value	Unit
b=	12.7	mm
d=	12.7	mm
s=	2.54	mm
t=	2.54	mm
h=	10.16	mm
Cx =	6.35	mm
Cy =	4.092222222	mm
Area =	58.0644	mm$_2$
I_{xc} =	6004.138314	mm$_4$
I_{yc} =	0	mm$_4$
J_{zc} =	6004.138314	mm$_4$

Table 15: Singularity Method- Sample 1

Position (mm)	Deflection (mm)								
	AL C-Channel	AL I-beam	AL Square T-beam	Ti C-Channel	Ti I-beam	Ti Square T-beam	Steel C-Channel	Steel I-beam	Steel Square T-beam
0	0.00E+00	0	0	0.00E+00	0	0	0	0	0
1	-8.70E-07	-1.018E-06	-1.98121E-07	-5.22E-07	-6.106E-07	-1.18872E-07	-3.00077E-07	-3.51088E-07	-6.83516E-08
2	-3.47E-06	-4.063E-06	-7.91034E-07	-2.08E-06	-2.438E-06	-4.7462E-07	-1.19812E-06	-1.40179E-06	-2.72907E-07
3	-7.80E-06	-9.125E-06	-1.77657E-06	-4.68E-06	-5.475E-06	-1.06594E-06	-2.69083E-06	-3.14824E-06	-6.12916E-07
4	-1.38E-05	-1.619E-05	-3.15255E-06	-8.30E-06	-9.716E-06	-1.89153E-06	-4.77491E-06	-5.58661E-06	-1.08763E-06
5	-2.16E-05	-2.526E-05	-4.91681E-06	-1.30E-05	-1.515E-05	-2.95008E-06	-7.44709E-06	-8.71304E-06	-1.6963E-06
6	-3.10E-05	-3.63E-05	-7.06717E-06	-1.86E-05	-2.178E-05	-4.2403E-06	-1.07041E-05	-1.25237E-05	-2.43817E-06
7	-4.22E-05	-4.932E-05	-9.60146E-06	-2.53E-05	-2.959E-05	-5.76088E-06	-1.45426E-05	-1.70147E-05	-3.3125E-06
8	-5.50E-05	-6.43E-05	-1.25175E-05	-3.30E-05	-3.858E-05	-7.51051E-06	-1.89593E-05	-2.21822E-05	-4.31854E-06
9	-6.94E-05	-8.122E-05	-1.58131E-05	-4.17E-05	-4.873E-05	-9.48789E-06	-2.39509E-05	-2.80224E-05	-5.45554E-06
10	-8.55E-05	-0.0001001	-1.94862E-05	-5.13E-05	-6.005E-05	-1.16917E-05	-2.95142E-05	-3.45313E-05	-6.72274E-06
11	-1.03E-04	-0.0001209	-2.35345E-05	-6.20E-05	-7.253E-05	-1.41207E-05	-3.56458E-05	-4.17053E-05	-8.1194E-06
12	-1.23E-04	-0.0001436	-2.79558E-05	-7.36E-05	-8.616E-05	-1.67735E-05	-4.23425E-05	-4.95403E-05	-9.64477E-06
13	-1.44E-04	-0.0001682	-3.27481E-05	-8.63E-05	-0.0001009	-1.96489E-05	-4.96009E-05	-5.80327E-05	-1.12981E-05
14	-1.66E-04	-0.0001947	-3.79091E-05	-9.99E-05	-0.0001168	-2.27455E-05	-5.74178E-05	-6.71784E-05	-1.30786E-05
15	-1.91E-04	-0.0002231	-4.34366E-05	-1.14E-04	-0.0001339	-2.6062E-05	-6.579E-05	-7.69737E-05	-1.49856E-05

Table 16: Singularity Method- Sample 2

100	-7.12E-03	-0.0083353	-0.001622758	-4.27E-03	-0.0050012	-0.000973655	-0.00245786	-0.002875676	-0.000559851
101	-7.25E-03	-0.0084839	-0.001651682	-4.35E-03	-0.0050903	-0.000991009	-0.002501669	-0.002926932	-0.00056983
102	-7.38E-03	-0.0086333	-0.001680783	-4.43E-03	-0.00518	-0.00100847	-0.002545747	-0.002978502	-0.00057987
103	-7.51E-03	-0.0087837	-0.00171006	-4.50E-03	-0.0052702	-0.001026036	-0.00259009	-0.003030383	-0.000589971
104	-7.64E-03	-0.008935	-0.00173951	-4.58E-03	-0.005361	-0.001043706	-0.002634696	-0.003082572	-0.000600131
105	-7.77E-03	-0.0090871	-0.001769131	-4.66E-03	-0.0054523	-0.001061479	-0.002679561	-0.003135063	-0.00061035
106	-7.90E-03	-0.0092402	-0.001798921	-4.74E-03	-0.0055441	-0.001079353	-0.002724681	-0.003187854	-0.000620628
107	-8.03E-03	-0.009394	-0.001828878	-4.82E-03	-0.0056364	-0.001097327	-0.002770054	-0.00324094	-0.000630963
108	-8.16E-03	-0.0095487	-0.001858999	-4.90E-03	-0.0057292	-0.001115399	-0.002815676	-0.003294317	-0.000641355
109	-8.29E-03	-0.0097043	-0.001889283	-4.98E-03	-0.0058226	-0.00113357	-0.002861544	-0.003347983	-0.000651802
110	-8.43E-03	-0.0098607	-0.001919726	-5.06E-03	-0.0059164	-0.001151836	-0.002907655	-0.003401932	-0.000662306
111	-8.56E-03	-0.0100179	-0.001950328	-5.14E-03	-0.0060107	-0.001170197	-0.002954005	-0.003456161	-0.000672863
112	-8.70E-03	-0.0101758	-0.001981086	-5.22E-03	-0.0061055	-0.001188651	-0.003000591	-0.003510666	-0.000683475
113	-8.83E-03	-0.0103346	-0.002011997	-5.30E-03	-0.0062008	-0.001207198	-0.00304741	-0.003565443	-0.000694139
114	-8.97E-03	-0.0104942	-0.002043059	-5.38E-03	-0.0062965	-0.001225836	-0.003094458	-0.003620489	-0.000704856
115	-9.11E-03	-0.0106545	-0.002074271	-5.46E-03	-0.0063927	-0.001244563	-0.003141732	-0.0036758	-0.000715624
116	-9.24E-03	-0.0108156	-0.002105631	-5.55E-03	-0.0064893	-0.001263378	-0.003189229	-0.003731371	-0.000726443
117	-9.38E-03	-0.0109774	-0.002137135	-5.63E-03	-0.0065864	-0.001282281	-0.003236946	-0.003787199	-0.000737311
118	-9.52E-03	-0.0111399	-0.002168782	-5.71E-03	-0.006684	-0.001301269	-0.003284879	-0.00384328	-0.00074823
119	-9.66E-03	-0.0113032	-0.002200569	-5.80E-03	-0.0067819	-0.001320341	-0.003333025	-0.003899611	-0.000759196
120	-9.80E-03	-0.0114672	-0.002232495	-5.88E-03	-0.0068803	-0.001339497	-0.003381381	-0.003956186	-0.000770211
121	-9.94E-03	-0.0116319	-0.002264557	-5.97E-03	-0.0069791	-0.001358734	-0.003429943	-0.004013004	-0.000781272
122	-1.01E-02	-0.0117973	-0.002296754	-6.05E-03	-0.0070784	-0.001378052	-0.003478708	-0.004070059	-0.00079238

Table 17: Singularity Method- Sample 3

170	-1.74E-02	-0.0203267	-0.003957304	-1.04E-02	-0.012196	-0.002374382	-0.00599381	-0.007012706	-0.00136527
171	-1.75E-02	-0.0205121	-0.00399341	-1.05E-02	-0.0123073	-0.002396046	-0.006048497	-0.007076689	-0.001377726
172	-1.77E-02	-0.0206977	-0.004029541	-1.06E-02	-0.0124186	-0.002417725	-0.006103223	-0.007140718	-0.001390192
173	-1.78E-02	-0.0208834	-0.004065696	-1.07E-02	-0.0125301	-0.002439418	-0.006157984	-0.007204788	-0.001402665
174	-1.80E-02	-0.0210693	-0.004101872	-1.08E-02	-0.0126416	-0.002461123	-0.006212777	-0.007268895	-0.001415146
175	-1.82E-02	-0.0212552	-0.004138068	-1.09E-02	-0.0127531	-0.002482841	-0.006267598	-0.007333036	-0.001427633
176	-1.83E-02	-0.0214412	-0.004174279	-1.10E-02	-0.0128647	-0.002504568	-0.006322446	-0.007397207	-0.001440126
177	-1.85E-02	-0.0216273	-0.004210506	-1.11E-02	-0.0129764	-0.002526304	-0.006377315	-0.007461404	-0.001452625
178	-1.86E-02	-0.0218134	-0.004246745	-1.12E-02	-0.013088	-0.002548047	-0.006432203	-0.007525623	-0.001465127
179	-1.88E-02	-0.0219996	-0.004282994	-1.13E-02	-0.0131998	-0.002569796	-0.006487107	-0.007589859	-0.001477633
180	-1.90E-02	-0.0221858	-0.004319251	-1.14E-02	-0.0133115	-0.002591551	-0.006542023	-0.007654111	-0.001490142
181	-1.91E-02	-0.0223721	-0.004355515	-1.15E-02	-0.0134233	-0.002613309	-0.006596948	-0.007718373	-0.001502653
182	-1.93E-02	-0.0225584	-0.004391782	-1.16E-02	-0.013535	-0.002635069	-0.006651879	-0.007782641	-0.001515165
183	-1.94E-02	-0.0227447	-0.00442805	-1.17E-02	-0.0136468	-0.00265683	-0.006706812	-0.007846912	-0.001527677
184	-1.96E-02	-0.022931	-0.004464318	-1.18E-02	-0.0137586	-0.002678591	-0.006761744	-0.007911183	-0.00154019
185	-1.98E-02	-0.0231172	-0.004500583	-1.19E-02	-0.0138703	-0.00270035	-0.006816672	-0.007975448	-0.001552701
186	-1.99E-02	-0.0233035	-0.004536844	-1.20E-02	-0.0139821	-0.002722106	-0.006871593	-0.008039704	-0.001565211
187	-2.01E-02	-0.0234897	-0.004573097	-1.20E-02	-0.0140938	-0.002743858	-0.006926502	-0.008103949	-0.001577718
188	-2.02E-02	-0.0236759	-0.004609341	-1.21E-02	-0.0142055	-0.002765605	-0.006981398	-0.008168176	-0.001590223
189	-2.04E-02	-0.023862	-0.004645573	-1.22E-02	-0.0143172	-0.002787344	-0.007036277	-0.008232383	-0.001602723

Appendix C. Code

```
#include <Servo.h>


int motorSpeed = 20;
int vibrationPer = 1;
double differential = 1;
int original[] = {0,0,0};
int temporary[] = {0,0,0};
Servo motors[4];
boolean active = false;
boolean printVal = false;
boolean modifiedDefault = false;


//Data variables.
boolean incomingData = false;
int pointer = 0;
```

```
char data[40];


//IMU variables.
boolean incomingIMUData = false;
int pointerIMU = 0;
char dataIMU[50];


/* NOT DONE */
void setup()
{
  //Initialize Serial system for Communication and for IMU.
  crashDive();
  Serial.begin(115200);
  Serial1.begin(115200);


  Servo temp;
  temp.attach(8);
  motors[0] = temp;


  Servo temp1;
  temp1.attach(9);
  motors[1] = temp1;


  Servo temp2;
```

```
temp2.attach(10);
motors[2] = temp2;

Servo temp3;
temp3.attach(11);
motors[3] = temp3;


//Call getValues.
getValues();
original[0] = 1;
original[1] = 3;

//Wait until the copter has been ordered to "power up"
while(!active)
{
  crashDive();
  getData();
}

//Danger zone. MOTORS WILL BE POWERED IN 5 SECONDS.
Serial.println("Arming motors");
delay(5000);
armMotors();
```

```
}


/* DONE */
void loop()
{
  if(active)
  {
    //Check for new data.
    getData();
    stabilize();
  }
  else
  {
    getData();
    crashDive();
  }

  if(printVal)
  {
    Serial.print("G:");
    for(int i = 0; i<3 ; i++)
    {
      Serial.print(temporary[i]);
      if(i != 2)
```

```
      {
        Serial.print(", ");
      }
    }
    Serial.println();
  }
}

/* DONE */
void getValues()
{
  //Draw values from IMU and store into Temp Array.
  if (incomingIMUData)
  {
      if(Serial1.available() > 0)
      {
        char temp;
        temp = Serial1.read();
        if (temp == 'G')
        {
          //Caught gyro command.
          processIMUData();
          incomingIMUData = false;
          pointerIMU = 0;
```

```
          return;
        }
        dataIMU[pointerIMU++] = temp;
      }
  }
  else if(Serial1.available() > 0 && Serial1.read() == 'T')
  {
    incomingIMUData = true;
  }
  else
  {
    Serial1.read();
  }
}

/* DONE */
void processIMUData()
{
   int value = 0;
   while(dataIMU[value] != 'A')
   {
     value++;
   }//Found first letter of "ACCELS.
```

```
while(dataIMU[value] != ':')
{
  value++;
}//Found ":" at the end of ACCELS.
value++;

int tempValue;

//Grab X, Y, and Z.
for (int i = 0; i < 3; i++)
{
  tempValue = 0;
  boolean neg = false;
  while(dataIMU[value] == ' ')
  {
    value++;
  }

  while((dataIMU[value] - '0' <= 9 && dataIMU[value] - '0' >= 0) || dataIMU[value]  == '-')
  {
      if(dataIMU[value] == '-')
      {
        neg = true;
      }
```

```
         else
         {
           tempValue = tempValue * 10;
           tempValue += dataIMU[value] - '0';
         }
         value++;
     }//Grab the X value;
     value++;
     if(neg) tempValue *= -1;
     temporary[i] = tempValue;
   }
}

/* DONE */
void armMotors()
{
  //Activate motors.
  for (int i = 0; i < 4; i++)
  {
    //Turn on each individual motor.
    Serial.print("Arming motor ");
    Serial.println(i);
    motors[i].write(1000);
    delayMicroseconds(1000);
```

```
    motors[i].write(2000);
    delayMicroseconds(1000);
    motors[i].write(1000);
    delay(1000);
  }
}

/* DONE */
void powerMotor(int motor, int motor2, double percentageOfPower, double percentageOfPower2)
{
    motors[motor].write(1000 + (percentageOfPower*10));
    motors[motor2].write(1000 + (percentageOfPower2*10));
}

/* DONE */
void stabilize()
{
  getValues();
  //Pitch -
  if (original[0] - temporary[0] > vibrationPer)
  {
    powerMotor(0,1,motorSpeed + differential,motorSpeed - differential);
  }
```

```
//Pitch +
else if (original[0] - temporary[0] < -vibrationPer)
{
  powerMotor(0,1,motorSpeed - differential,motorSpeed + differential);
}
else
{
  powerMotor(0,1, motorSpeed, motorSpeed);
}

//Roll -
if (original[1] - temporary[1] > vibrationPer)
{
  powerMotor(2,3,motorSpeed + differential,motorSpeed - differential);
}
//Roll +
else if (original[1] - temporary[1] < -vibrationPer)
{
  powerMotor(2,3,motorSpeed - differential,motorSpeed + differential);
}
else
{
  powerMotor(2,3, motorSpeed, motorSpeed);
}
```

```
}


/* DONE */
void getData()
{
  if (incomingData)
  {
    while(Serial.available() > 0)
    {
      char temp;
      if(Serial.available() > 0)
      {
        temp = Serial.read();
      }
      if (temp == '>')
      {
        processData();
        incomingData = false;
        pointer = 0;
        return;
      }
      data[pointer++] = temp;
    }
  }
```

```
  else if(Serial.available() > 0)
  {
    if(Serial.read() == '<')
    {
      incomingData = true;
    }
  }
}

/* NEEDS MORE COMMANDS */
void processData()
{
  int value = 0;
  if (data[value] == 'E')
  {
    crashDive();
    Serial.println("Crash Dive In Progress");
  }
  else if (data[value] == 'A')
  {
    active = true;
    Serial.println("Quad Active.");
  }
  else if (data[value] == 'S')
```

```
  {
    int finalValue = 0;
    value++;
    while(value < pointer)
    {
      finalValue = finalValue * 10;
      finalValue += data[value] - '0';
      value++;
    }
    Serial.print("Setting motor speed to ");
    Serial.println(finalValue);
    motorSpeed = finalValue;
  }
  else if (data[value] == 'V')
  {
    printVal = !printVal;
  }
  //Handle incoming commands.
}

/* DONE */
void  crashDive()
{
  active = false;
```

```
  powerMotor(0,1,0,0);

  powerMotor(2,3,0,0);


}
```