

DASL UAV Antenna Gimbal

Final Proposal

Kalli Albright

Kaitlyn Barr

Dustin Branges

Daniel Johnson

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Project Sponsor: Dr. Michael Shafer

Faculty Advisor: Sarah Oman

DISCLAIMER

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EXECUTIVE SUMMARY

This report serves the purpose of documenting the progress of the design and manufacturing of a gimbal for an unmanned aerial vehicle (UAV) antenna. The purpose of this project is to make the tracking of wild animals faster, easier, and more accurate. The client, Dr. Michael Shafer, through the Dynamic and Active Systems Lab (DASL), is in the progress of designing a UAV capable of carrying a directional antenna that can detect the source of very high frequency (VHF) telemetry tags on animals. However, the current design only allows for the antenna to be mounted parallel to the ground. Due to the radiation pattern of the antenna, it has been determined that more accurate data can be collected if the device was able to pitch towards the ground. This task of pitching the antenna has been entrusted to team D1 of the Northern Arizona University Capstone team 2017-2018. To successfully complete this project, the team must create a gimbal device that will allow the antenna to rotate up to 45° . This motion shall be done in one of two modes, where the user may either enter a specific desired angle, or through a constant sweeping motion. The antenna must be able to confirm its angle position and relay it back to the user in real time. More specific requirements are further discussed in this report such as weight and size restraints.

Working towards the objective of the project, the team created a linkage system. This design consists of two points of connection between the UAV and antenna. The first point is towards the back of the antenna and acts solely as a free moving pin connection. This is achieved through two mounting brackets and a pivot base that attaches around the body of the antenna. The linkage towards the front of the system is the portion that controls movement. This system again consists of two mounting brackets and a pivot base, however, between these two components is a rigid bar. One end of the rigid bar attaches directly to the pivot base, while the other goes through the mounting bracket and is connected to a small motor. As this motor rotates, it forces the bar to rotate respectively along with the antenna, due to the connection through the pivot base. With this design, the team is able to easily modify the achievable angle, by changing the distance between mounts, or the length of the rigid bar. The overall estimated cost of this contraption comes in just under \$200, which is well within the \$500 dollar goal for the team. This margin allows the team the potential to buy a lighter weight, more efficient motor, create more prototypes for testing, or provide the client with spare parts.

The manufacturing of the design described above will be implemented next semester through several phases of prototyping, followed by extensive testing. All testing will first be conducted on the ground to ensure no malfunctions cause damage to the client's pre-existing UAV. Once the device has been proven to work successfully on the ground, the team may attach it to the UAV for field testing. A detailed schedule of implementation for the second semester has also been included in this report.

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1 BACKGROUND

1.1 Introduction

Wildlife is tracked using Very High Frequency (VHF) telemetry tags. Traditionally, humans spend hours in nature triangulating signals coming from the tags on the wildlife. This process can be both time consuming and strenuous. The Dynamic and Active Systems Lab (DASL), led by Dr. Michael Shafer is currently developing an Unmanned Aerial Vehicle (UAV) with a Telonics RA-23K VHF antenna, to make the tracking of wildlife easier and more efficient. Rather than humans tracking through forests, a UAV can fly above the forest canopy to locate the source of a signal. However, the antenna is not able to properly receive data if a tag is below the UAV and therefore not within the radiation pattern. Therefore, the D1 Capstone team is tasked with creating a gimbal system for the user to control the angle of the antenna while the quadcopter is in flight. The system must also be able to report the angle of the antenna back to the user to ensure accurate and reliable data. The goal of this project is to make the collection of data faster, therefore allowing the user to be more productive in the tracking of animals. This system is of interest to the DASL because the ability to angle and rotate the antenna will remove the need for the UAV to pitch, ultimately making flight more stable. Creating a system that can pitch the antenna while the UAV remains stable will allow the user to receive more accurate data on the location of tags. Overall this will assist in resolving ecological research paradigms as wildlife tracking will be fast and efficient. The next section will further describe the project.

1.2 Project Description

The following is the original project description provided by the sponsor:

“The Dynamic and Active Systems Lab is currently developing an unmanned aerial vehicle for use in tracking small wildlife using VHF radio beacon tags. The project team would like to be able to move the VHF receiving antenna on the UAV in flight. Students on this project will build a gimbal system that can rotate an antennal about a single axis continually or to a specified angle. Communication will be maintained to a flight computer, which will send commands and receive angle position information from the subsystem. Detailed requirements regarding size, weight, power, communication, etc. will be determined in the early stages of the project. The ideal team would consist of two mechanical and two electrical engineering students.” [1].

Since receiving this description, the only thing that has differed is the team composition. The team now consists of four mechanical engineers. Additional, details have been specified by meetings with the client, which will be discussed in the next chapter of the report.

2 REQUIREMENTS

This chapter will discuss the requirements of the project including customer requirements and engineering requirements. These will then be weighted against each other in the house of quality to determine the how crucial each requirement is. The chapter begins with the customer requirements explained in section 2.1.

2.1 Customer Requirements (CRs)

Here the customer needs and their related importance to the project will be discussed. After gathering notes from the first meeting with the client, the team formulated five needs they deemed necessary for the project. These needs include a simple, modular design, which has multiple modes of movement and can relay the angle to the user. The design should also be maintainable, as it will be exposed to a high potential for damage. Each customer need is ranked on a scale from 1-5 based on what the team believes to be the most important. Each need is described thoroughly in the following subsections.

2.1.1 Simple

Simplicity is one of the main needs stressed by the client. It is important to have a device, which works well rather than a complicated design that fails to complete the desired task. To achieve simplicity, the device shall use as few linkages as possible. On top of this, there shall be as few total components as possible, such as screws, bolts, plates, etc. This will help ensure low cost and success in the field. The team ranked this need as a 4/5 due to the client's insistence on a well-done and simple project rather than an incomplete and complex design.

2.1.2 Modular

The second customer need is that the device must fit on a pre-existing modular housing for the UAV. Each part shall be easily integrated with the pre-existing UAV design, to ensure the success of each flight. The modular design is important, but the team has flexibility in how their device may be mounted and moves, so the modular design is ranked as 3/5 for importance of the customer need.

2.1.3 Multiple modes of movement

Another customer request is that the device shall be able to move in multiple modes. One mode shall be manual, controlled from the ground, in minimum desired intervals. The other mode shall be automatic. The operator shall be able to enable an automatic mode and have the gimbal move the antenna continuously on a predetermined path. Although the sweep mode would be beneficial to the client, no emphasis was directly placed on this topic, therefore it was only ranked as 2/5 for customer needs.

2.1.4 Relay angle to user

The most crucial customer need is that the angle of the antenna may be communicated to the client. This information shall be accurate and easy to read. This requirement is crucial to the customer, because without knowing the exact angle of pitch for the antenna, the data loses accuracy and becomes meaningless. Failing to meet this need would render the project a failure; therefore it is ranked as 5/5 for importance.

2.1.5 Maintainable

The last customer requirement is for the device to be made with easily maintainable parts. When necessary the parts shall be replaceable with off the shelf parts, which are easily obtainable, or with spare parts provided by the team. When possible, 3D printing will enable recreation of parts for lower cost and ease of manufacturability. All part files will be maintained for future production. The maintainability of

the device is also crucial to the project, as the device will be mounted on the bottom of a quadcopter and has the most potential for damage if a fall occurs. This means the device shall be easy to manage and maintain, even in the field. This led the team to rank the need as 4/5.

Overall, the team's objective is to deliver a simple, maintainable, and modular antenna gimbal that has the capability to move in multiple modes while conveying the exact angle back to the user. Engineering requirements developed based on these customer requirements will be discussed in the next section.

2.2 Engineering Requirements (ERs)

This section will discuss the nine engineer requirements provided by the client, and further developed by the team. Each of the requirements, listed in Table 1, must be met in order for the device to successfully fulfill the project objectives. If one requirement is not met, the device becomes useless to the customer.

Table 1: Engineering Requirements for Antenna Gimbal

Requirement	Units	Target	Tolerance	Range
Weight	lbs	0.5	-0.1	.4-.5
Size	in	5.4x5.4x3	±1	N/A
Serial Communication	Bd	9600	N/A	N/A
Angle of travel	degrees	60	30	0-90
Power Input	V	5	±.5	4.5-5.5
Cost	\$	500	500	500-1000
Linkages	#	4	N/A	N/A
Degrees of freedom	#	1	+1	1-2
Part Installation	minutes	60	±10	50-70

Each of the requirements shown in Table 1, are further explained in the following subsections.

2.2.1 Gimbal Weight

Due to the maximum payload the UAV can carry, the gimbal attachment shall not exceed 0.5 lbs. Idealistically, the team will be able to create a gimbal even lighter, which will allow for longer sustained flight of the UAV.

2.2.2 Size

The external dimensions of the gimbal are defined by the existing modular design of the quadcopter. For the gimbal to be used it shall fit within the allotted space of the modular UAV housing. This means, the design shall adhere to a space no larger than 5.4 in. x 5.4 in.

2.2.3 Serial communication

The existing UAV is controlled through a Raspberry Pi computer. To be able to integrate the gimbal into the onboard flight controller, an Arduino microcontroller must be used to control the gimbal. The Arduino system shall be able to communicate at a 9600 Baud rate via USB to the onboard Raspberry Pi. Without this communication, the user would not be able to control the gimbal angle or know the precise angle of the antenna. The Baud rate can be measured using an oscilloscope, which the team has access to through the DASL.

2.2.4 Angle of Travel

The gimbal must allow for no less than 60° of travel below the horizontal axis. If possible the client would prefer the gimbal be able to travel to 90°^{below} the horizontal axis, but it is not critical to success. The team will strive to meet desired qualities, after successfully completing stated requirements.

2.2.5 Power Input

The gimbal and controller shall be able to operate off the UAV's own power supply. The team is allotted 5 V to run the gimbal system after all necessary flight component power consumptions are accounted for. To test the power the team will use a digital multimeter, which they also have access to through the DASL.

2.2.6 Cost

For this project, the team is given an ideal budget of no greater than \$500.00. However, if allowable circumstances arise, the client is willing to provide funding up to \$1,000.00.

2.2.7 Linkages

In order to maintain a simple design, the system shall contain less than 4 linkages for movement of gimbal. This requirement also helps to keep the design maintainable, as there are fewer components to repair in the case of an accident in the field.

2.2.8 Degrees of Freedom

The gimbal must be able to lower the antenna on a single axis. Furthermore, if weight and cost allows, the client would also like for the gimbal to be able to rotate about a second horizontal axis, if it does not over complicate the simplicity of the design.

2.2.9 Part Installation Time

Given the modular design of the UAV, the gimbal shall be able to either be installed or removed in no more than 60 min with a ± 10 min tolerance. This shall ensure the device is maintainable in the field in the case of a crash or other failure.

2.3 Testing Procedures (TPs)

This section will outline testing procedures to verify all engineering requirements are met by the system. The majority of the tests will either pass or fail, with no room for tolerances. Each test is described in the following subsections.

2.3.1 Size

The overall surface area of the system mounting to the UAV shall be less than 15 in². This requirement shall be tested by measuring the surface area of the system that will attach directly to the UAV, such as the top of the mounts. This area can be measured with a ruler and calculated using the geometry of the shape of the mounts. If this area is less than 15 in², the design passes the size requirement test.

2.3.2 Gimbal Weight

To test the weight requirement, the system shall be weighed with a postal scale or other high accuracy scale provided by the DASL. The total mass of the device shall fit within the allotted mass of 0.5 lbs.

2.3.3 Angle of Travel

The angle of travel shall meet or exceed the ability to go from 0° (horizontal) to 45° (new requirement proposed by client, no longer 60°) below horizontal. This shall be tested within the modular plates of the UAV to ensure correct angles are achieved. It will be measured using the angle reported by the system and approximated with a protractor or by eye to ensure a correct reading from the system.

2.3.4 Modes of Rotation

The device shall be tested for both stepping modes and continuous motion. This shall be performed with the motor outside of the assembly. The team will run a program, telling the motor to go to either move to a specific angle, or continuously sweep from 0° to 45°. The motor shall then be installed into the system and tested with all components to ensure correct function inside the UAV assembly. If the system is capable of moving the antenna to a specified angle as well as continuously, the requirement will be met. This test shall be conducted without measurement tools, as it can be observed by watching the movements.

2.3.5 Serial Communication

To allow communication between the Arduino Pro Mini, which will control the antenna assembly, and the Raspberry Pi, which acts as the UAV onboard flight controller, the system must operate at the same baud rate. The team was given a specified baud rate of 9600 that should allow the Arduino Pro Mini and Raspberry Pi to communicate. From past experiences, the team is aware that the baud rate of two devices set the same still do not always communicate. To test against this, the team will run a code which displays the actual operating baud rate of the Arduino Pro Mini. The team will then be able to adjust the baud rate until communication with the Raspberry Pi is achieved.

2.3.6 Power Input

The power input test will be conducted by using a digital multimeter (DMM) to measure the voltage supply from the UAV to ensure the correct voltage is being supplied to the Arduino Pro Mini. To operate, the Arduino must have an incoming voltage of 5V to 12V. Next, the DMM will be used to measure the current being supplied. The Arduino Pro Mini has a recommended operating current between 0.5A to 2A. If the power supplied from the UAV is within these requirements then the Arduino will be easily incorporated into the system. If the power supplied is insufficient in anyway, the team will instead have to incorporate a battery with the correct power characteristics in order to operate the Arduino.

2.3.7 Cost

All costs for components and services shall not exceed the budget of \$500. This requirement will be tested by adding the total cost of components for the gimbal system. If the total budget is less than \$500, the requirement is met.

2.3.8 Linkages

The total number of moving components shall not exceed 4. This requirement can be tested by counting the number of linkages present in the design. There are no special tools or equipment required to measure this specification.

2.3.9 Part Installation Time

The installation of the system shall take no more than one hour. The team shall conduct multiple trials of replacing the entire system. This will be done using a timer found on any iPhone with a resolution of

3 EXISTING DESIGNS

This chapter discusses the approaches to designing the antenna gimbal system. Sources used for research include article databases, and pre-existing design websites. In addition to researching pre-existing designs, this chapter includes the functional decomposition including the black box and functional models. Lastly the team researched the subsystems required for their project and researched existing designs at each subsystem level.

3.1 Design Research

To begin design research, the team first needed a basic understanding in VHF telemetry tracking. It was determined that “to locate an animal using VHF radio tracking, scientists must be close enough to the animal with the radio antenna so they can pick up the signal from the radio transmitter on the animal” [2]. Once a signal is located, the scientists and researchers are able to follow the direction from which the signal is the strongest in order to locate the animal. This is traditionally done on foot, which can be painstaking and time consuming. Some scientists take to cars or planes to reach the signal faster. With this information, the benefit of being able to track wildlife using a UAV became more apparent. The UAV could cut out the time for tracking on foot, the accessibility cars and trucks might not be able to reach, and the cost of renting an airplane. However, after further research on the reception radiation pattern for VHF, pertaining especially to the RA-23K VHF Antenna used by the DASL lab, the team also saw a need for the need for a rotating antenna. As seen in Figure 1, the RA-23K antenna receives radiation patterns on a horizontal plane, with more information incoming to the front of the antenna compared to the back. Being able to pitch the antenna using a gimbal on the UAV would allow for a larger range of reception and higher data collection and accuracy, especially if the signal is coming from below the UAV.

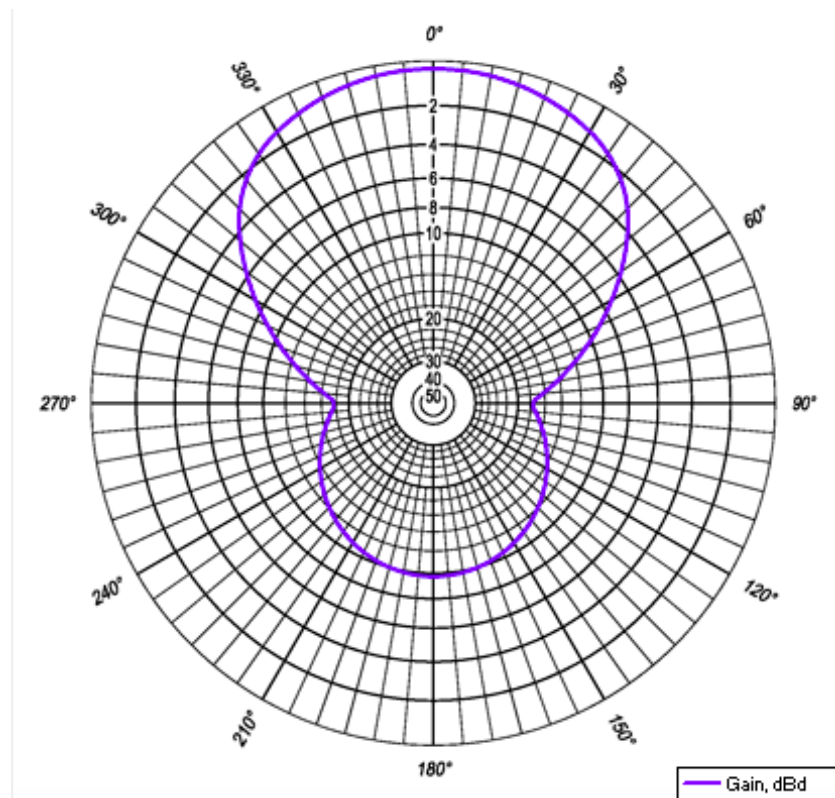


Figure 1: RA-23K Reception Radiation Pattern [3]

After basic research on VHF telemetry tracking, the team began looking into existing designs. Using the engineering database, Compendex, the team found that using UAVs to track wildlife is an ongoing development. Other researchers have also reported “the use of small unmanned aircraft systems (UAS) for wildlife tracking offer many advantages such as cost reduction, human effort reduction and data acquisition efficiency due to the usage flexibility offered by the system in comparison to conventional methods” [4]. This article describes the use of acoustic telemetry to track wildlife using a small UAV. This varies from the team's project as the RA-23K antenna reads VHF and requires a pitch angle. Another team was able to use a commercial radio controlled model aircraft to locate fish tags placed both on land and underwater [5]. While these reports showed the real life applications of using UAVs in tracking wildlife, they did not focus on the rotation of the antenna, so the team began searching the web for antenna pointing mechanisms to help formulate ideas and concepts they might incorporate into their own device. Upon this search, the team found a large range of designs including the MOOG Antenna Pointing Mechanism, Octopus UAV Tracking Antenna, and Marcus UAV Retractable Gimbal. Each of these designs are further described next in the system level section of the report.

3.2 System Level

This section discusses existing designs that address similar requirements relevant to the DASL UAV Antenna project. The three designs found each have desirable qualities for the team’s project, however, they also all have features that would not be compatible with the DASL UAV, which will be explained in each subsection.

3.2.1 Existing Design #1: MOOG Antenna Pointing Mechanism

The MOOG Antenna Pointing Mechanism [6], Figure 2, is a small device commonly mounted on spacecraft. It meets many of the requirements needed for the DASL UAV gimbal antenna. This mechanism is able to rotate in two directions and in multiple modes to relay information back to the user. However, this product does not meet the low cost need nor is it maintainable, making it impractical for this design. However, this does provide the team with one example of allowing two directional rotation, which is not a critical requirement, but desired by the client.



Figure 2: MOOG Antenna Pointing Mechanism [6]

3.2.2 Existing Design #2: Octopus UAV Tracking Antenna

The Octopus Tracking Antenna [7], Figure 3, is used on the ground to track UAVs in the air, but could potentially be used to mount to a UAV and track other signals. The advantage of this tracking antenna is that it can be switched between a directional and omni antenna. It also has an integrated pointed algorithm that automatically points towards the direction of the strongest signal. This could be very useful while tracking wildlife, especially if the team’s system is able to relay the exact angle to the user. Rather than the user inputting multiple angles and trying to find the strongest signal, the antenna would automatically

sweep for the strongest signal and point towards it. This angle would then be reported back for quick and accurate data collection. The limiting factors to this existing design is the weight, which would not be feasible on a UAV.



Figure 3: Octopus UAV Tracking Antenna [7]

3.2.3 Existing Design #3: Marcus UAV Retractable Gimbal

The Marcus UAV Retractable Gimbal [8], Figure 4, is a 2 direction rotational gimbal mounted to a UAV. However, instead of mounting an antenna to the gimbal, they use it for a camera. This gimbal still meets several requirements such as multiple modes of movement, lightweight, and full range rotation. The full range of movement comes from the fact that the camera is embedded in the system rather than sticking out like an antenna. However, the team can use this design to further formulate encapsulating designs for the antenna gimbal.

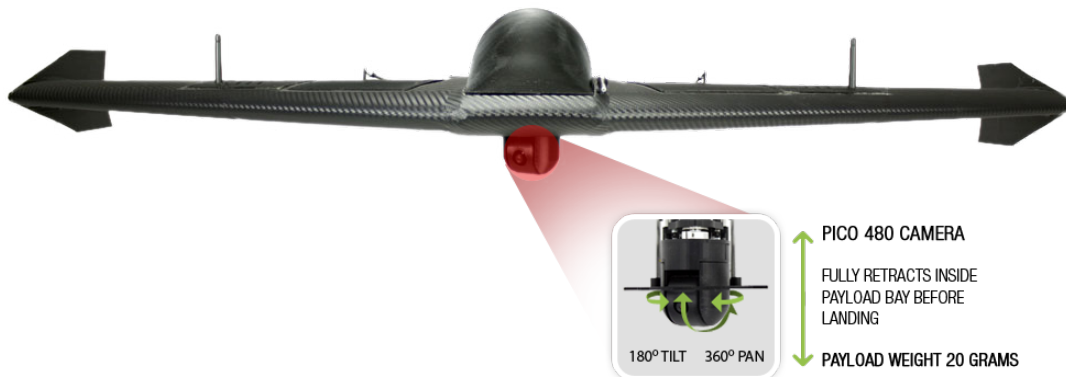


Figure 4: Marcus UAV Retractable Gimbal [8]

3.3 Functional Decomposition

In this section, the functional decomposition is analyzed in two parts. First, the black box will simplify the total function of the gimbal system and categorize the inputs and outputs by material, energy, and signal. The main function of the system is to move the antenna at the request of the user. The action of the system will be further broken down in the functional model by each step that is performed and the individual input and output.

3.3.1 Black Box Model

The black box model allows for an easier understanding of what the device needs to accomplish. This is done by simplifying the design down to the basic inputs and outputs, specifically materials, energy, and signal. This allows the design team to focus on the core elements and ensure that the device successfully addresses the needs of the client.

The black box model, as seen in Figure 5, shows all materials that enter and exit the system, meaning no material stays in the system. Electric energy as well as human energy enters the black box and comes out as heat and sound. Lastly, a signal to move the antenna is sent and out of the box comes a signal indicating the relative position of the antenna to the drone.

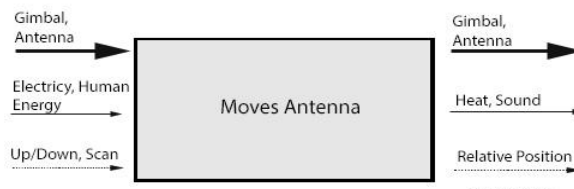


Figure 5: Black Box Model

The next section further analyzes the action of moving the antenna seen in the black box model and fully breaks it down into a functional model.

3.3.2 Functional Model/Work-Process Diagram/Hierarchical Task Analysis

The section describes the functional model for the antenna gimbal. A functional model is a breakdown of how the team theorizes the gimbal system shall work. This is derived from the black box model by analyzing the material, energy, and signal imports and exports. The gimbal system takes in electricity from the UAV and human energy from hands controlling the remote and transmits it to rotational movement of the antenna and data back to the user. This process can be visualized in steps in Figure 6. Through this model, the team can visualize that their critical actions of regulating the angle, receiving VHF signal, and reporting that data back to the user all rely on electricity to run the operations while in the air. From this model, it is apparent that the functionality of the device is critical for being able to meet requirements for electric usage as described in the engineering requirements, in order for any of the main operations to take place.

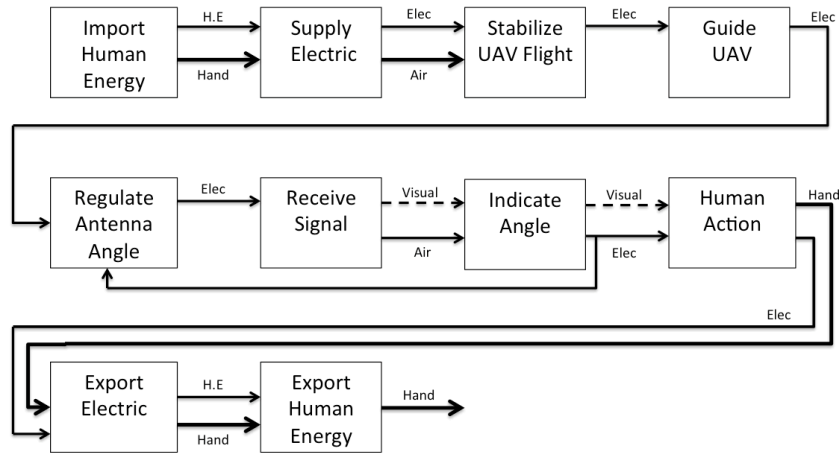


Figure 6.1: Hypothetical Functional Model for Gimbal Antenna

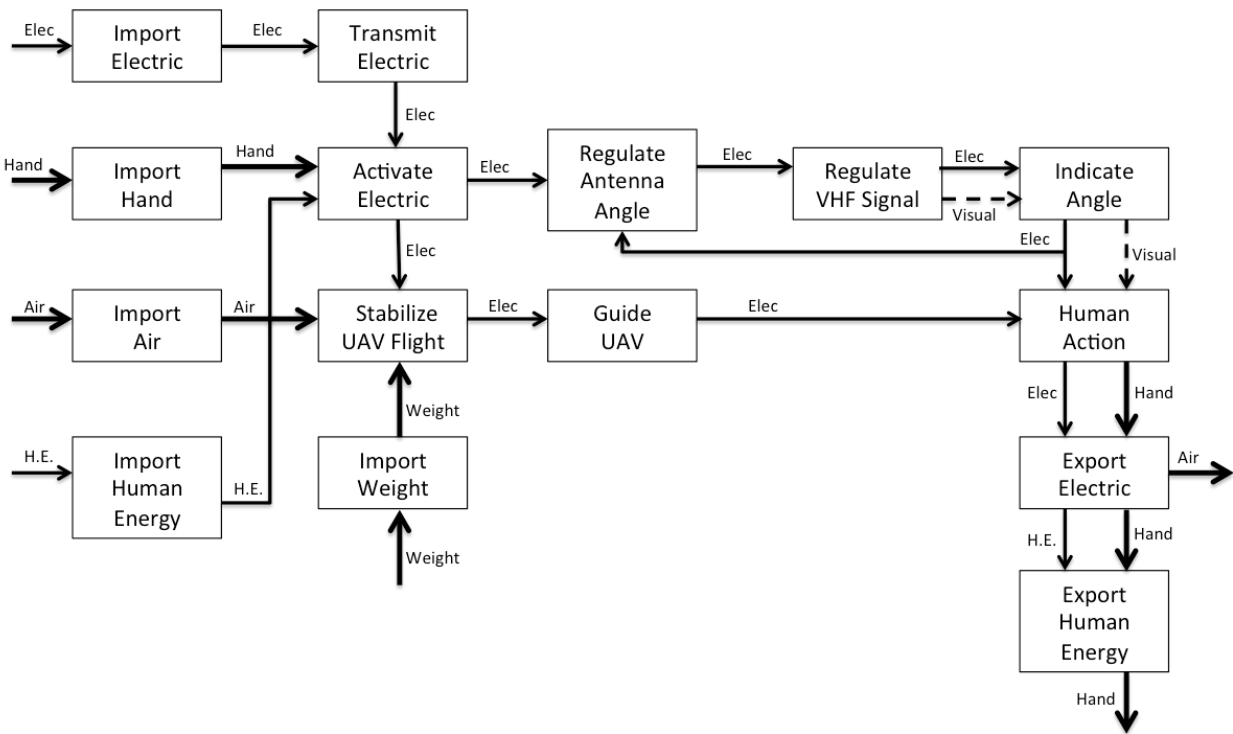


Figure 6.2: Actual Functional Model for Gimbal Antenna

3.4 Subsystem Level

This section will discuss the different subsystems used to make an antenna gimbal. Currently, gimbals and their controllers are typically applied to stabilize video recording. While incorporating a gimbal to control a VHF antenna is a fairly unique idea, the overall system and controllers can be applied to either situation. The antenna gimbal system was broken into three subsystems including the control system, motor, and frame/mount. Each of these subsystems are further described in the following subsections along with existing designs for each.

3.4.1 Subsystem #1: Control System

The control subsystem is important in the design of the antenna gimbal because it enables the control of the angle and readout. This device shall be used to take information from the on board computer and output angles, then relay that information back to the on board computer for communication to the ground.

3.4.1.1 Existing Design #1: Arduino

The Arduino is the industry standard in terms of small microcontrollers. This microcontroller has a large amount of user support due to it being so ubiquitous [8]. An advantage to this control system is there are many forums of existing code the team could use to their advantage in programming.

3.4.1.2 Existing Design #2: MSP430 LaunchPad

The MSP430 LaunchPad is a lightweight microcontroller. Where this device differs from the Arduino is in its lower power consumption, weight, and cost. This device comes in at \$4.30 which is about half that of an Arduino unit [9].

3.4.1.3 Existing Design #3: Teensy 2.0

The Teensy 2.0 is by far the smallest microcontroller. It comes in at about the size of a quarter and has the capability of running Arduino programs and sketches. This device is great for projects that are constricted on weight and or space while needing to run Arduino code [9]. The size of this system would be beneficial in fitting to the small modular design for the team.

3.4.2 Subsystem #2: Motor

This component of the gimbal is imperative to hit the requirements laid out for the team. These motors shall hold a certain amount of torque at a steady angle under flight power, while maintaining a lightweight requirement. This device needs to also be repeatable to maintain accuracy.

3.4.2.1 Existing Design #1: Short Range Servo Motor

This design has the capability to be finely controlled. While it is a stepper motor it has the capability to be put into an orientation and then hold that orientation. They are highly efficient and are great for applications where vibration is an important consideration [10].

3.4.2.2 Existing Design #2: Goteck Metal Gear Micro Servo

This micro servo is designed to be used in lightweight flying machines. It has a high stall torque which would be helpful while maintaining a slim and lightweight design. This servo can run off standard flight batteries and has low power consumption [11].

3.4.2.3 Existing Design #3: DSM 44

This servo motor is designed specifically with RC control in mind. It is both small and lightweight, runs off standard 5 volt supplies and has a high torque output for its size [12].

3.4.3 Subsystem #3: Frame/Mount

This part of the device is important to maintain a rigid platform for the antenna to gimbal from. It shall be structurally strong, while being lightweight, and capable of being attached to the UAV via the modular design plates provided.

3.4.3.1 Existing Design #1: Channel Master 3079 Antenna Mount

This antenna mount is a very basic design made from conventional materials. Do to this it is readily available and cheap to purchase. At over half a pound it may not be right for our applications but it is worth consideration [13].

3.4.3.2 Existing Design #2: Panel-Hanging Bracket from McMaster-Carr

This off the shelf bracket is extremely accessible and cost effective. Made from stainless steel it is corrosion resistant and easy to maintain. It may be heavy for its weight but overall may be the best choice. This could be modified in house to match our modular design for easy of assembly in the field [14].

3.4.3.3 Existing Design #3: Generic L-bracket

Using this is very similar to the use of the off the shelf bracket from McMaster-Carr but this offers easier obtainability with a lighter weight design. Again it can be made to fit our modular design with some slight modification keeping cost down [15].

4 DESIGNS CONSIDERED

Chapter four will serve the purpose of describing the designs for the DASL UAV Antenna Gimbal as brainstormed by the team. The team formed ten ideas ranging in capability, feasibility and simplicity. Each of the designs are described as follows and displayed in Figures 7-16.

4.1 Design #1: Plate with Motor

In Design 1, Figure 7, the antenna is mounted through a plate, which is controlled by a motor. The plate is supported by two brackets fastened to the octagonal UAV housing. As the motor rotates, the plate and antenna rotate as well. The advantage of this system is simplicity as it only contains four components not including the antenna. It can be made low cost and would be easily maintainable. The disadvantage of this design is the need for a high torque motor that would still be lightweight. Another potential downside is a limited range of movement.



Figure 7: Plate with Motor

4.2 Design #2: Motor with Lead Screw

In this design, a lead screw drives the back end of the antenna to control the angle of attack. As seen in Figure 8, the antenna is pinned near its center to the base of the UAV. The lead screw is mounted above one end allowing it to push the antenna down to a desired angle. In this system, the linear movement must be converted into rotational measurements to relay the exact angle to the client. The advantage of this design is simplicity and lightweight mechanisms; however, the downfall is that the lead screw would always be sticking out during flight and offer a limited range of motion.



Figure 8: Motor with Lead Screw

4.3 Design #3: Pulley System

This system uses a simple cord attached to the antenna. The motor would draw in the cord onto a spool and therefore retracting the antenna upward towards the base of the UAV. This system would also consist of a potentiometer to determine the angle, which the antenna is resting at. An advantage of this design is that the sweep mode would be easily incorporated with a constant rpm of the motor. Potential issues

include the cord, which is not rigid, could cause the antenna to move with turbulence of the UAV.



Figure 9: Pulley System

4.4 Design #4: Linkage System

This system uses a linkage to drive the angle of attack, Figure 10. The motor is attached to the linkage and that drives the antenna. The linkage cams a boss on the antenna mount to move the angle up or down. The advantage to this design is that all mechanical operation can be seen and problems can be diagnosed quickly. The main disadvantage would be the torque required to power the cam and measuring the angle of attack.



Figure 10: Linkage System

4.5 Design #5: Hydraulic Piston

This is the same as the lead screw but with a self contained hydraulic unit, Figure 11. The system would incorporate a pump, reservoir, and piston system. This unfortunately would both add weight and complexity. However the design has the advantage of being much more self-contained when compared to the lead screw as there are no parts that extend beyond the antenna when retracted.



Figure 11: Hydraulic Piston

4.6 Design #6: Two Motors

Design 6 is similar to Design 1 in the way it rotates the antenna. In this system, rather than the antenna being directly attached to the rotating plate, another motor is first fastened to the plate, then the antenna is

connected to the second motor. This allows the system to have two degrees of freedom, which the client showed interest in. Unfortunately the motor rotations could interfere with each other and this would have to be kept in mind during dimensioning and designing of the system.



Figure 12: Two Motors

4.7 Design #7: Centered Pulley

This design, as seen in Figure 13, mostly mimics that of design 3, however in an effort to maintain the same center of gravity as the original UAV, the mounting location for the antenna is offset towards of the edge of the UAV with the motor and microcontroller located in a more central position. The disadvantage of this design is again a lack of rigidity as the cable allows for fluctuation of the antenna during flight.



Figure 13: Centered Pulley

4.8 Design #8: Single High Torque Motor

Design 8, as seen in Figure 14, works by attaching a high torque motor in a 1:1 ratio, directly to the antenna. This design offers for a more simplistic design, however would require the use of a rotary encoder, or resolver, to track the orientation of the antenna. While the weight of the motor in this design may be high, is the only mass of the component. This design does not account for the length of the antenna and therefore would most likely have interference issues.



Figure 14: Single High Torque Motor

4.9 Design #9: Two Hydraulic Pistons

Similar to design 5, this concept involves two hydraulic pistons. There would be one attached closer to the front of the antenna and another towards the back. They would work in unison (one retracts as the

other extends), to cause the antenna to pivot. This would allow the pistons to be smaller since compared to the single piston design. A disadvantage of this design would include that the UAV would need to house a pump and water reservoir to allow the pistons to function and therefore adding unnecessary amounts of weight to the system.



Figure 15: Two hydraulic Pistons

4.10 Design #10: Stirling Engine

Design 10 incorporates a stirling engine into the system as seen in Figure 6. This mechanism moves based on a heat differential. A constant difference in temperature would allow for continuous movement of the antenna. However, there is not a simple way to control the exact angle of the antenna, leading to inconsistent data.



Figure 16: Stirling Engine

5 DESIGN SELECTED

Chapter 5 serves the purpose of explaining the rationale for the design selected by the team.

5.1 Design Selection

This section will explain the rationale of selecting a design for the UAV antenna gimbal. The design was carefully selected after evaluations of the designs using a decision matrix and through meetings with the client as described in the following subsections.

5.1.1 Original Design Selection

To help the team form a rational decision for one of the ten designs described in Chapter 4, they formed a decision matrix, seen in Table 3. The team decided upon five criteria from both customer needs and engineering requirements. The first and most important criterion is the weight of the system. If the device cannot be lifted by the UAV, it is not a viable design. The second most important criterion is the ability to relay an accurate angle of the antenna to the user. Without this piece, the device would not provide accurate data and would be pointless. Third most important is maintainability. Since the UAV is at risk of crashing, and the antenna gimbal is attached to the bottom, it is important that the system be maintainable so that it can continue functioning and collecting data for the user. The team also determined the angle range and position to be important, as the device needs to allow ample rotation to gather quality data, as well as hold the angle in position rather than letting it bounce or hang freely. Lastly the team considered cost. This requirement is not as high of a concern as the budget is loose, however, the team would like to stick to the desired budget of under \$500, so cost must be taken into consideration. To evaluate the designs, the team first picked four of what they thought to be the most viable designs. They then scored each design on a scale of 1-10 for each criterion and applied the weight. Through this process, the team found Design 1: Plate with Motor, to be the best option. This design meets all customer needs of simple, maintainable, modular, able to relay an angle, and able to have multiple modes of movement. It is also able to meet each of the engineering requirements, which shall ensure through more careful designing of the idea. Therefore, this is the first design the team chose, but is subject to change as seen in the next section.

Table 3: Decision Matrix

Criteria	Weighting	Design 1 Plate with Motor		Design 2 Motor with Lead		Design 3 Pulley System		Design 4 Linkage System	
		Score	WS	Score	WS	Score	WS	Score	WS
Weight	30%	7	2.1	6	1.8	8	2.4	6	1.8
Relay Angle to User	25%	8	2	9	2.25	2	0.5	7	1.75
Maintainable	20%	8	1.6	6	1.2	9	1.8	6	1.2
Angle Range and Position	15%	6	0.9	6	0.9	3	0.45	7	1.05
Cost	10%	7	0.7	8	0.8	9	0.9	7	0.7
			7.3		6.95		6.05		6.5

5.1.2 Current Design Selection

After utilizing the decision matrix to select Design 1, the team presented a prototype of the design to the client, Dr. Michael Shafer. He then expressed concern for the structural stability of Design 1, as the mounts that would attach the gimbal to the UAV would be long and thin, making it more prone to breaking upon impact. After looking at the proposed prototype, the client expressed a new interest for the design to be able to operate using short mounts so that it can now fit between two modular plates, rather than just on the bottom of the last plate as discussed in the initial scope of the project. To accommodate for the decrease in space allotted, the client will allow for a smaller rotation and now asks for a minimum of 45 degree angle rather than 60 degrees. Dr. Shafer also recommended that the team have two points of contact between the antenna and the UAV rather than one, as seen in Design 1. After reviewing the

team's other design options, he preferred the idea of a linkage system as proposed in Design 4, which ranked third in the decision matrix. From these new points of consideration, the team created a new design, extenuating from Design 4, which will be described in the next section.

5.2 Design Description

After a meeting with the client, several concerns were uncovered with the team's original design. To resolve problems with the original designs, as well as to incorporate new requests from the client the team formed a linkage concept, depicted in Figure 17. As seen in the figure, this design allows for two points of connection between the antenna and UAV, as desired by the customer. At the back end of the antenna, there is a simple pin connection allowing pure rotation. Towards the front end there is a linkage arm attached to a clamp around the antenna. As the arm is pitched up or down by a small motor, the antenna will also rotate to the desired angle input by the user. Exact measurements can be viewed in Appendix A Figures A1-A6. Overall, this new concept is more compact, secure, and cost effective than previously discussed designs.

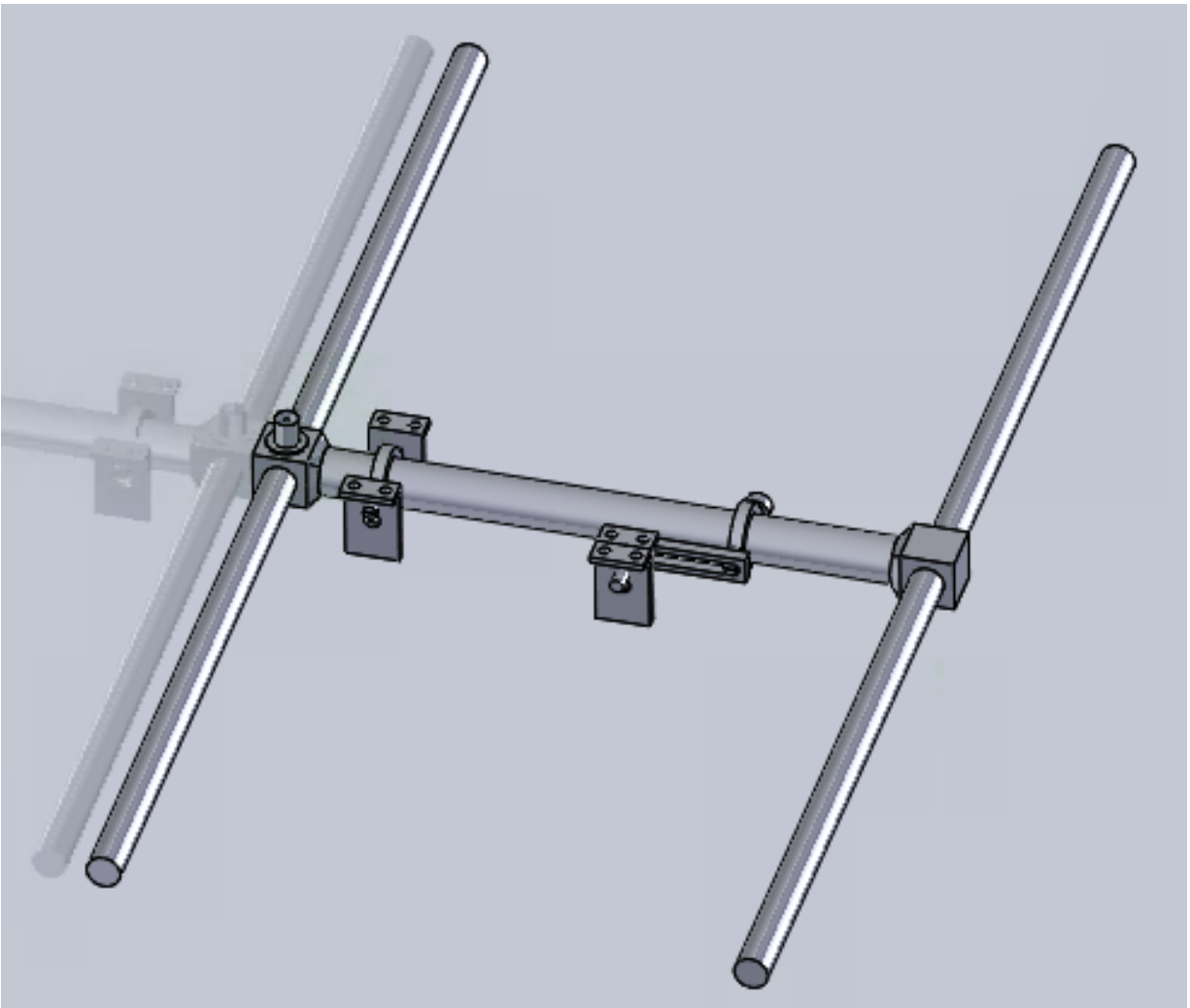


Figure 17: Current Antenna Gimbal Design

6 PROPOSED DESIGN – First Semester

This section serves the purpose of discussing the implementation and fabrication of the antenna gimbal. After selecting the design discussed in section 5.2, the team chose to 3D print a prototype for a proof of concept. Through this prototype, they found that the mounts connecting the antenna to the UAV do not allow full rotation of the pivot base. From this prototype, the team expanded the length of the mounts to create a fully moveable system. The team shall continue to print prototypes with their personal 3D printers to ensure problems such as this can be avoided before the final fabrication of the system. Initial prototypes are printed using PLA. Final prototypes and the final system shall be printed using ABS, which can be smoothed with acetone for better tolerances and fits. The use of 3D printing reduces the emphasis on tolerancing as the parts being produced will carry the same tolerances, this does not however reduce the necessity of clearances, which are included in the design. The team has chosen to keep the final design manufactured through 3D printing, to keep the system easily maintainable for the client in case of part failure during a strong impact. Through the use of 3D printing, the client only needs the part files and use of a 3D printer which can be accessed several places on Northern Arizona University campus. Once prototyping has finished, the team will mock up the system working towards full integration. In this phase, the team will work to create a fully functioning system as depicted in Figures 18 and 19. The mock up of the design allows the team to still adjust for improvements.

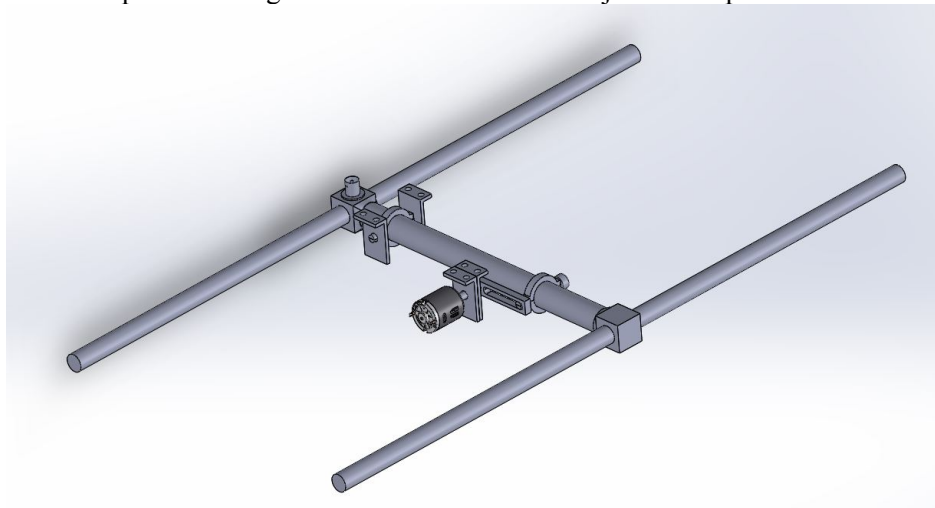


Figure 18: Design Assembly View

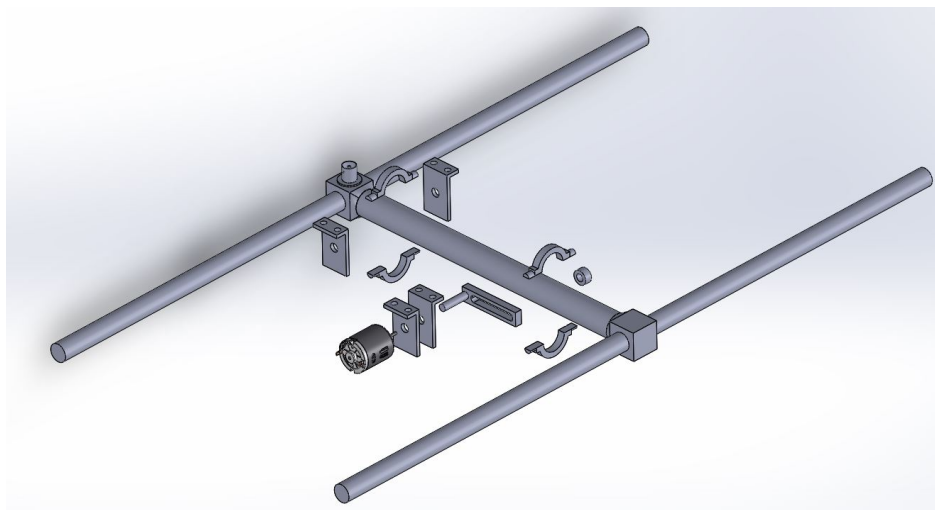


Figure 19: Design Exploded View

With a basic setup of the system, the team will be able to implement a program to run the motor and test the abilities of the device (e.g. range of motion, lifting capabilities, sweeping features, etc.). Resources needed for this testing include a postal scale and raspberry pi, which will attach to the Arduino. Each of these can be found in the DASL. The system shall then be tested thoroughly on the ground. At this stage, if modifications need to be made to better integrate the program, motor, and physical system, it can be done before a final device is fabricated. Once proven to be fully operational on the ground, the team shall then attach the system to the UAV and ensure that it will work as expected in the field. Different courses can be flown, in different orientations, and different settings to double-check that no errors occur. Should errors occur during this phase of testing, troubleshooting will be immediate and replacement parts will be produced quickly. The overall schedule for these implementation tasks are displayed in Appendix B, Figures B1 and B2. The resources required for the antenna gimbal are listed in Table 4, along with their corresponding costs. Materials for the system will be purchased online from SparkFun [16] and McMaster-Carr [14]. The main source of cost comes from the stepper motor, motor driver, and other electrical components such as the FTDI cable, real time clock, and open log. The team is willing to spend a significant amount on the motor, as it needs to be able to provide enough torque to pivot the antenna, as well as be light enough in weight to satisfy the 0.5 lb weight restriction.

Table 4: Bill of Materials and Budget

Part Name	Part #	Cost (\$/part)	Quantity	Total (\$)	Location
Arduino Pro Mini 5V	DEV-11113	9.95	1	9.95	SparkFun
FTDI Cable 5v	DEV-09718	17.95	1	17.95	SparkFun
Break Away Headers - Straight	PRT-00116	1.50	1	1.50	SparkFun
Break Away Male Headers- Right Angle	PRT-00553	1.95	1	1.95	SparkFun
Female Headers	PRT-00115	1.50	1	1.50	SparkFun
Real Time Clock Module	BOB-12708	14.95	1	14.95	SparkFun
Jumper Wires Premium 12" M/F	PRT-09385	4.50	1	4.50	SparkFun
Juper Wires Premium 6" F/F	PRT-08430	3.95	1	3.95	SparkFun
Jumper Wires Premium 6" M/M	PRT-08431	3.95	1	3.95	SparkFun
OpenLog	DEV-13712	14.95	1	14.95	SparkFun
Stepper Motor- 68 oz.in (400steps/rev)	ROB-10846	39.95	1	39.95	SparkFun
EasyDriver-Stepper Motor Driver	ROB-12779	29.95	1	29.95	SparkFun
Fasteners	MISC	0.25	20	5.00	
3D Printing (ABS)		0.1	50 grams	5.00	RAPIDLab
Acetone	N/A	5.95	1	5.95	Amazon
			Total Part Cost	161.00	
			Est. Tax & Shipping	35.00	
			Final Total	196.00	

7 REFERENCES

- [1] S. Oman “Mechanical Engineering Capstone Projects.” (2017, August). [Print].
- [2] “Tracking Wildlife | Wildlife Journal Junior,” *Wildlife Journal Junior*. [Online]. Available: <http://www.nhptv.org/wild/tracking.asp>. [Accessed: 25-Sep-2017].
- [3] T. Inc., “RA-23K VHF Antenna,” *RA-23K VHF Antenna | Telonics Inc.* [Online]. Available: <http://www.telonics.com/products/vhfAntennas/RA-23K.php>. [Accessed: 25-Sep-2017].
- [4] M. Leonardo et al. (2013). A Miniature Wildlife Tracking UAV Payload System using Acoustic Biotelemetry. *Proceedings of the ASME Design Engineering Technical Conference*. [Print]. Volume 4
- [5] T. Consi et al. (2016, February). An Unmanned Aerial Vehicle for Localization of radio-tagged sturgeon. *OCEANS*. [Print].
- [6] Inc., Moog. “Antenna Pointing Mechanisms.” *MOOG*, 2017. [Online]. Available: <http://www.moog.com/content/sites/global/en/products/actuators-servoactuators/space/spacecraft/antenna-pointing-mechanisms.html>. [Accessed: 06-Oct-2017].
- [7] “UAV TRACKING ANTENNA.” *Octopus ISR Systems*. [Online]. Available: <http://octopus.uavfactory.com/uav-payloads-equipment/portable-tracking-antenna>. [Accessed: 06-Oct-2017].
- [8] “Retractable Gimbal Payload.” *Marcus UAV Unmanned Aerial Vehicles*, 2016. [Online]. Available: <http://www.marcusuav.com/gimbal/>. [Accessed: 06-Oct-2017].
- [9] C. Davis, “Arduino Alternatives: 5 Microcontrollers You Should Know,” *Popular Mechanics*, 11-Nov-2015. [Online]. Available: <http://www.popularmechanics.com/technology/how-to/g1426/arduino-alternatives-5-microcontrollers-you-should-know/>. [Accessed: 06-Oct-2017].
- [10] “Servo Motors (Motor Only),” *Servo Motors (Moor Only)*. [Online]. Available: <http://www.orientalmotor.com/servo-motors/servo-motor-only.html>. [Accessed: 28 Sept. 2017].
- [11] Robotshop.com. (2017). *2.5kg Goteck Metal Gear Micro Servo*. [Online] Available: <http://www.robotshop.com/en/25kg-goteck-metal-gear-micro-servo.html> [Accessed 28 Oct. 2017].
- [12] “Pololu - Power HD High-Speed Digital Micro Servo DSM44,” *Pololu Robotics & Electronics*. [Online]. Available: <https://www.pololu.com/product/2142>. [Accessed: 28 Sept. 2017].
- [13] “Channel Master 3079 Antenna Mount Kit - 2 Pack: Home Audio & Theater,” *Amazon.com: Channel Master 3079 Antenna Mount Kit - 2 Pack: Home Audio & Theater*. [Online]. Available: <https://www.amazon.com/Channel-Master-3079-Antenna-Mount/dp/B002SAOHH2>. [Accessed: 28 Sept. 2017].
- [14] “McMaster-Carr,” *McMaster-Carr*. [Online]. Available:

<https://www.mcmaster.com/#1755a11/=19jlcud>. [Accessed: 28 Sep 2017].

- [15] MIKEP313, Eddie, Richelieu, Danny, Brynn, Richierich03, Bonair, and MomtheBuilder, "Everbilt 1-1/2 in. Zinc-Plated Corner Brace (4-Pack)-15304," *The Home Depot*, 13-Jun-2017. [Online]. Available: <http://www.homedepot.com/p/Everbilt-1-1-2-in-Zinc-Plated-Corner-Brace-4-Pack-15304/202033892>. [Accessed: 28-Sep-2017].
- [16] "SparkFun," *SparkFun*. [Online]. Available: <https://www.sparkfun.com/> [Accessed: 28 Sep 2017].

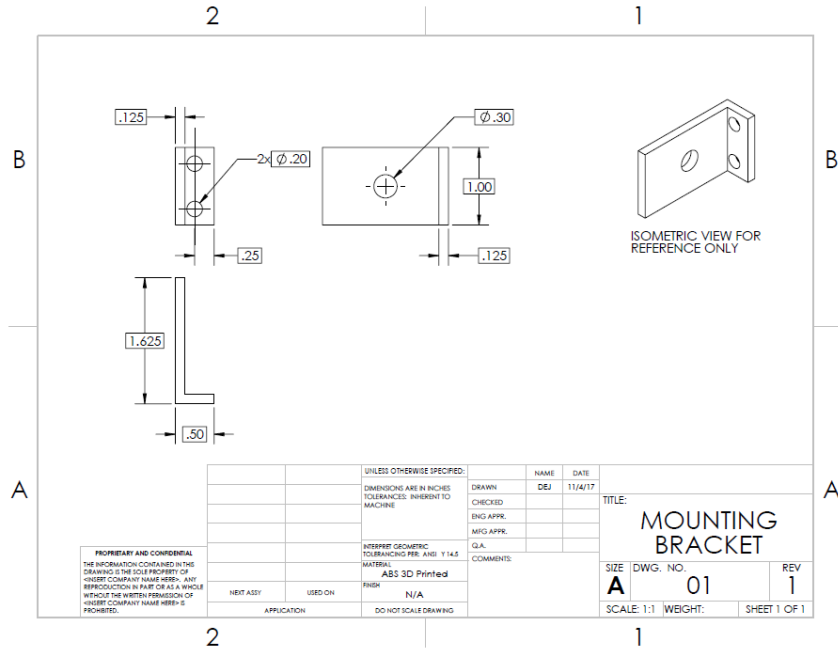


Figure A3: Mounting Bracket Drawing

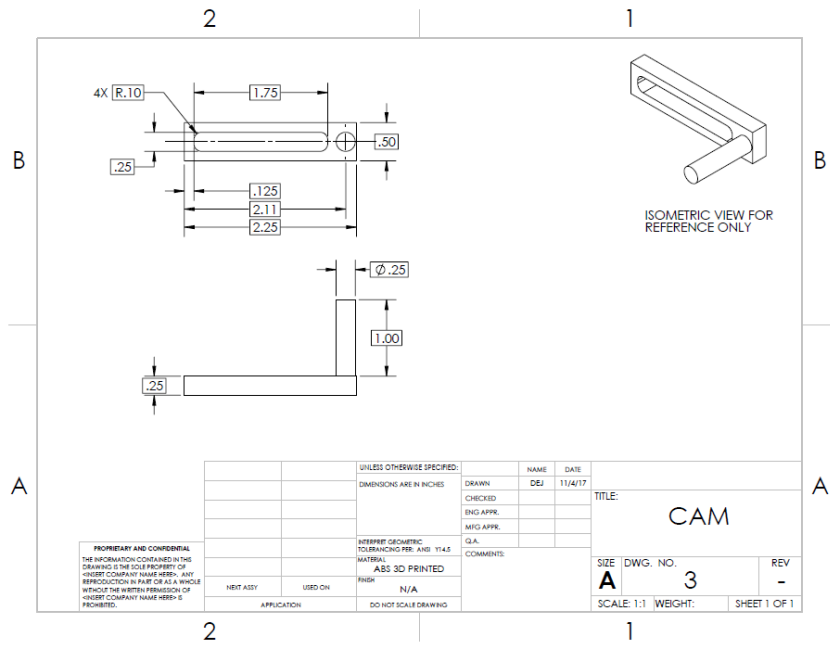


Figure A4: Cam Drawing

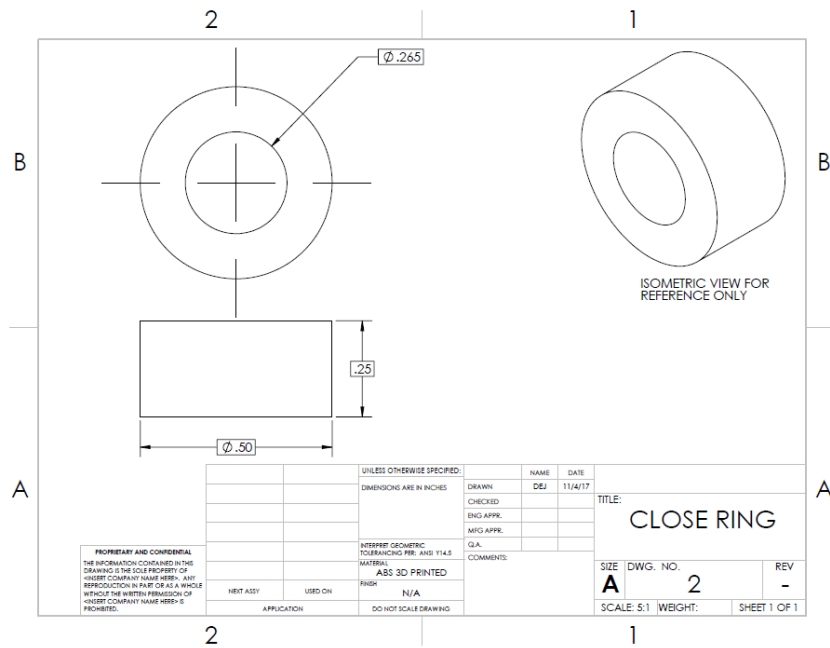


Figure A5: Close Ring Drawing

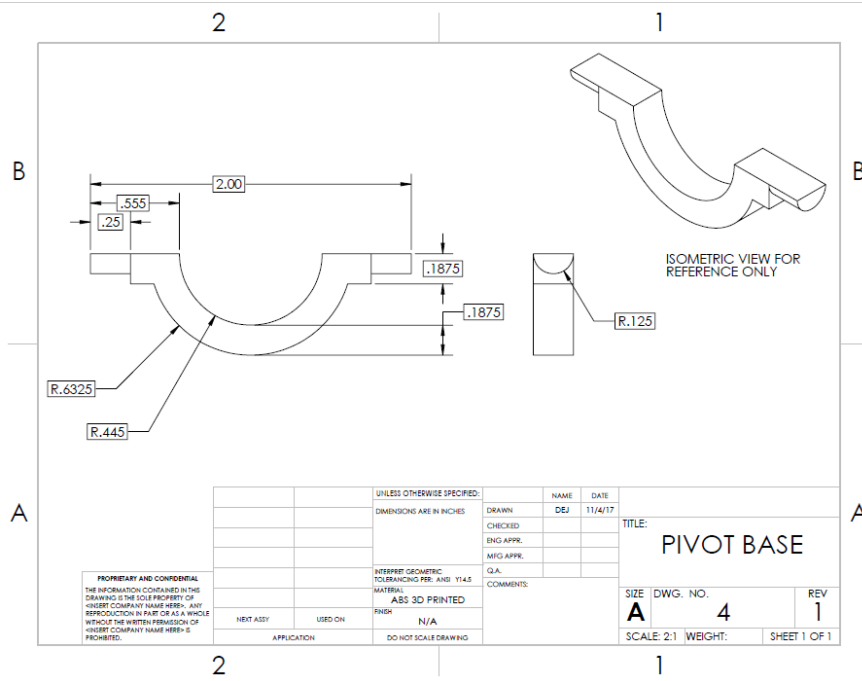


Figure A6: Pivot Base Drawing

8.2 Appendix B: Second Semester Schedule

Table B1: Second Semester Weeks 1-7

Task	Responsible Party	Week 1			Week 2			Week 3			Week 4			Week 5			Week 6			Week 7			
		1/15	1/17	1/19	1/22	1/24	1/26	1/29	1/31	2/2	2/5	2/7	2/9	2/12	2/14	2/16	2/19	2/21	2/23	2/26	2/28	3/2	
Post Mortem	All																						
Building for Hardware Review 1	All	Complete Final Physical Proof of Concept																					
Peer Evaluation	All																						
Form Analysis Topics	All																						
Individual Analysis	All																						
Building for Hardware Review 2	All													Integrate Code into the System									
Manufacturing Section	Dustin Branges																						
Design Changes Section	Daniel Johnson																						
Testing Section	Kalli Albright																						

Table B2: Second Semester Weeks 8-15

Task	Responsible Party	Week 8			Week 9			Week 10			Week 11			Week 12			Week 13			Week 14			Week 15		
		3/5	3/7	3/9	3/12	3/14	3/16	3/26	3/28	3/30	4/2	4/4	4/6	4/9	4/11	4/13	4/16	4/18	4/20	4/23	4/25	4/27	4/30	5/2	5/4
Midpoint Report Editing	Kaitlyn																								
Peer Evaluation	All																								
Continue Build Work	All	Begin Final Build of Device						Finish Build																	
Poster Work Draft	Kalli Albright																								
Operations Manual Draft	Daniel Johnson																								
Poster Work	Kaitlyn Barr																								
Operations Manual	Dustin Branges																								
Final CAD Package	All																								
Final Report	All																								
Peer Evaluation	All																								