Drone Coupler

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Report for Drone Coupler System

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EXECUTIVE SUMMARY

This report is an in-depth overview of an unmanned aerial vehicle (UAV) coupler system for sensor drop off. The project, called Drone Coupler, was designed and constructed for the University of Nebraska – Lincoln NIMBUS Lab by a senior Mechanical Engineering design team. NIMBUS lab is located in the Shore Center and conducts research for the Computer Science department. The NIMBUS lab identified a need for a drone system attachment that would drop off sensors in the field that would collect undisclosed data. The design involved creating an attachment to the underside of the drone, which would allow the drone to remotely pick up and drop off sensors in the field. Some design constraints were weight, size, ease of attachment, and power consumption. This report thoroughly discusses the design concept and provides insight into the inner workings of the design.

Background Information

The NIMBUS Lab

The Nebraska Intelligent Mobile Unmanned Systems (NIMBUS) Lab is in the Shore Center and conducts drone research for the Computer Science department. Most of their research team is comprised of computer scientists or computer engineers. This lab conducts research in the areas of systems engineering, robotics, and sensor networks to develop more capable and dependable UAV's. The lab is funded mainly through the Air Force, National Science Foundation, USDA, and UNL.

Problem Statement and Interest

The NIMBUS lab is currently researching the possibility of developing a sensor node that can be placed in the field that can collect important data, can be wirelessly monitored and recharged by drones. A drone coupler mechanism could expand the capability of the sensor network by allowing placement to be performed by drones. This mechanism would no longer require humans to manually place the sensors in the field. Additionally, a coupler could be used to attach more than just sensor nodes. It would be used as a universal mount for attaching other accessories like cameras or pumps. Unifying the connector to the drone would make it easier to switch out what accessory is attached to the drone.

PROJECT SCOPE

The scope of the project involves designing a mechanical coupler system for drones that would allow it to pick up sensors to deploy them in the field. The system would attach to the underside of the drone and allow it to remotely pick up sensors. Some design considerations are weight, size, ease of attachment, and power consumption. Weight must be kept to a minimum, as drones can often not lift heavy objects. Further, similar drones will be used to go back to these sensors to read data from them. It would be preferable to not have to detach the coupler from the drone when it is not in use to avoid extra work; lighter couplers would be less of a concern about carrying along all the time, as they would be less of a drain on the battery.

Size is also a design consideration. The coupler would have to fit under a drone and not stick out from under the body in order to avoid interfering with the trust from the propellers. Additionally, a larger coupler naturally makes it heavier.

It is also important for the coupler to be able to attach to the sensors easily. Though drones are relatively stable, precision of flight can be a challenge, so the coupler must be able to mate with the sensor within a range of relative positions.

Finally, the coupler must not use very much power as drones have a limited battery capacity and adding more batteries adds more weight. Ideally, the system would passively lock, meaning that when no current is flowing through the coupler, the sensor would be locked in place. We want to save as much power as possible, so once the sensor is released we would like to conserve power while the coupler is not in operation.

Schedule

Below is a list of steps that were followed to accomplish the project goal. The actual schedule can be found in Appendix 7. Following is the list of major components of the project schedule.

Deciding and Defining Problem Statement – determine the problem statement and narrow down the specific issue we are trying to solve.

Defining Project Scope – Come up with the scope and the breadth of the project and how far we would like to proceed with the project.

Functional Decomposition of Ideas – Come up with a number of ideas and solutions to address the problem.

Morphology and Pugh Matrix – The use of these tools were needed in order to narrow down designs.

Brainstorm Solutions – After narrowing down to the design we would like to purse, we brainstormed solutions.

Feasibility Analysis of Ideas – After brainstorming we analyzed the feasibility of ideas.

Project Modeling, Drawings and Design – Began the SolidWorks modeling of the mechanical components of the part.

Prototyping – Create a working prototype of the mechanical component combined with the electrical components to make a working part.

Materials Gathering – Create a Bill of Materials and purchase parts to order.

Construction – Construct the prototype very carefully.

Lab/Testing – Test the prototype for bugs and fix them as needed.

Product Report - Finish the design report with drawings and information as needed to design and create the drone coupler.

Preparation for Final Presentation - Prepare to present ideas and design to the Mechanical and Materials Engineering department at the University of Nebraska – Lincoln.

Design Approach

When the design team was first tasked with creating a mechanical attachment for a drone that could deploy sensors into the field, many specifications were given that the project had to meet. First, the specific drone model we are using for our deployment system is the Ascending Technologies Hummingbirds, DJI Phantoms and also Ascending Technologies (AscTec) Fireflies. Each of these drones has different payload limits and they are as follows 200g, 300g, and 600g respectively. For our project payload weight is very important, as we need to be able to safely carry the sensor node and the mechanical component on flight without crossing the payload limit. Power consumption will also be an issue since the batteries on the drone are not meant to power servos or actuators that would be required to control the mechanical components. Sensor redesign is also in our agenda, as it will help with the stability of the payload. These are some design constraints that we kept in mind while performing our brainstorming and narrowing down our design ideas. These ideas fell into three categories as seen in Figure 1.

FUNCTIONAL DECOMPOSITION

Functional Decomposition		
Attach Base to Drone	**Design Legs for Drone**	**Design Gripping Mechanism**
Mating Sliding Mechanism	Fold Out Legs	Robot Gripper
3M Velcro Dual-Lock	Hoop Skirt	Harpoon
Adhesive Velcro	Tripod	Balloon Vacuum System
Straps	Wheel Legs from Airplane	Coupler System
Magnets	Helicopter Skids	Slipknot
		Cam System
		Flywheels
		Actuator w/light bulb fixture
		Contrint movement of sensor
		Claw Machine Gripper
		Iris Mechanism

Figure 1: Functional Decomposition of Ideas

We started brainstorming ideas as a group and we decided to develop ideas under three main categories. The three categories are as follows: how we would attach the mechanism to the base of the drone, leg design for drone, and the type of gripping mechanism.

Some ideas discussed for attaching the base to the drone include a sliding mechanism that would be easy to remove the component when needed. Velcro was a popular idea when you are dealing with lightweight objects it seems like a reasonable option. Lastly, some sort of strap system to hold the mechanism in place was considered.

Moving on to designing the legs for the drone, we were able to come up with having a hoop skirt design where the legs had a circular base. This idea would help stabilize the drone onto the ground but also give us more room to work with underneath. Another idea was to create a tripod system for the legs, which would also help with stability and will not give us as much room as the hoop skirt idea. The last idea is the helicopter skids, which seem like the easiest and most efficient option since the drone already has them as its default legs. If we decided to go with helicopter skid legs then all we would need to do is lengthen the legs so it would give us more clearance for the mechanical component underneath the drone.

Further, we came up with ideas for the design of the gripping mechanism. Some ideas discussed include a robotic arm that would have grippers, which can pinch the sensor node tightly until deployment. A coupler system with the use of a solenoid was also discussed as a viable option to deploy sensors; the downfall to this option is that it is very difficult to align the drone to pick up the sensor node. The flywheel ideal was also popular as we discussed using flywheels to create a vacuum of sorts to bring in the sensor node and safely held by the flywheels. The actuator used in light bulb fixtures was thoroughly discussed, as we wanted to redesign its purpose to fit our drone system where we could control the actuator remotely to grab the sensor node. We also had the idea of using the claw gripper that would grab the sensor and hold it in place until it reached the deployment site. This idea is very versatile as other materials or objects can be grabbed other than the sensor node.

Lastly, we discussed an idea of creating a iris mechanism like the ones that you see on camera shutters. This would be a creative idea to go with because it would close in on the sensor node from all direction and help us with the precision aspect on securing the sensor node. These were some of the designs we discussed briefly as we were going through the design process as a team.

Morphology

After creating a list of ideas we decided to create a morphology chart of different concepts and compared them seen in Figure 2. Concept 1 involves using a high strength Velcro to attach the mechanism to the underside of the drone, design a hoop skirt as a landing mechanism for the drone to give us

Morphology							
	Concept 1	Concept 2	Concept 3	Concept 4	Concept 5	Hybrid	Iris Design
Attaching Base to Drone	3M Velcro Dual-Lock	3M Velcro Dual-Lock	Mating Sliding Mechanism	Straps	Mating Sliding Mechanism	Mating Sliding Mechanism	Mating Sliding Mechanism
Landing Mechanism	Hoop Skirt	Hoop Skirt	Helicopter Skids	Tripod	Hoop Skirt	Circular Helicopter Skids	Helicopter Skids
Gripping Mechanism	Claw Gripper	Actuator w/light bulb fixture	Coupler System	Flywheels	Actuator w/light bulb fixture	Robot Gripper	Iris Mechanism

Figure 2: Morphology Chart

more space to work with, and design a claw gripper to pick up and deploy sensors.

Concept 2 also involves using Velcro for attachment, a hoop skirt for landing, and an actuator as used in a light bulb fixture as a way to pick up and deploy drones. This concept is very practical and also less design oriented.

Concept 3 involves creating a sliding mechanism which would eventually mate creating a strong fixture to the drone, the use of helicopter skids to land the drone, and a coupler mechanism with the use of a solenoid would be used to deploy drones. This concept is very challenging due to the accuracy needed to grab the sensor with the use of a coupler system.

Concept 4 involves using a strap to attach the mechanism to the drone, a tripod system to for the landing apparatus, and the use of multiple flywheels to force the sensor into the grasp of the drone. This concept is very impractical as using the flywheels are not the best way to deploy sensors nodes. Concept 5 is using a mating/sliding mechanism to secure the mechanism to the drone, a hoop skirt to land, and an actuator to properly secure the sensor to the drone. This option is very practical and safe because the mechanism is securely attached to the drone, the hoop skirt gives the drone stability, and lastly the actuator with light bulb fixture seems like a good idea to work with. The hybrid design consists of mix of our concepts.

Concept 5, the iris design was created because we wanted more precision in our gripping mechanism and the iris gives us a way to come in on the sensor node from all directions. This design also uses the helicopter skids and the sliding mating mechanism to attach to drone. This idea was very popular with our group and after discussing all the options we decided to proceed with the iris design.

Pugh Matrix

Pugh Matrix							
Criteria	**Concept 1**	**Concept 2**	**Concept 3**	**Concept 4**	**Concept 5**	**Hybrid**	**Iris Design**
Cost	0	1	1	0	0	0	1
Reliability	1	0	0	0	1	1	1
Complexity	-1	-1	-1	-1	0	0	0
Speed of Gripping Mechanism	1	0	1	1	1	1	0
Size	-1	-1	1	1	1	0	0
Implementation	0	-1	0	-1	0	0	-1
Weight	0	-1	0	-1	-1	0	1
Assembly Profile	-1	1	1	1	-1	0	1
Required Flight Precision	0	0	-1	1	1	1	1
Electrical Design	1	1	1	-1	1	0	-1
Sum	0	-1	3	0	3	3	3

Figure 3: Pugh Matrix

The Pugh matrix in Figure 3 above shows the different design concepts being compared to each other by the defining criteria. A Pugh matrix is a weighted decision matrix operates in the same way as the basic decision matrix but introduces the concept of weighting the criteria in order of importance. The sum scores reflect the importance to the decision maker of the criteria involved. Based on this matrix it is clear to see that the Iris design was tied with hybrid, Concept 5 and Concept 3. Out of these four designs, the iris design was chosen for further development due to the scoring result and team's interests.

Prototyping and Analysis

The first prototype was based on a 12 leaf system. A leaf is what can be seen in the middle of Figure 1 extending outward. When coming up with design for this system many inspirations from other designs were used. The original leaf design had 2 circle pegs that were driven by the drive rings. The drive rings were also originally identical but flipped to provide for the required motion of the leaves. The slots for the pegs of the leaves were set to be tangent with the inside circle. This design worked but allowed for too much movement of the leaves when not in a locked position. This lead to the 1st prototype, which used small slots instead of pegs on the backside of the leaves. This leaf design can be seen in Figure 4. Note that the angle of the original slot on the leaf was adjusted until the leaf acquired the required motion. This leaf can be seen in Figure 5.

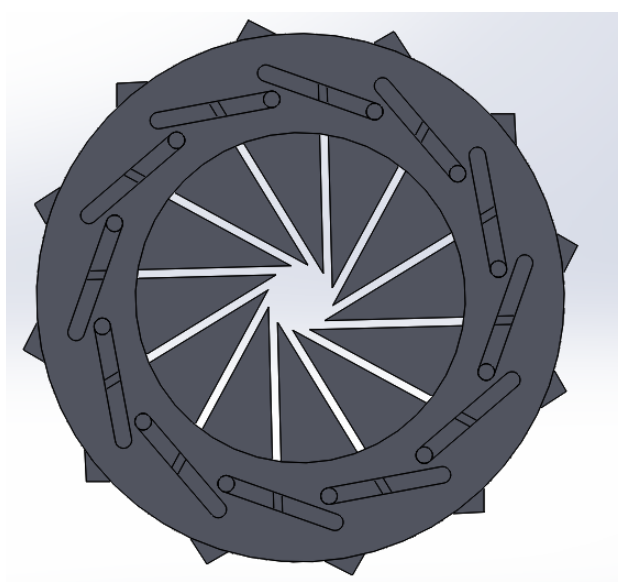

Figure 4: 12 Leaf system prototype

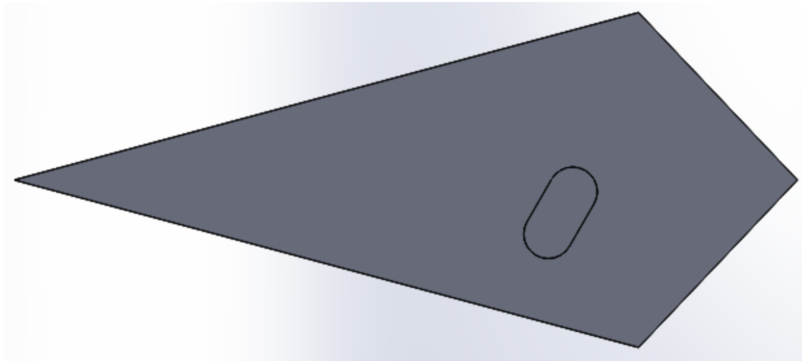

Figure 5: Leaf with Original Slot

These three designs allowed for the first working prototype to be built. For reference, all of the parts can be seen in Figure 6 and Figure 7.

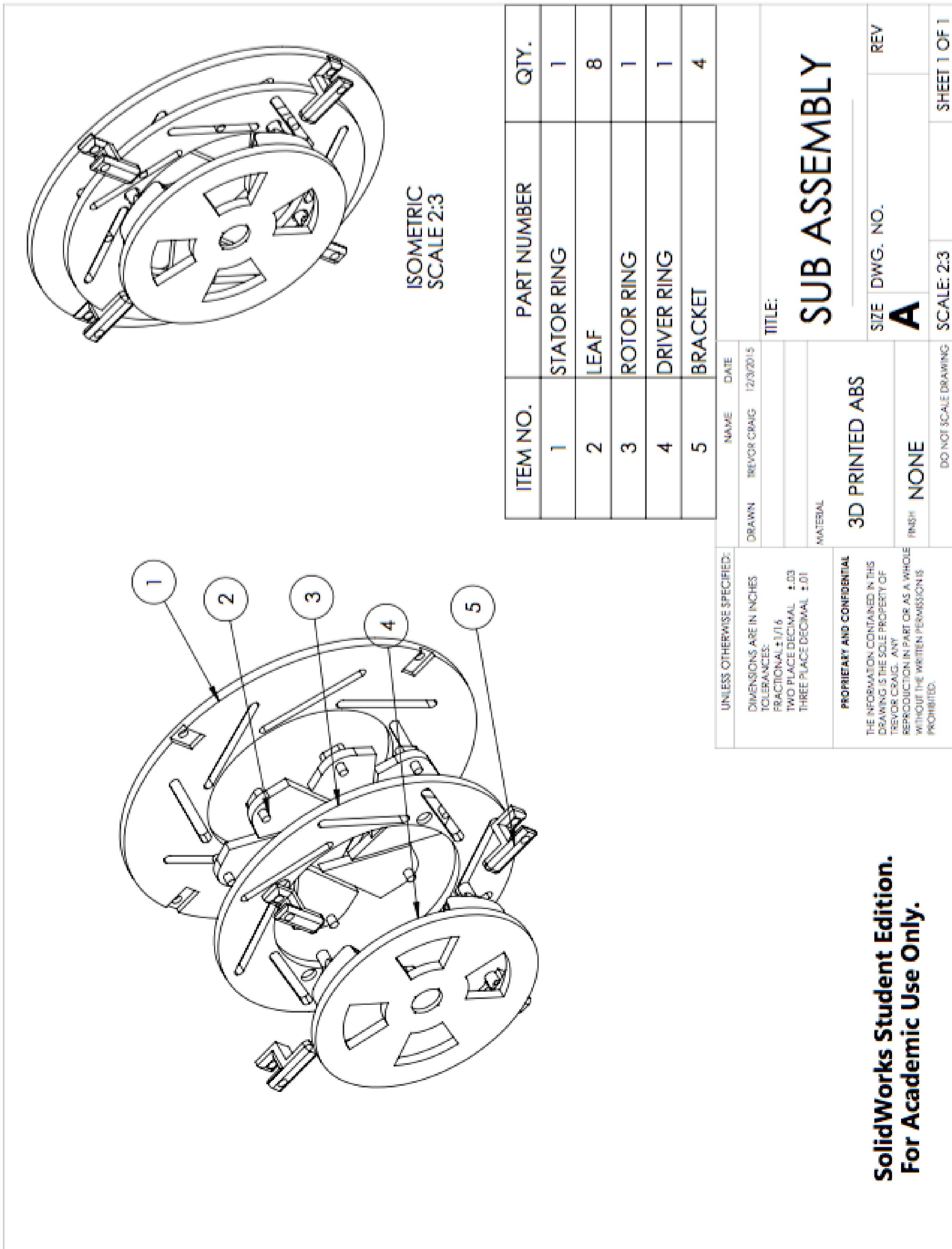

Figure 6: Subassembly drawing

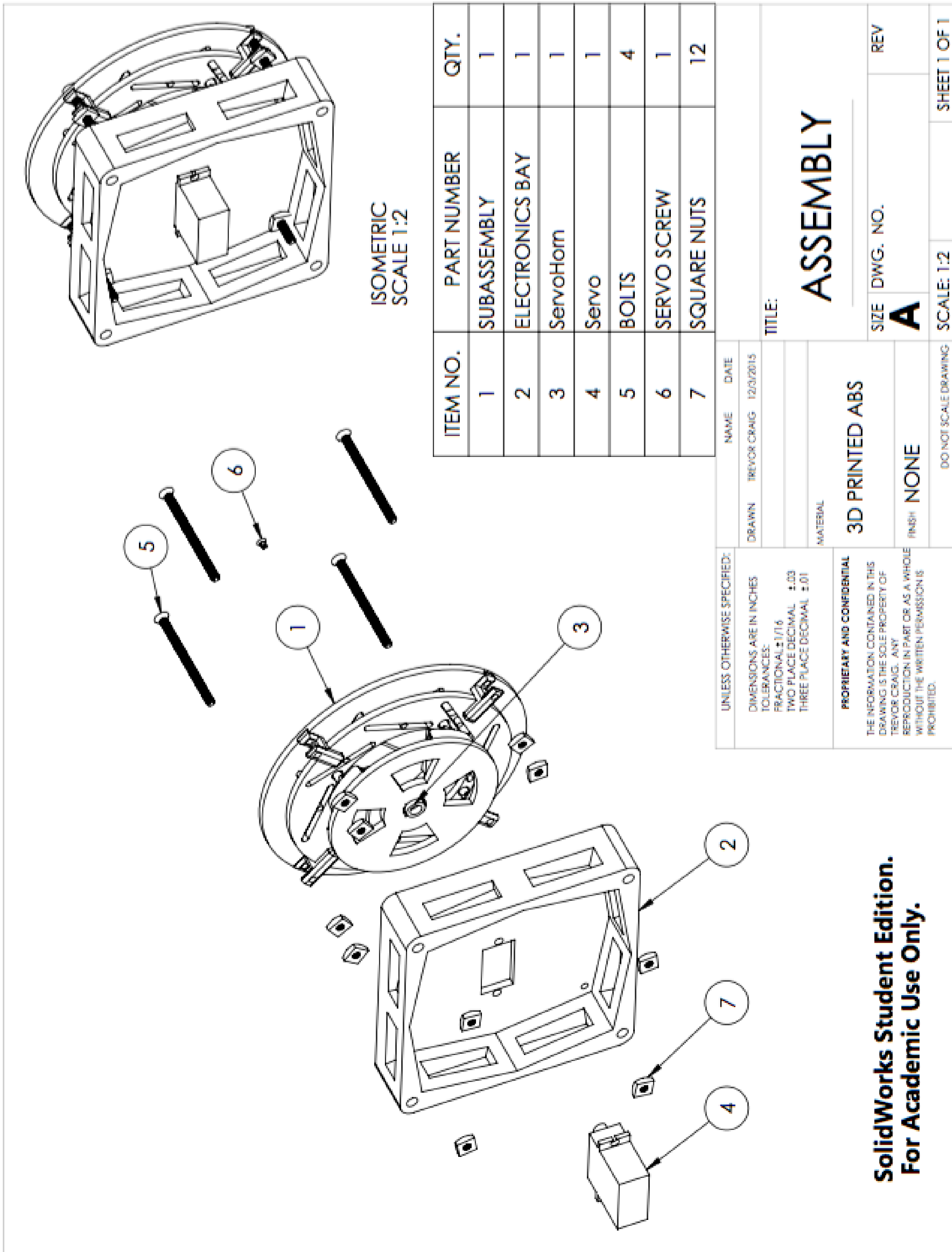

Figure 7: Full assembly

The first prototype was 3D printed on a Makerbot Replicator Z18 3d printer. It was printed with no supports, utilized a build pan and was honeycomb filled. The quality of this print ended up being quite low and the overall design fell apart quite easily when not held tightly together. Other problems were the leaves locking up against each other and the force required to turn was greater than anticipated. A picture of the 1st prototype can be seen below in Figure 8. Notice the roughness of the components. This provided too much friction. Also due to small size and many parts, it was not very easy to assembly and fell apart easily if rings were separated even a little.

Figure 8: Prototype one

Although there was many problems with prototype 1 it made it pretty clear what needed to be fixed in the next iteration. In designing the next iteration a few new ideas were used to help create a better working mechanism. The first major idea was trying to find a way to overcome friction. Due to restraints in time, while designing the next prototype the idea was to use 3d printed material in acetone and then a low friction material like Delrin for the final draft.

Another large change was the location and orientation of the slider on the leaf. For comparison look at Figure 5 compared to Figure 9. This new leaf design accounted for all the force in the driven component to act like a peg that was radial from the center and also was now in the same place as the peg. The advantage to this is now the angular forces for both the peg and the slider were located at the same distance from the center and allowed for more consistent forces throughout the sliding process.

Another change between the first and second prototype was cutting the leaf to allow them to fully be within the rings within the required motion, for reference check Figure 4. By trimming these leaves, it also allowed for the friction to decrease across the plates to the leaves due to less material sliding, which in turn allowed an easier driving.

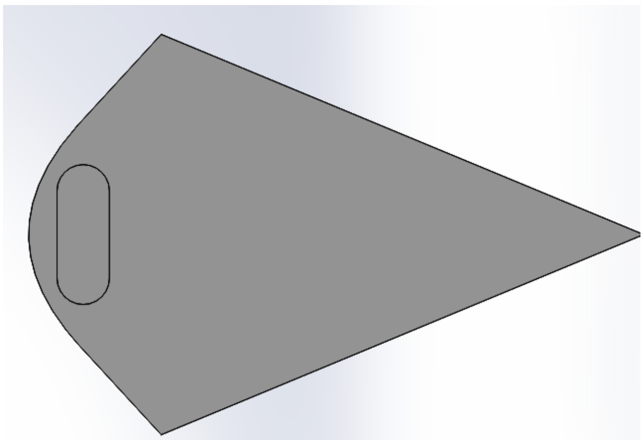

Figure 9: Leaf Design for Prototype 2

Another design change was the decision to increase the thickness of all parts from 0.125” to 0.25”. This was to allow for, not only more force into the system for turning, but also for the pegs on the leaves to have more contact so they don’t snap off.

After switching the leaves to share a common location for both the hole and the slider, slight modifications were done on the rotor ring to account for this new motion. As a result of many tests within SolidWorks, a common process was discovered for making the iris system. As a result, an iris with a 4, 6, 8, and 12-leaf system was designed. An eight-leaf system was chosen, as it still allowed a near circular pattern throughout its open and closed process, which was required for other parts of the design. Other aspects of the eight-leaf design included easier assembly, as there were fewer parts. Less moving parts were further beneficial as there was less parts to jam against each other and cause friction.

The results for Prototype 2 can be seen in Figure 10. There was a lot of changes between Prototype 1 and Prototype 2 so hopes were high that it would still function as intended. As a result of the mechanism being printed on a Dimension Elite printer by Stratasys. The resolution on this printer allowed for the print to be at a layer thickness of 0.01” and resolution of 0.007”. It also utilizes both support and model filament. The model filament and support filament are made of slightly different material, which do not stick together well. This allows for the supports to be easily removed after printing, this helped surface finish on the bottom plates. Also due to the high resolution of this printer the smooth finish was satisfactory not to warrant an acetone bath. One of the sayings from the Dimension Elite 3D Printer is that, with the Elite the proof is in the prototype. This motto became quite clear as the parts were removed from the printer.

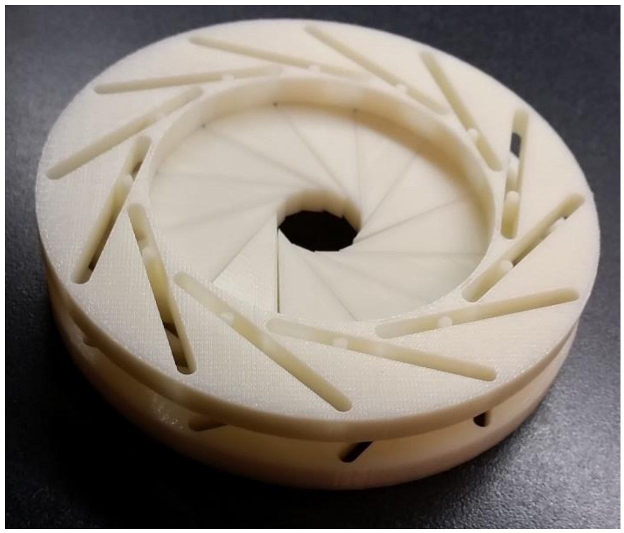

Figure 10: Prototype 2

The leaves when placed in the drive ring were originally a tight fit but just a little sanding allowed the parts to have an easy slide. This was later corrected by making the size of the leaves pegs slightly smaller. Due to the increase in thickness leaves were no longer coming out of their slots and this prototype was extremely strong. One bad thing noticed with this prototype was due to small inaccuracies in the system. If the drive rings lost concentricity, the mechanism was allowed to lock. Due to no constraint on concentricity of the rings, the device self-corrected but this was not acceptable. The way to test to if the drive rings were concentric was to place the mechanism in a square box and turning the rings to check for binds. There was no binding and as a conclusion a new restraint was added for making the rings forced to be concentric.

The overall concepts learned from Prototype 2 was decrease the size of the leaves a little, force the rings to be concentric, and use the smoothness of the finer resolution to prevent excess friction. All of these concepts would help to create Prototype 3, which incorporated the drone more heavily.

The third prototype was to account for the entire mechanism to be concentric and attached to the drone. The other important aspect considered was being able to drive the mechanism while achieving a shared equal force throughout the ring. After many considerations, a 3rd driver ring was decided upon and was designed to sit on top of the original drive ring. This can be seen in the figure<> below as the top plate. The bottom ring was expanded to allow for the connections of the support arms also seen in the Figure 11.

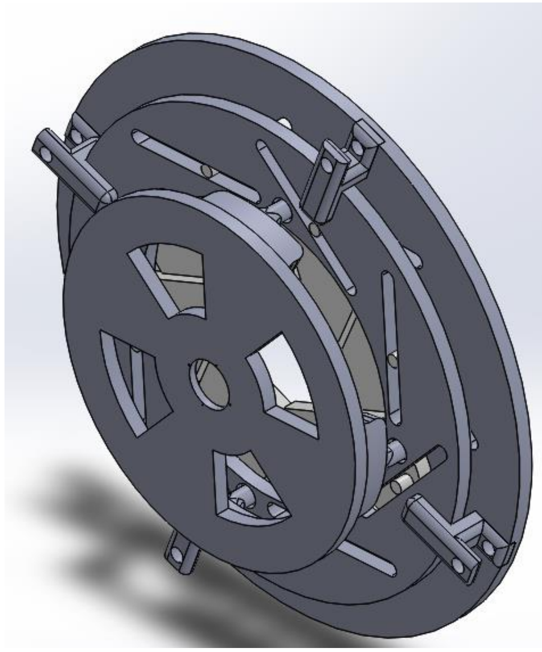

Figure 11: Prototype 3

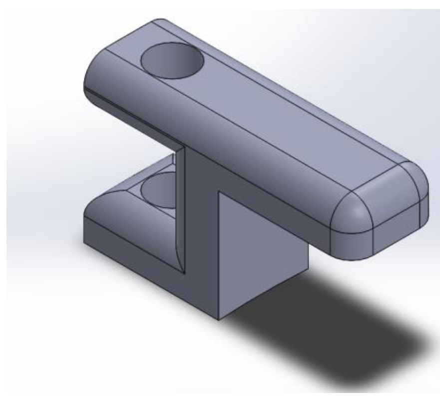

Figure 12: Bracket used to maintain concentricity

The brackets were designed to match the inner and outer profiles of the rings to have no part sticking out and allow easy slighting of the rotor ring. The bracket can be seen in Figure 12. Another consideration was the placement of the support arms as if placed incorrectly they may interfere with the leaves. These supports also served another purpose, and that was to keep the mechanism all together and attach it to the other part of the drone. By locking the stator ring through the brackets and up into the drone body panel the mechanism is driven by the driver ring and then into the rotor ring which moves the leaves to the require motion.

The input to this system was originally planned to be a stepper motor due to weight, size, and toque output. This was changed to be a servo as questions about specific control and possibility of losing steps was considered. The servo can be set exactly to a specific value and the servo will stay at this value allowing the mechanism not to lose steps and a servo also allows for more torque output. As a result two different driver rings were created to allow for the connection of the servo head and the original stepper motor. The ring for the stepper motor can be seen in Figure 13.

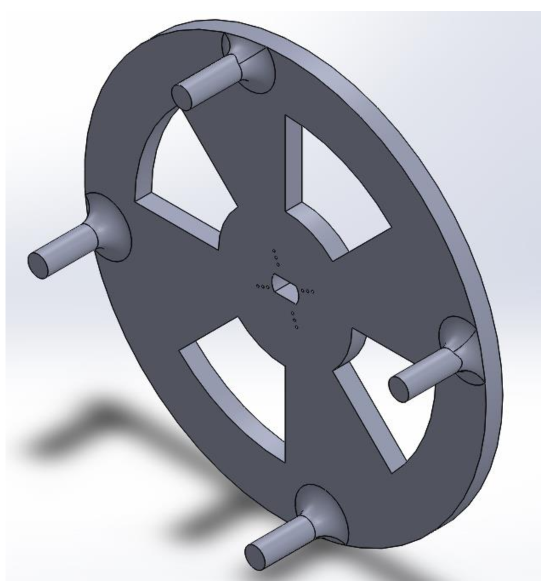

Figure 13: Stepper motor driver ring

The servo head chosen was a circle horn that was to be placed into the bottom of the driver ring seen in Figure 14 and then glued and then attached to the rest of the system. This allowed for a lot of saved space in the height requirement. The original stepper design accounted for the stepper to be driven from its axel directly into the driver.

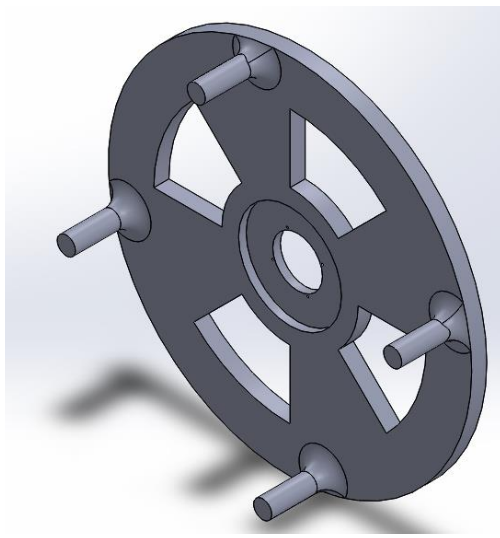

Figure 14: Servo driver ring

After assembly of all the components in the servo system it was discovered that the forces on the pegs for the driver were very high. When the program eventually glitches, the drive ring jerked violently exceeding its torque output that it was rated for. This also exceeded the safety factor for the ring and broke the pegs. As a result the drive ring was modified to have more supports. This included large filets and support arms. After further refinement the final drive ring was created and can be seen in the Figure 15.

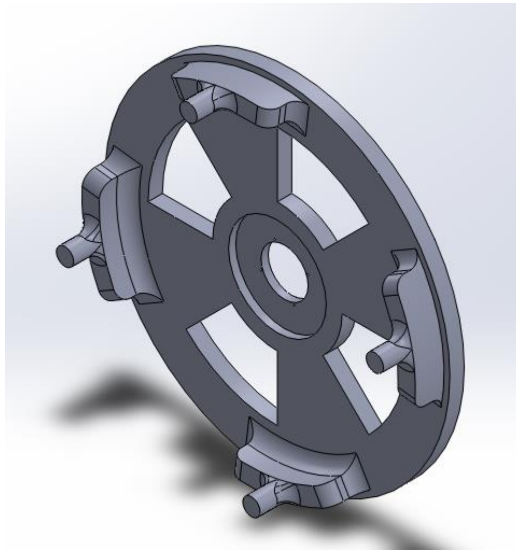

Figure 15: Final driver ring

By using this ring the moment caused by the motor and the connection into the drive ring were no longer as large and were capable of withstanding the forces required to turn the leaves. Although other problems that existed were if the mechanism was not tightened evenly across all the joints they could become slightly offset and bind. Due to the increased torque of the servo this was able to overcome the binding and allow for a smoother opening and closing.

FAILURE MODES AND EFFECTS ANALYSIS

With any system there is threat of danger and knowing these possible modes of failure can greatly enhance user interaction and future design effectiveness. The first large failure mode worth noting is, of course the stress acting on the pins and driver ring. Should the servo twitch or randomly jerk very quickly could cause the driver ring legs to buckle and break off with the addition of breaking the pins off the leaves completely. To mitigate this issue we did strengthen the pins on the leaves and also increase the diameter of the legs on the driver ring. With the current safety measures in place the risk of such catastrophic failure is extremely low.

Electronic failure could result from many different areas of the system such as power brown outs, servo jams, and a dead battery. Power brown outs could occur through the malfunction of the electronics on board and could cause loss of communication with drone and also cause servo jams. Another issue is when the battery dies during flight and could cause the drone to come crashing down. These issues would results in catastrophic failure of the mission and also cause massive damage to the drone system. In order to fix this issue we have installed voltage dividers in the circuitry to warn us when electronics are malfunctioning so we can safely take action. With these safety measures in plate the risk of electronics failure is much lower than before. Although this failure is not completely preventable, damage to the system would be limited with the addition of the voltage dividers, making this failure made not catastrophic.

A detailed failure modes and effects analysis chart of the drone coupler design can be found in Appendix 8.

Parts and Accessories

Parts for the iris were designed with 3D printing in mind. This method was chosen because it allowed for rapid procession through revisions, allowing the model to be tested, redesigned, and tested again. This production method also allows for anyone with the build files and a 3D printer to make their own. Many research labs already have 3D printing capability, making it ideal, given we predict they will have the most interest in our product.

Designing for 3D printing entails a few main considerations. The first is to limit overhangs; these are anything that spans an open space beneath them. These are hard for 3D printers to accomplish, as the resin will tend to sag as it is laid across the overhang. Another main consideration for 3D printing is tolerances. A 3D printer is able to keep pretty good tolerances, but each printer prints a little different. This means that our design needs to have tolerances that accept a wide range of printers. A third consideration for 3D printing is surface finish. This too can vary widely from printer to printer and will greatly affect the friction between the parts.

The iris mechanism is comprised of several different parts. The main parts are the leaves that open and close, the stator ring, and the rotor ring. The stator and rotor rings are what move the leaves in and out opening and closing the iris. There are several other supporting parts, such as the stabilizing brackets and the electronics bay.

Leaf

The leaves are the actual parts that move in and out to open and close the iris. They slide along each other in order open and close. Because of this, their geometry is very strictly confined by how many leaves there are. As discussed in Prototyping and Analysis, we ended up with eight leaves. A single leaf can be seen in Figure 16.

Figure 16: Rendering of the final leaf

The leaves shape is very important to keeping a closed polygon opening. If the angles did not line up correctly, the opening created by the iris would either bind or have cracks. Binding would prevent the system from moving. By allowing the opening to have cracks, then something could potentially get in the crack and jam the mechanism when it is trying to close.

The leaves interface with the stator and drive rings through two pins. One pin is round and the other is rounded rectangle. The circular pin helps support the leaf as it is cantilevered when loaded. It is also a locating pin, helping keep the concentricity of all the parts. Additionally, force is applied to if from the driver ring. This force is transferred through the leaf into the rectangular pin where it interacts with the stator ring. The rectangular pin is what causes the sliding action of the pin. As the rings are turned, a force is applied to the rectangular pin, driving the leaf in or out.

The leaves are printed on their edge with support material supporting each pin. This allows for the last amount of support to be used. If it were printed on its face, support material would have to be built up around the pin for the full area of the leave the thickness of the pin. This not only adds support material, but also adds more post-processing.

Stator Ring

The stator ring is the bottom stationary ring that interacts with the rectangular pins. It has slots in it just like those in the driver ring, but mirrored. The stator ring is on the bottom of the assembly for two reasons. The first is that it is easier to interact with drive ring with the servo if it is closer to the servo. The second is that, if the drone were to land fully on the drone coupler system, the iris should still be able to close without having to rotate the whole drone. The final stator ring can be seen in Figure 17.

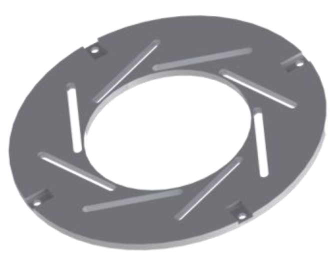

Figure 17: Render of the final stator ring

The stator ring was designed so that it was basically completely flat. The only parts of it that aren't flat are four recesses that are used to mate with the stabilizing brackets. These four recesses allow for easier assembly as they help hold the stabilizing brackets in place. This part can be 3D printed with no support material because of how flat it is and all the recesses can be printed on the top, eliminating any potential overhangs.

Driver Ring

The driver ring is what interacts with the servo and applied the force to the drive ring. It is in between the electronics bay and the drive ring. This allows the driver ring to be directly driven by the servo while keeping the servo housed in the electronics bay. A direct drive system is much more reliable than routing the power through gears or pulleys because it has fewer parts. Housing the servo in the electronics bay also has the advantage of keeping its weight centralized and close to the drone. The final driver ring can be seen in Figure 18.

Figure 18: Render of the final driver ring

The driver ring did have a little more complex geometry than the stator as it had a recess for the servo horn to be glued into along with four beams that interlock with the drive ring.

DRIVEN RING

The drive ring is the actual ring that moves the leaves. Torque from the servo is applied to the drive ring through the driver ring. This force is then applied to the round pin in the leaves. This force exerts a force on the rectangular pins moving them in or out.

The drive ring only has through slots and a few small holes to interface with the driver ring. All of the holes are on the same side, so the ring is printed with this side up. This allows for the ring to be printed with no support material. The final version of the driven ring can be seen in Figure 19.

Figure 19: Render of the final driven ring

SUPPORT BRACKETS

Small brackets were made to help support the drive ring and make the connection from the stator ring to the screws more stable. They sit in recesses in the stator ring. Their general shape resembles a chair and they are printed on their side so that nothing needs supports. Though the holes through the supports are overhangs in this configuration, the holes are small enough that no support material is needed. The final bracket can be seen in Figure 20.

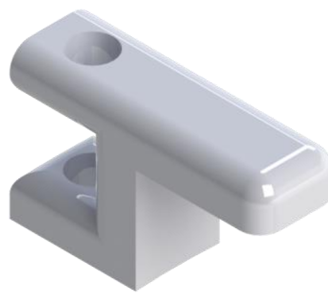

Figure 20: Render of the final support bracket

Electronics Bay

The electronics bay is a specialized box designed to hold all of the electronic components that control the iris that are onboard the drone. It has a special hole in the middle that allows the servo to stick out the bottom to interface with the driver ring. This hole is toleranced so that the servo is a press fit. The press fit is sufficient to hold the servo in place, as there shouldn't be any upward force on the servo. Though, as an extra precaution, when the drone coupler is installed on a drone, the bottom of the servo is pressed up against the drone body, further locking it in place.

The electronics bay is, by far, the heaviest of the 3D printed parts. To help eliminate some weight, small windows were put in the sides of the box and the walls tapper toward the middle to reduce wall thickness. The small windows have the added benefit of allowing air to flow through the electronics bay. This airflow is important as both the servo and the voltage regulator can get quite hot. The thicker walls are needed at the corners to allow for screw holes to mount the whole system to the drone. The final electronics bay can be seen in Figure 21.

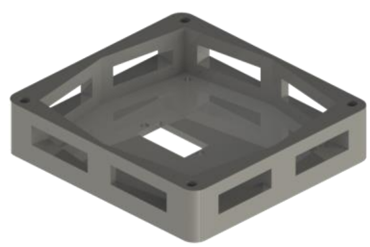

Figure 21: Render of the final electronics bay

THROUGH SCREWS

The whole system is built in layers. These layers are stacked and held together with four screws that go all the way from the stator ring at the bottom to the electronics bay at the top. Number 6 screws were chosen based on their thin size and the fact that they are readily available.

Mounting Screws

The whole system is mounted to the underside of a drone using four mounting screws. These screws go through holes in the corners of the electronics bay and up into the body of the drone. The holes allow for screws up to a number 10, though the strength of a number 6 screw should be easily enough to hold the hole system onto the drone.

Assembly and Trials

This design followed a simple top down construction protocols that resulted in an easy assembly as outlined by the assembly instructions in Appendix 4 and exploded view and mechanical drawings in Appendix 7.

Testing

The first test for the coupler mechanism was performed on December 2^{nd}, 2015. During the testing phase the iris mechanism locked itself and the servo had a hard time opening and closing the iris. Due to this locking issue, the servo heated up very quickly and caused a burn out of the control board inside the servo. This eventually made the servo unusable and it is now unable to perform its intended actions. Pictures of the fried circuit board can be seen in Figure 22.

Getting past this servo failure, the testing process continued as this was the first time the coupler mechanism was tested attached to the drone. The drone was able to carry the entire mechanism with the inclusion of the senor node.

Figure 22: Burnt transistors on the internal servo driver board

FUTURE WORK

The design as it is functional but there are some things about it that could be improved. The first thing that could be improved is the design for the knob on top of the node that is used to it pick up. The problem with the knob design at present is if the iris doesn't land on it low enough, when the iris closes it will be pushed up off the knob because of its hemispherical shape. One way this design can be improved is if the hemisphere is changed into an upside down conical shape so that if the iris doesn't land on it perfectly the knob will push the iris down instead of it wanting to go up. The next thing that could use a redesign is the bracket that holds the two disks together. The brackets are skeletal and thin making them prone to breaking. For the future design of this component, they should be a solid piece between the plates for added rigidity as well as increased in width for extra strength because in tests, the brackets have split when drilled through because they are so thin.

Another idea that was discussed for improving the design is include spacers for the mounting the iris to the electronics bay. Through testing the design, it appears that the iris can be mounted crooked and cause the iris to lock up or be mounted too tightly with the same result. Spacers could be used to maintain alignment and not allow the ring to get too tight. Another idea from testing the design, the friction on the leaves can easily be too large and cause the iris to bind up. A possible solution to explore is to change the material of the at least the stator and rotor ring to of a lower friction material such as Delrin or use some sort of lubricant to decrease the friction.

For the electronic, it was found that if the motor was to bind up the servomotor can pull too much energy and burn itself out. For the future, a current limiter should be set in place to have a safety measure against such problems. The last thing that could be improved is moving all the electronics to a soldered PCB. Right now, a solder less breadboard connects all of the electronics. This could prove troublesome because the wires could come out while the drone is flying. To fix this potential problem, the idea would be to change this to a perforated board so that all of the connections can be soldered in together so there would be no risk of them coming undone.

Conclusions

When the problem was initially put forth by NIMBUS lab here on campus, they needed a system for drones that would allow it to pick up sensor nodes to deploy them in the field. The system would attach to the underside of the drone and allow it to remotely pick up sensors. Not only has this project satisfied the requirements set forth by the NIBUS Lab, but also expanded on them with quick interchangeable coupler system, easy programming and software interface. The complete system can be seen in Appendix 8. The complete system can be interchanged between different drones and the systems can completely function on its own without connecting to the drone's electrical systems. Furthermore, the coupler system can withstand quick agile maneuvers from the drone and can carry the specified weight asked by NIMBUS Lab. This drone coupler project will no doubt be a point of interest and further research topic at the NIMBUS Lab for years to come.

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Appendices

Appendix 1 – Stress Analysis

The forces on the coupler will be reviewed here. Now there are a lot of forces acting on the system at any given time however, there are three main components with the most forces acting on them and are the most likely to fail. They are the leaves, the rotor ring of the iris, and the driver ring for the whole system.

The first piece to look at is the leaves. There are eight leaves in the design but for the purpose of this analysis it will be assumed that the entire load of the node is on one leaf as a sort of worst-case scenario. Only the pin will be analyzed for forces because that will be the most likely part to break. The node is measured to be about 0.15 kg in mass so the downward force exerted on the leaf would be:

$$0.15kg * \frac{9.81m}{s} = 1.4715N \approx 0.331\ lbf$$

This force would be distrusted across the contact surface but for this analysis it is assumed to be applied to the very tip of the leaf. Using the length of the wedge, the moment applied by the weight of the node to the wedge is found:

$$M = F * L = 0.331lbf * 1.35in = 0.44685lbf - in$$

Then using the sum of the moments around the center of the pins to find to force applied to both pins using the length of the pins which is 0.125in:

$$\sum M = 0 = FL - 2fl = 0.44685lbf - in - (2 * 0.125in)f$$

$$f = \frac{0.44685lbf - in}{2 * 0.125in} = 1.7874lbf$$

The force diagram for all of this can be found below in Figure 23. Then using this force, the bending stress on the smaller top pin is analyzed using the equation:

$$\sigma = \frac{My}{I_x}$$

Where the I_x in this case for a circular cross section is:

$$I_x = \frac{\pi}{4} r^4$$

Where r for the pin is 0.055in. Therefore, calculating the stress on the top pin is as follows:

$$\sigma = \frac{1.7874 * 0.125in * \frac{0.055}{2} in}{\frac{\pi}{4} 0.055^4 \; in^4} = \frac{854.9167lbf}{in^2}$$

Using the material properties for ABS plastic, the yield strength is conservatively 6160 psi. So the safety factor for the pin is:

$$n = \frac{S_y}{\sigma} = \frac{6160 \; psi}{854.9167} = 7.21$$

So the pin should safe from any fracturing.

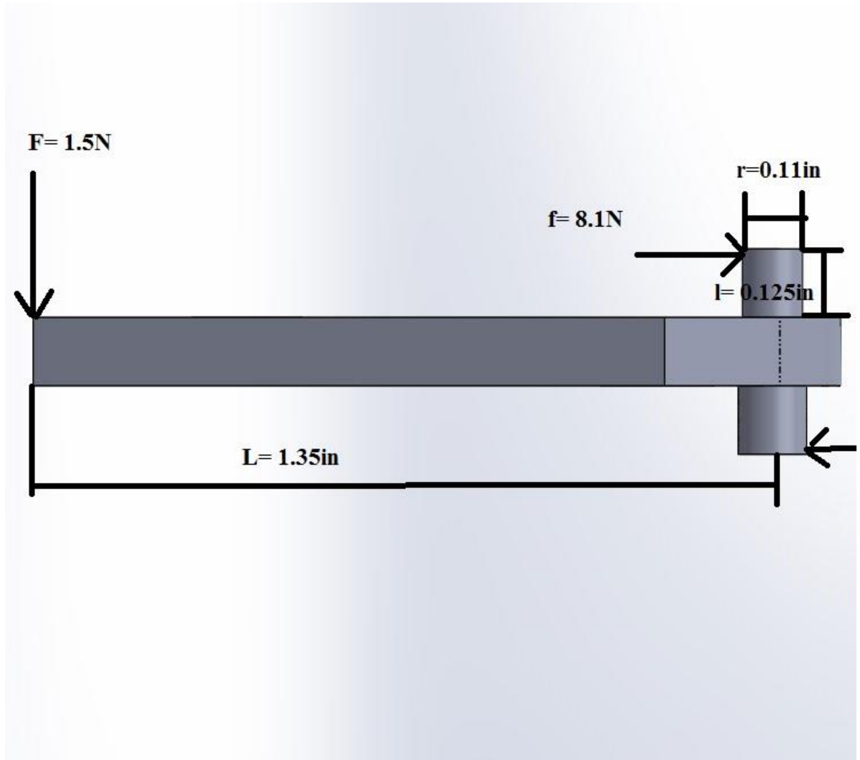


Figure 23: Wedge Force Diagram

The next component that is to be analyzed is the forces on the rotor ring. The force diagram of this piece can be found in Figure 24. The top ring is being loaded with a torque applied by the driver ring and in a worst case scenario where there isn't the lower pin counter acting the down force, a force inward due to the wedge, seen in Figure 24. The force due to the servo motor is equal to the radius from the center of the circle to the times the rated torque for the servo which is found:

$$F = \frac{T}{r} = \frac{(44oz - in)}{1.25in} * \frac{1lbf}{16oz} = 2.2lbf$$

The most likely mode of failure is the tear out of these driving holes. To find the tear out shear stress the hole to the edge, 0.20in, and the thickness of the hole, 0.0625 in, are needed to calculate it using the equation:

$$\tau = \frac{F}{2et} = \frac{2.2lbf}{2 * 0.20in * 0.0625in} = 88psi$$

Then finding the safety factor using the yielding shear stress for abs is:

$$n = \frac{0.5S_y}{\tau} = \frac{0.5 * 6160psi}{88psi} = 35$$

The safety factor is high enough that this shouldn't be a problem even if the motor presently used was increased considerably giving it a lot of wiggle room. The second mode of failure to check is the shear force due to the wedge that could be applied to the slot. The force on the pin calculated before 1.7874lbf is assumed to be applied to the side of the slot and the smallest distance possible between the slot edge and the center circle is used to find the area over which this force acts, seen in Figure 24. The thickness of the entire plate is need which is 0.125in. So the shear force in this case is found:

$$\tau = \frac{V}{dt} = \frac{1.7874lbf}{0.0375in * 0.125in} = 381.312psi$$

So again the safety factor for this mode of failure is evaluated:

$$n = \frac{0.5S_y}{\tau} = \frac{0.5 * 6160psi}{381.312psi} = 8.08$$

This safety factor is still high enough that the breaking shouldn't be an issue and gives the rotor ring an overall safety factor of 8.08.

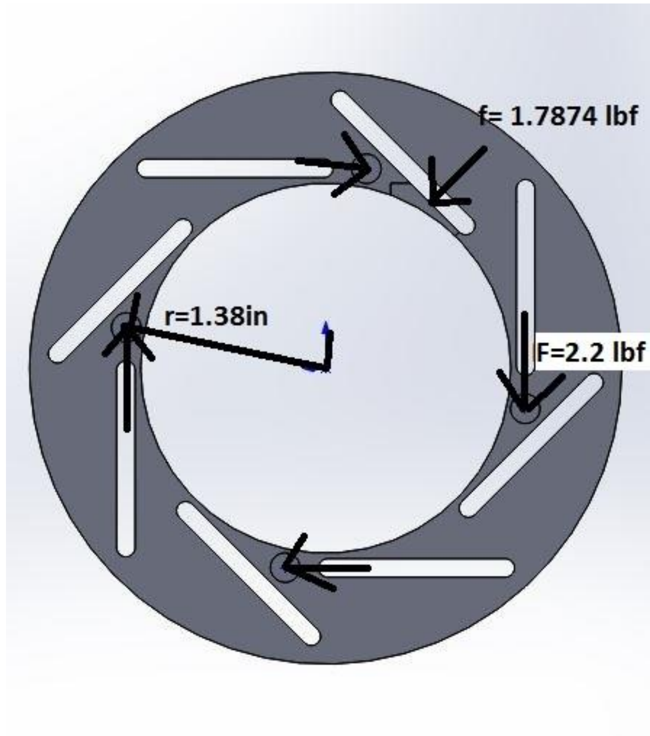


Figure 24: Rotor ring force diagram

The last part that needs to be analyzed is the driver ring. The most concerning part of the driver ring that needs to be analyzed is the legs which bear the brunt of the load. The legs have an odd shape and all calculations shall assume that it is a constant cross-section cylinder with a radius equal to the lower pin. The driver ring is being driven by the 44 oz-in servo motor at a radius of 1.25 from the legs, show in Figure 25, so the force applied to them is calculated:

$$F = \frac{T}{R} = \frac{44oz - in}{1.25in} * \frac{1lbf}{16oz} = 2.2lbf$$

Which is the same as the amount applied to the driving holes in the rotor ring. So then the bending force that this force, assumed to be applied to one leg, would be calculated using the length of the leg with is 0.5 in, seen in Figure 26:

$$M = FL = 2.2lbf * 0.5in = 1.1lbf - in$$

Now, the bending stress needs to be calculated using the equation and the radius of the leg which is 0.075in:

$$\sigma = \frac{My}{\frac{\pi}{4}r^4} = \frac{1.1lbf - in * \frac{0.075in}{2}}{\frac{\pi}{4}0.075^4 in^4} = 1659.927psi$$

Then the safety factor is calculated using the yield strength:

$$n = \frac{S_y}{\sigma} = \frac{6160psi}{1659.927psi} = 3.711$$

Now this is the lowest safety factor that we've seen so far for the model which means there may be some room for improvement in this design.
In summary, the overall safety factor of the device is 3.711 which is limited by the driver ring's legs which have the lowest safety factor however it is probably more than this due to the assumption of uniform cross section. These calculations are all also done assuming solid ABS plastic meaning that is the 3-D material is at a lower fill then it might not even reach this safety factor.

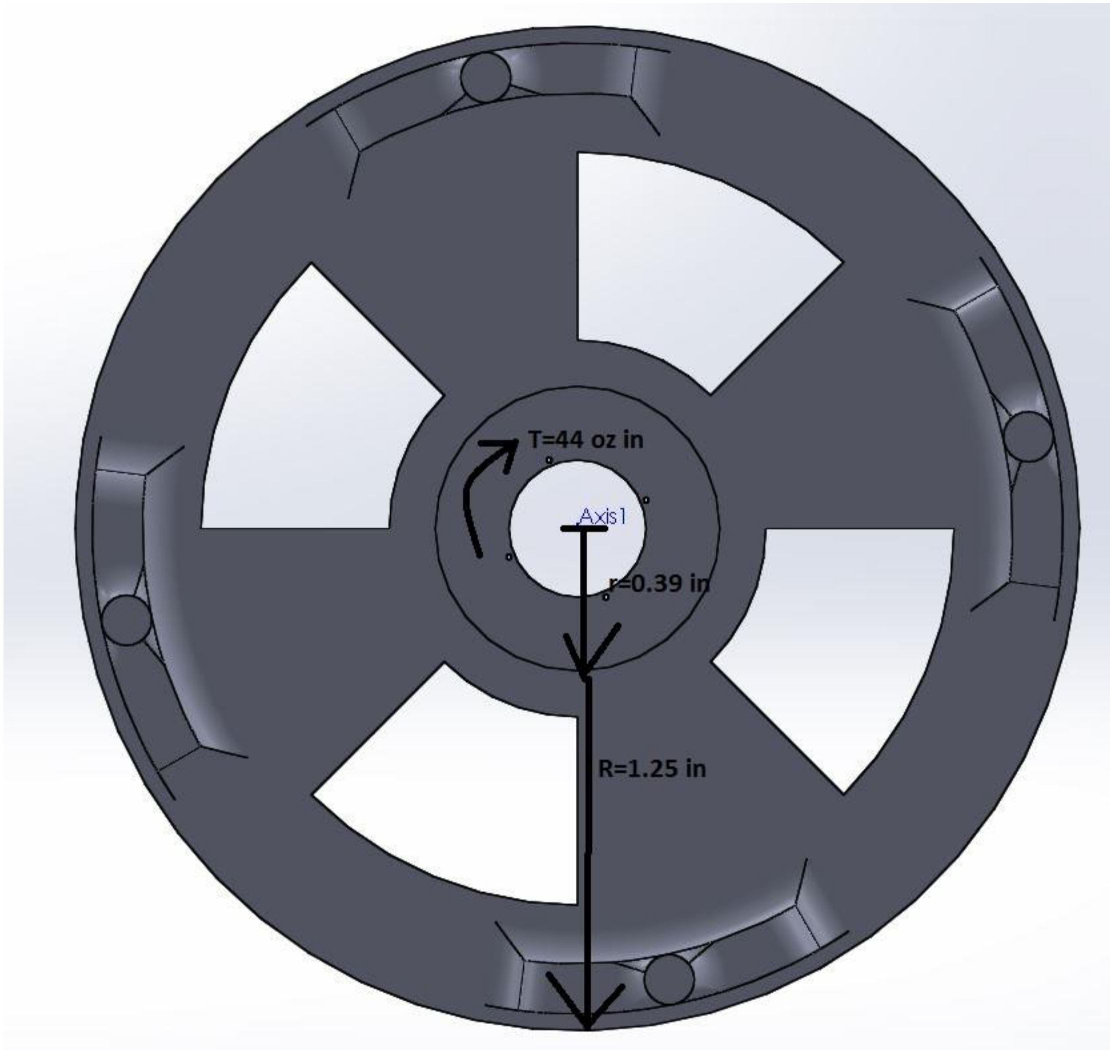


Figure 25: Rotor Ring Torque

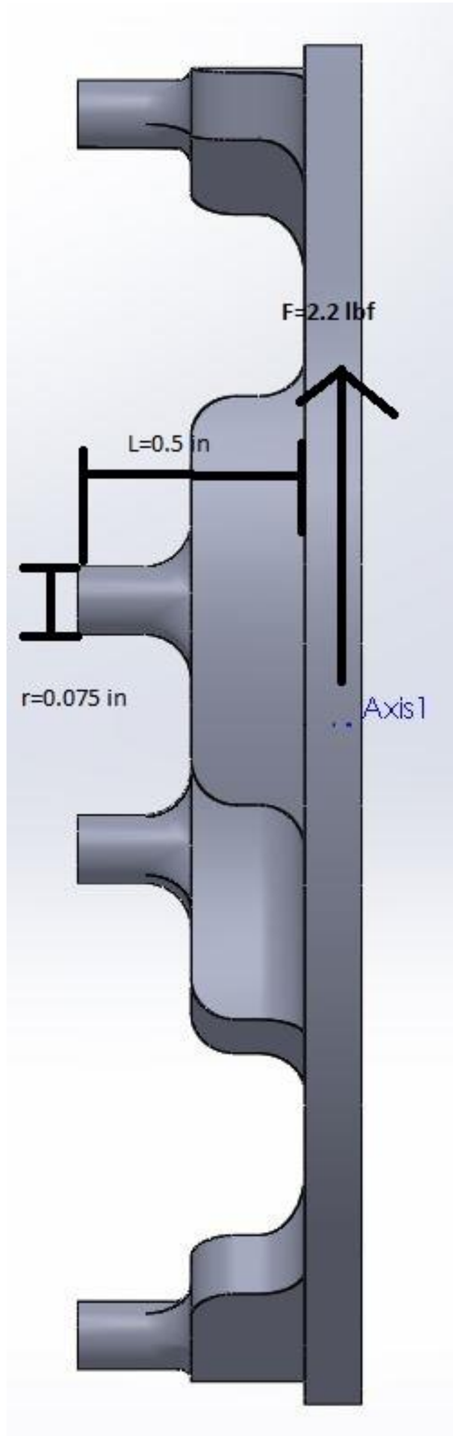


Figure 26: Rotor Ring Force Diagram

APPENDIX 2 – FINITE ELEMENT ANALYSIS

Using Solidworks built in finite element analysis tool, the forces found in Appendix 1 were applied to the leaves, the driver ring, and the rotor ring of the iris and ran to check for failure in each part due to Von Mises Stresses. These part were chosen because they are the parts with the most stress behind them and the most likely to fail. The parts printed for the prototype was ABS 3-D printed material however since there isn't an accurate model for the yield stresses for this material considering there is variable fill density, therefore for the FEA, delrin was assumed for material properties because in the future work section delrin is considered as an alternate material.

The leaves were loaded with a force of 1.5 N over the area rough of there the knob would sit, seen outlined in purple arrows below in Figure 27, on the wedge while it is be in flight. This test assumed that most, if not all of the weight of the node would be resting on the one single leaf. The pins on top and the slider on the bottom were fixed for the model. Running the test show, exaggeratedly, the deflection of the leaf is shown in Figure 28 below. From looking at Figure 29 and 30, it can be seen that the maximum amount of stress is at the base of the top rotating pin and where the leaf rest upon the bottom ring. Although, the safety factor found was 37.0033 regardless which gives good confidence to the strength of the leaves.

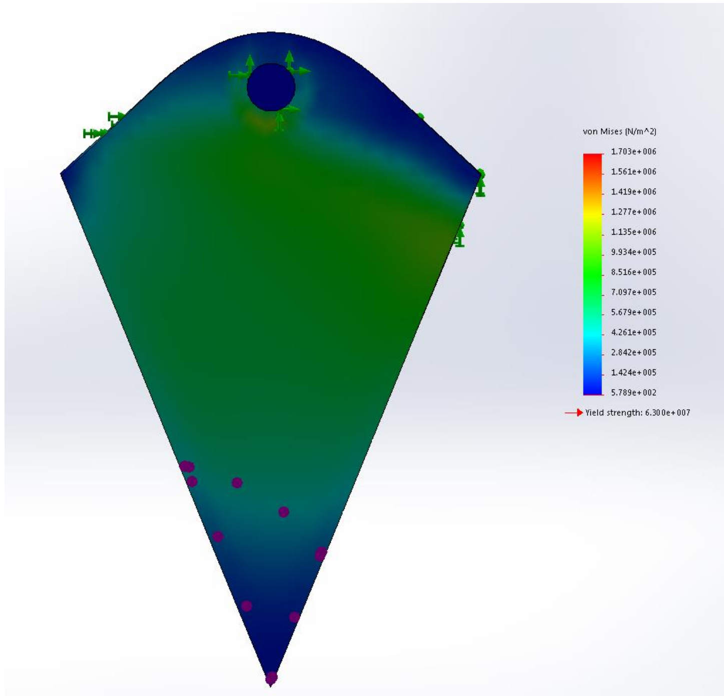


Figure 27: Top View of leaf FEA

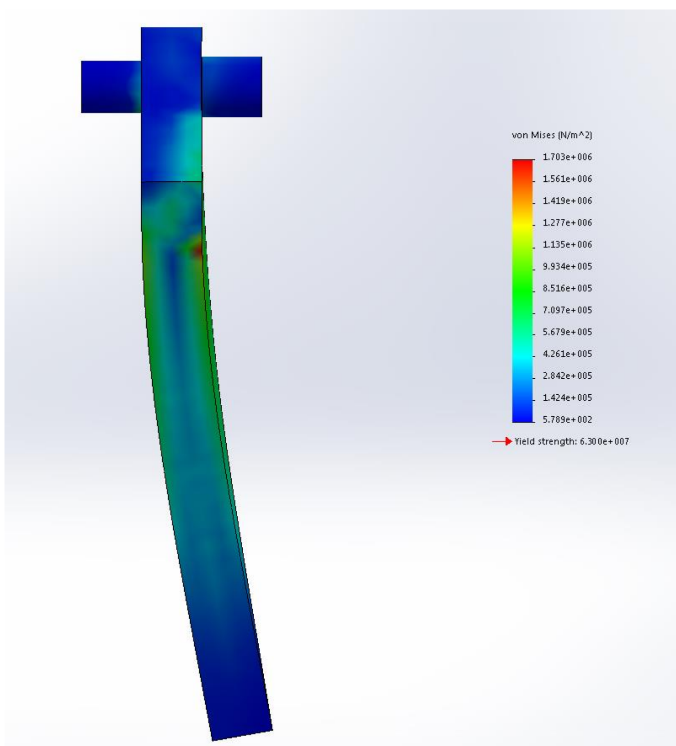


Figure 28: Side View of Leaf FEA

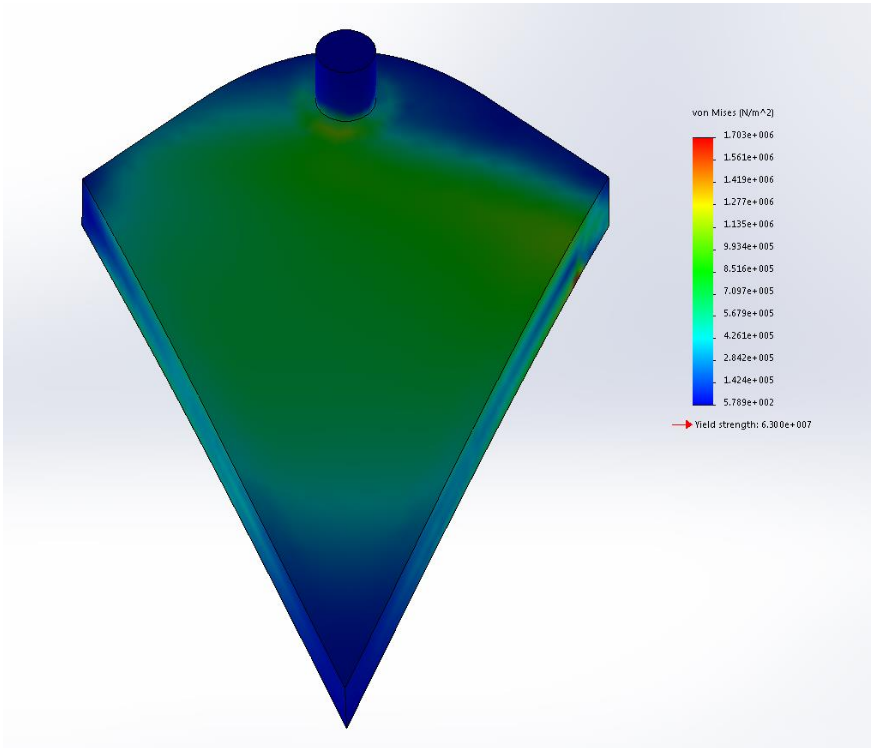


Figure 29: Angled top view of leaf FEA

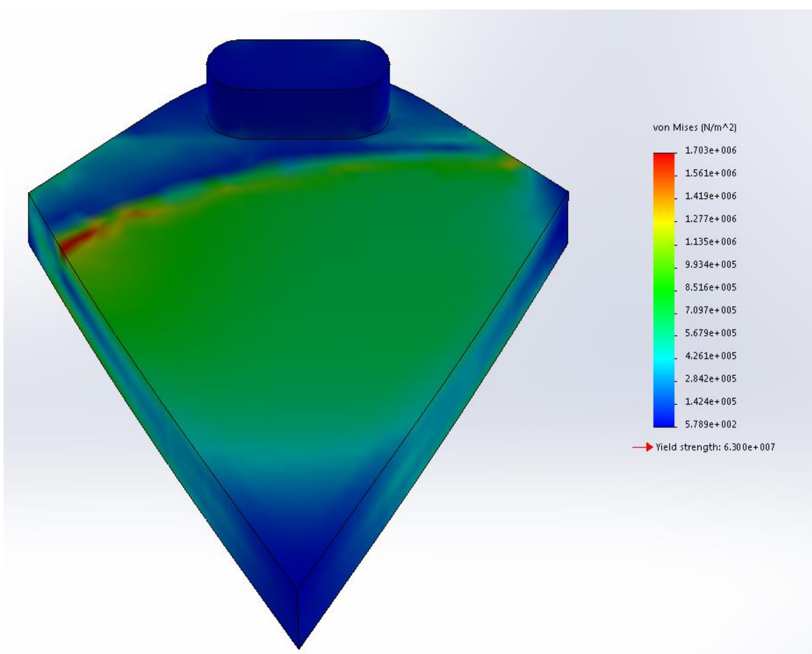


Figure 30: Angled bottom view of leaf FEA

Next, looking at the rotor ring finite element analysis loaded with 2 lbf, from Appendix 1, in each of the hole that attach it to the driver ring. The ring is also loaded with the weight of the node and the leaf bending into the side of one of the slots to analyze the ring at maximum load. The loading of the rotor ring is shown in Figure 31 below. The Von Mises Stress are highlighted from the FEA in Figure 32 below. From the figure, it is noted that the emphasized deformation shows that the most likely form of failure to be tear out of the holes into the slots which shows the greatest levels of stress. From the FEA, the rotor ring is calculated to have a 88.6075 minimum safety factor which is even higher than that of the wedges which is good because with the sudden jerks and jostles from flying with the node it shouldn't be a problem.

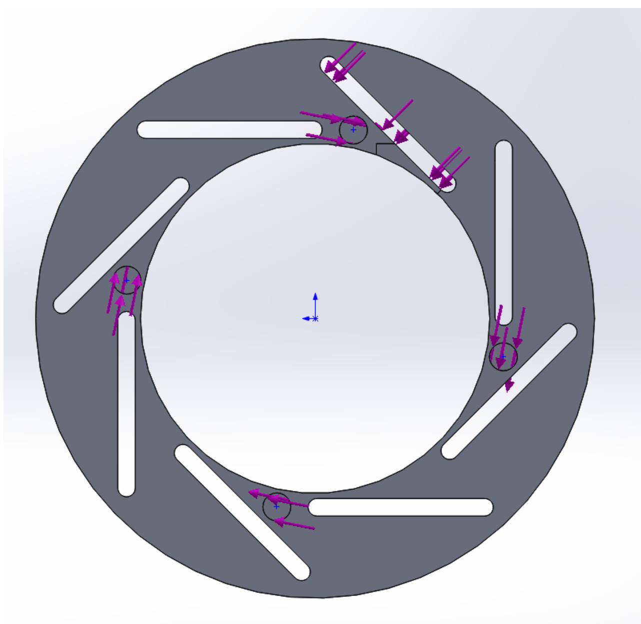


Figure 31: Rotor ring force loading

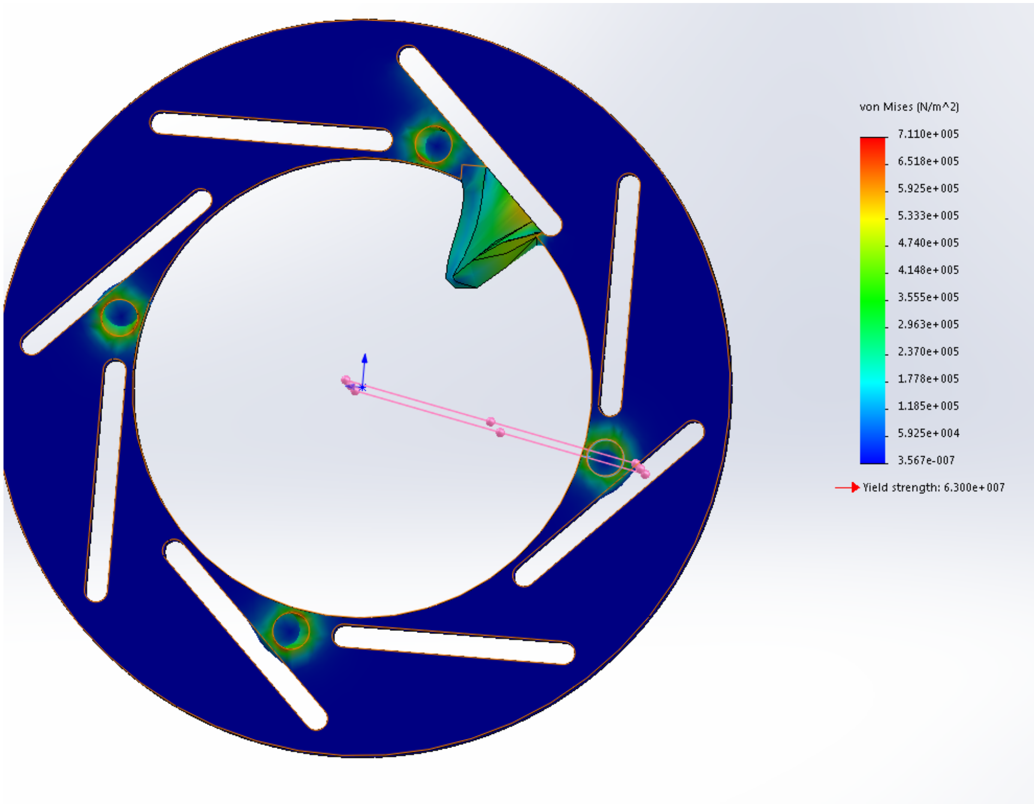


Figure 32: Rotor ring Von Mises stress

Lastly, the driver ring of the iris was analyzed with the applied 3 lbf-in torque loaded in the driver hole in the middle of the ring. After running the FEA, the resulting factor of safety (FOS) results can be from in Figures 33 and Figure 34 below. From there it can be observed that the majority of stress is where the servo drives the ring and were the legs change dimensions. However, even at these spots the factor of safety is still large than 45 which means the design is safe from breaking due to Von Mises stresses.

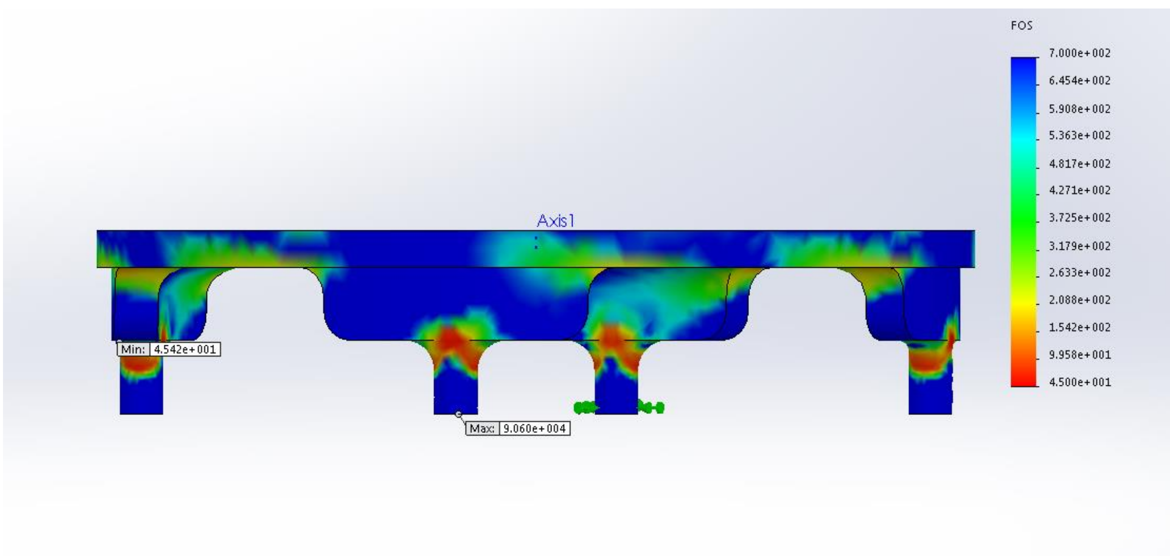


Figure 33: Driver Ring Side View FEA (FOS)

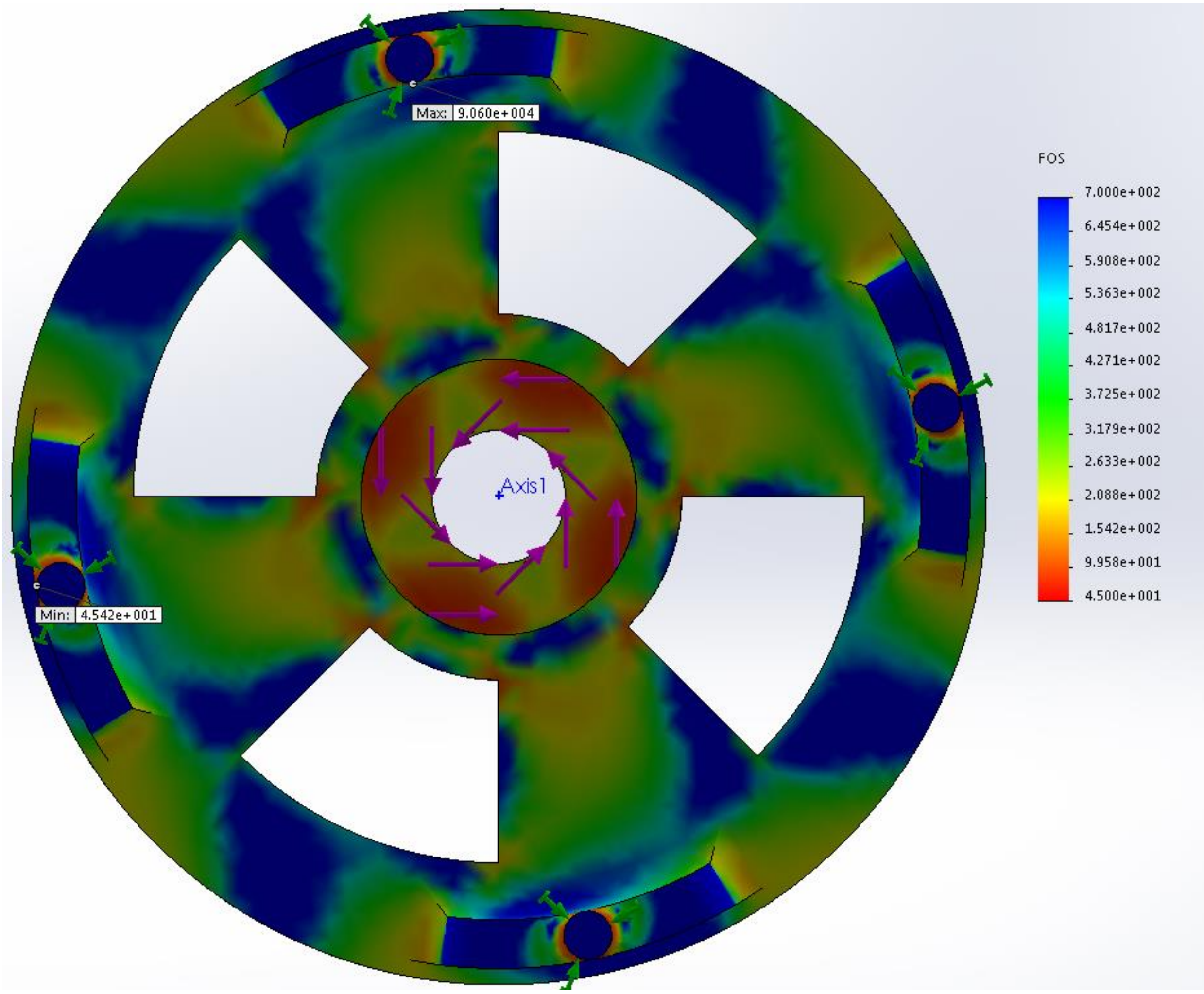


Figure 34: Driver Ring Bottom View FEA (FOS)

APPENDIX 3 – BILL OF MATERIALS

Part	Volume (in^3)	Number	Cost ($)
Support Arms	0.04	4	0.12
Slotted Ring	1.39	1	1.0425
Leaves	0.09	8	0.54
Drive Ring	0.79	1	0.5925
Driver	0.81	1	0.6075
Base Plate	5.13	1	3.8475
		Total	6.75

Final List			
XBee Adapter kit - v1.1	10	2	20
XBee Module - Series 1 - 1mW with Wire Antenna - XB24-AWI-001	22.95	2	45.9
Terminal Block - 2-pin 3.5mm - pack of 5!	2.95	1	2.95
Breadboard-friendly SPDT Slide Switch	0.95	1	0.95
Power Boost 1000 Charger - Rechargeable 5V Lipo USB Boost @ 1A - 1000C	19.95	1	19.95
Arduino Pro Mini 328 - 5V/16 MHz	9.95	2	19.9
Break-away 0.1" 36-pin strip male header (10 pieces)	4.95	1	4.95
2mm Pitch 25-Pin Female Socket Headers - Pack of 5	3.95	1	3.95
Lithium Ion Polymer Battery - 3.7v 2500mAh	14.95	1	14.95
Servo - Generic Metal Gear (Micro Size)	10.95	1	10.95
Helion Li-Ion Battery 7.4 V/700 mAh	13.99	1	13.99
		Total Electronics Cost	158.44
		Material Cost	6.75
		Total Cost	165.19

Appendix 4 – Technical Specifications of Electronics

The electronics in controlling the drone coupler are split into two systems, the master and the slave. The master subsystem is comprised of an Arduino, potentiometer, batter and an XBee.

Master Arduino

The master subsystem's Arduino is a Sparkfun Redboard, an Arduino Uno clone. This was chosen based on its. Smaller boards were available, but we already had a Redboard that could be used to keep costs down. This board can be seen in Figure 35.

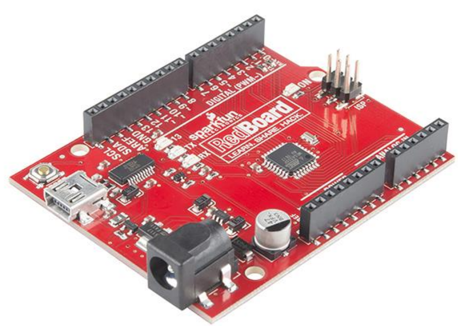


Figure 35: Picture of the Sparkfun Redboard used for the master subsystem

Features for this board that are required was an analog input and serial communication. The analog input was needed to read the potentiometer for user input and the serial communication is used to talk to the other Arduino through the XBees.

POTENTIOMETER

A potentiometer was used as the user input. A potentiometer was chosen because of how easy it is to interface with the Arduino and how easy it is for the user to relate the rotation of the potentiometer to the rotation required to open and close the ring. An example of the potentiometer used can be found in Figure 36.

Figure 36: Example picture of a potentiometer

Any potentiometer could be used since they act as a voltage divider and the output is based on the resistance ratio, not the absolute resistances. More specifically, the output voltage is compared to the overall voltage applied to the potentiometer. A linear potentiometer was used because the output voltage changes at a linear rate corresponding to the rotational position of the knob. This is more intuitive to a user as opposed to the other option being a logarithmic potentiometer.

XBee

XBee radios were used to communicate between the master to the slave subsystem. XBee radios are used to simplify serial communication from one place to another wirelessly. They have a few different ratings, but all work in a similar manner. We used a very basic one because they only need to prove proof of concept. A picture of an XBee similar to ones used in this project can be found in Figure 37.

Figure 37: Product picture of an XBee

This XBee has a broadcast strength of 1mW giving it a range of around 300 feet, unimpeded. This range is much less than would be required to use this system in the field, but XBees that have an appropriate range are much more expensive. These were good for proof of concept and stronger XBees could be dropped in easily, as they are often pin for pin compatible. This same XBee was used in the slave subsystem.

XBees simplify the serial communication by having onboard circuitry that establishes the connection between the two. This hides a lot of the communication setup so that the pair can be used the same as a wired serial communication.

Master Subsystem Battery

A basic battery was used to power the master subsystem. The power was delivered to the subsystem through the barrel jack on the Redboard. This jack will take any input voltage from 7 to 15 volts. In the most basic form, a 9 volt battery could be used. The current draw from this battery is pretty low because the only things drawing power are Redboard, the potentiometer, and the XBee. This should total less than 100 milliamps.

Slave Arduino

An Arduino Pro Mini 5 volt controls the slave subsystem. This can be seen in Figure 38. This Arduino compatible board was chosen based on its size and weight. It weighs less than two grams and is only 18 mm by 33 mm. To save space and weight, it uses FTDI to program the board instead of the normal USB connector which requires another connector and another chip. Features required on this board include a PWM pin to control the servo along with serial communication.

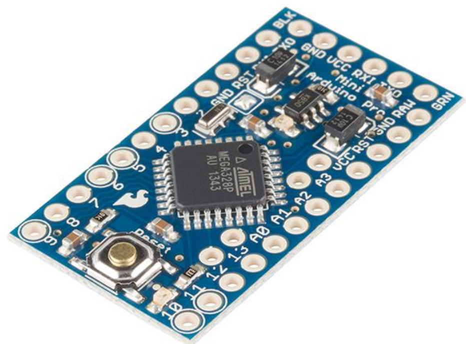


Figure 38: Arduino Pro Mini

There are other boards that are a little smaller than this board, but the Arduino Pro Mini was chosen based on its proven reliability, readily available, and our past experience with the board. The other boards also have quite a bit fewer inputs and outputs, which we wanted to keep options open in case we needed to add features later, such as a voltage monitor.

SERVO

A servo was used as the electromechanical portion of the slave subsystem that allowed the Arduino to physically move the mechanism. A stepper motor was also considered as the electromechanical portion, but was later decided against because steppers have much lower torque to weight ratio, required external circuitry to control, and could loose track of their position in case steps were skipped. The servo used in our application can be seen in Figure 39.

Figure 39: Servo used in the drone coupler system

This servo has an operating voltage between 4.8 and 6.0 volts. When operating at 4.8 volts, 38.8 oz-in. and 44.4 oz-in. at 6.0 volts. For comparison, the stepper motor that was considered had a stall torque of just 2.0 oz-in. This servo has a rotation of 180^{o}, only about 90^{o} are needed to fully open and close the mechanism. This servo also only weighs 20 grams.

Other features that make this servo a good choice include its speed and construction. It has a full metal gearbox making the probability of stripped gears low. It also has dual ball bearings, keeping the drive shaft in line. This is important, as the concentricity geometrical tolerances are tight for this design. The speed of the servo is 0.20 seconds to turn 60^{o} at 4.8 volts and 0.18 seconds at 6.0 volts.

Slave Subsystem Battery

A two-cell lithium polymer battery was used for the slave subsystem battery. This chemistry was chosen based on its high energy to weight ratio. They are also capable of sourcing much more current than the slave subsystem will need. Two-cell batteries were chosen because they supply a nominal 7.4 volts, which is enough to run everything, even after passed through the regulator. The battery voltage should not be too close to the output volt from the regulator or else the regulator will not be able to output a constant voltage.

A three-cell battery could also have been used as it would have sufficient voltage, but regulating down the extra 3.7 volts would just increase the heat dissipation through the regulator. This is problematic because it can heat up the electronics around it, which is bad for them, and increasing the heat of the regulator decreases its current handling capabilities. Further, the extra cell adds more weight to the battery with no positive gain for the subsystem.

5 Volt Voltage Regulator

The servo can draw a lot of current if it needs to exert a larger torque. The Arduino Pro Mini can only source 150 mA of current so an alternative was needed. The solution is a voltage regulator seen in Figure 40.

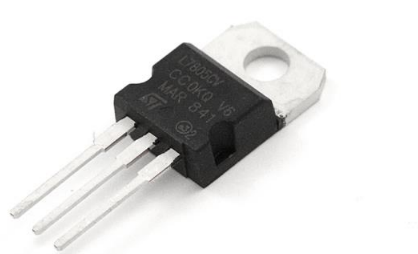


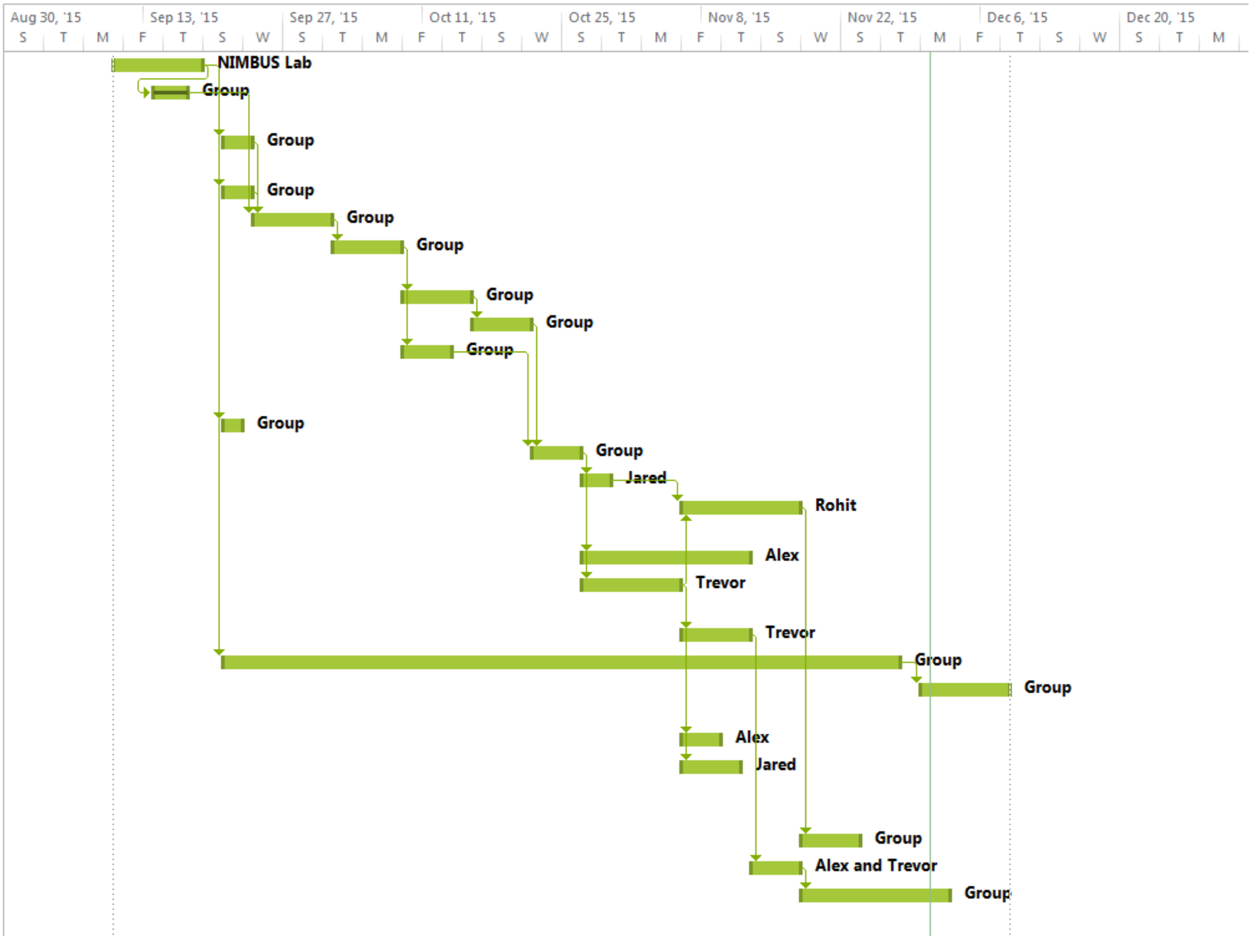
Figure 40: 5 volt voltage regulator in a TO-220 package

This voltage regulator is capable of sourcing 1.5 amps of current regulated at 5 volts plus or minus 0.2 volts. This voltage fluctuation is acceptable, because that means it fluctuates between 4.8 and 5.2 volts, which is within the operating voltage for the servo it is driving.

To avoid using multiple batteries, the voltage regulator is directly tied into the main batter that also runs the battery. This allows all the current to be pulled from the battery instead of through the Arduino. So long as the regulator and the rest of the circuit maintain a common ground, this will be able to supply the servo with as much current as it needs. The common ground is important to keep all circuit voltages based on the same base point.

Appendix 5 – Project Gantt Chart

		Task Mode	Task Name	Duration	Start	Finish	Predecessors	Resource Names
1			Design Goals	7 days	Thu 9/10/15	Fri 9/18/15		NIMBUS Lab
2	✓		Generate Design Constraints	3.5 days	Mon 9/14/15	Thu 9/17/15	1	Group
3			Background Research	3 days	Mon 9/21/15	Wed 9/23/15	1	Group
4			Patents Search	3 days	Mon 9/21/15	Wed 9/23/15	1,2	Group
5			Brainstorm Ideas	6 days	Thu 9/24/15	Thu 10/1/15	2,3,4	Group
6			Functional Decomposition	5 days	Fri 10/2/15	Thu 10/8/15	5	Group
7			Morphology	5 days	Fri 10/9/15	Thu 10/15/15	6	Group
8			Pugh Matrix	4 days	Fri 10/16/15	Wed 10/21/15	7	Group
9			Quality Functional Deployment Analysis	3 days	Fri 10/9/15	Tue 10/13/15	6	Group
10			PERT Diagram	2 days	Mon 9/21/15	Tue 9/22/15	1	Group
11			Select approach	3 days	Thu 10/22/15	Mon 10/26/15	8,9	Group
12			Material Selections	3 days	Tue 10/27/15	Thu 10/29/15	11	Jared
13			Engineering Calculations	8 days	Fri 11/6/15	Tue 11/17/15	12,15	Rohit
14			Electrical Design	13 days	Tue 10/27/15	Thu 11/12/15	11	Alex
15			Generate CAD Model	8 days	Tue 10/27/15	Thu 11/5/15	11	Trevor
16			Order Parts	5 days	Fri 11/6/15	Thu 11/12/15	15	Trevor
17			Write Final Paper	50 days	Mon 9/21/15	Fri 11/27/15	1	Group
18			Prepare Presentation	7 days	Mon 11/30/15	Tue 12/8/15	17	Group
19			Create EBOM	2 days	Fri 11/6/15	Mon 11/9/15	15	Alex
20			Design for Manufacture (DFM) Analysis	4 days	Fri 11/6/15	Wed 11/11/15	15	Jared
21			Sensitivity Analysis	4 days	Wed 11/18/15	Mon 11/23/15	13	Group
22			Assemble	3 days	Fri 11/13/15	Tue 11/17/15	16	Alex and Trevor
23			Testing	11 days	Wed 11/18/15	Wed 12/2/15	22	Group



Appendix 6 – Exploded View and Mechanical Drawings

To assemble the entire system the leaves need to be placed into the stator ring. The slotted part of the leaf should go into the stator ring. Then carefully fit on the driven ring. Next prepare the driver ring. Take a circle servo head and glue it into the driver ring as illustrated below. Please not the position of the servo head will need to line up with the servo so place accordingly.

Figure 41: Left: Driver ring with servo horn, Right: Driver ring without servo horn

Figure 42: Gluing the servo horn into the driver ring

Wait for the glue to dry. Now that glue has dried, line up the holes in the driven ring with the holes of the driver ring, seen above. The next step is to then place the supporters into the slots of the stator ring. These may need to be held down during assembly with tape or glue. This process is documented in Figure 41 and Figure 42.

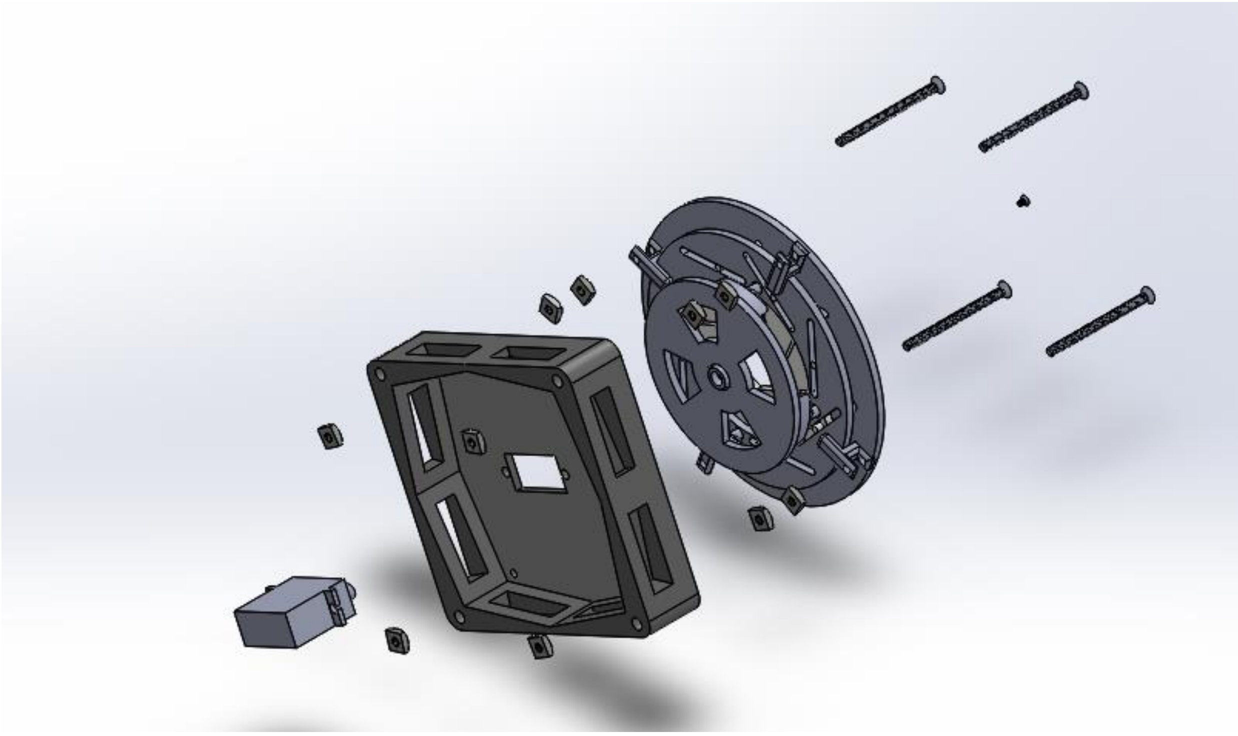
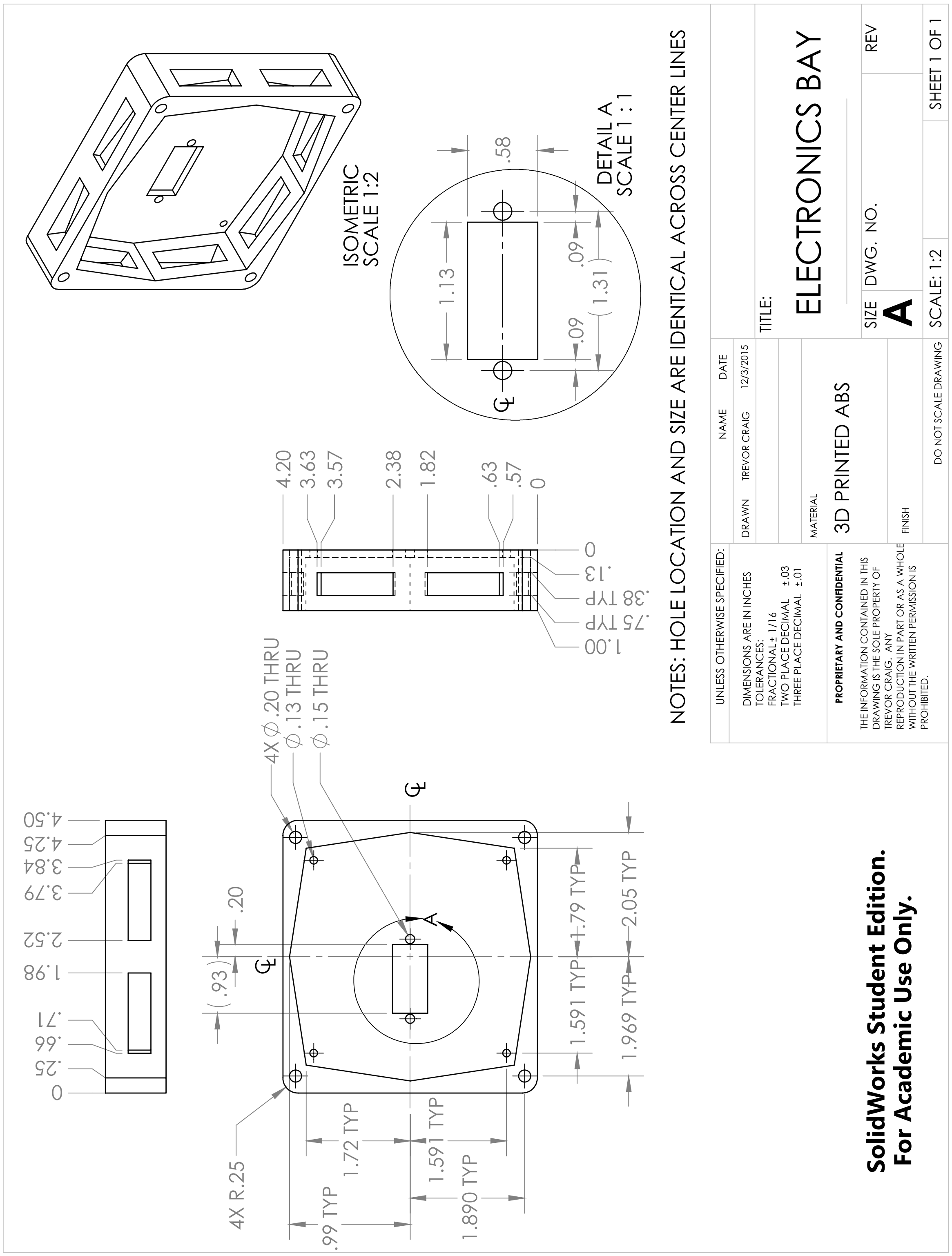


Figure 43: Exploded view of the whole assembly

Take your base plate and fit the servo into its hole in the base plate. Ensure that the servo head is in the middle of the plate. Place the servo into the driver ring servo head that was glued earlier. This now allows for the assembly to be screwed together. Take your bolts and start at the stator ring and go through the supporter. Attach two nuts to the bolts and continue screwing them in until they are through the base plate. At this point add another nut to the bolt. In this prototype square nuts were used to allow easy adjustments and provide “weld nuts” inside the base plate as they could not move due to the geometry. Tighten all nuts till they show no gaps between any components. It is ideal to have the nuts that attach the supporter to be a little loose to avoid placing to much force on the driven ring. At this point the mechanical parts should be fully assembled. This can be seen in Figure 43.

Insert the electrical components into the base plate and then you are ready to attach it to a drone. Depending on the drone the holes through the base plate would work or the slots on the side can be used to zip tie to the bottom.


ELECTRONICS BAY
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DETAIL A
SCALE 1 : 1
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Ø.13 THRU
Ø.15 THRU
4X R.25
1.99 TYP
1.72 TYP
1.591 TYP
1.890 TYP
1.591 TYP
1.969 TYP
1.79 TYP
2.05 TYP
(.93)
.20
4.20
3.63
3.57
2.38
1.82
.63
.57
0
.13
.38 TYP
.75 TYP
1.00
.58
1.13
.09
.09
(1.31)
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL± 1/16
TWO PLACE DECIMAL ±.03
THREE PLACE DECIMAL ±.01
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TREVOR CRAIG
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MATERIAL
3D PRINTED ABS
FINISH
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DWG. NO.
REV
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SHEET 1 OF 1
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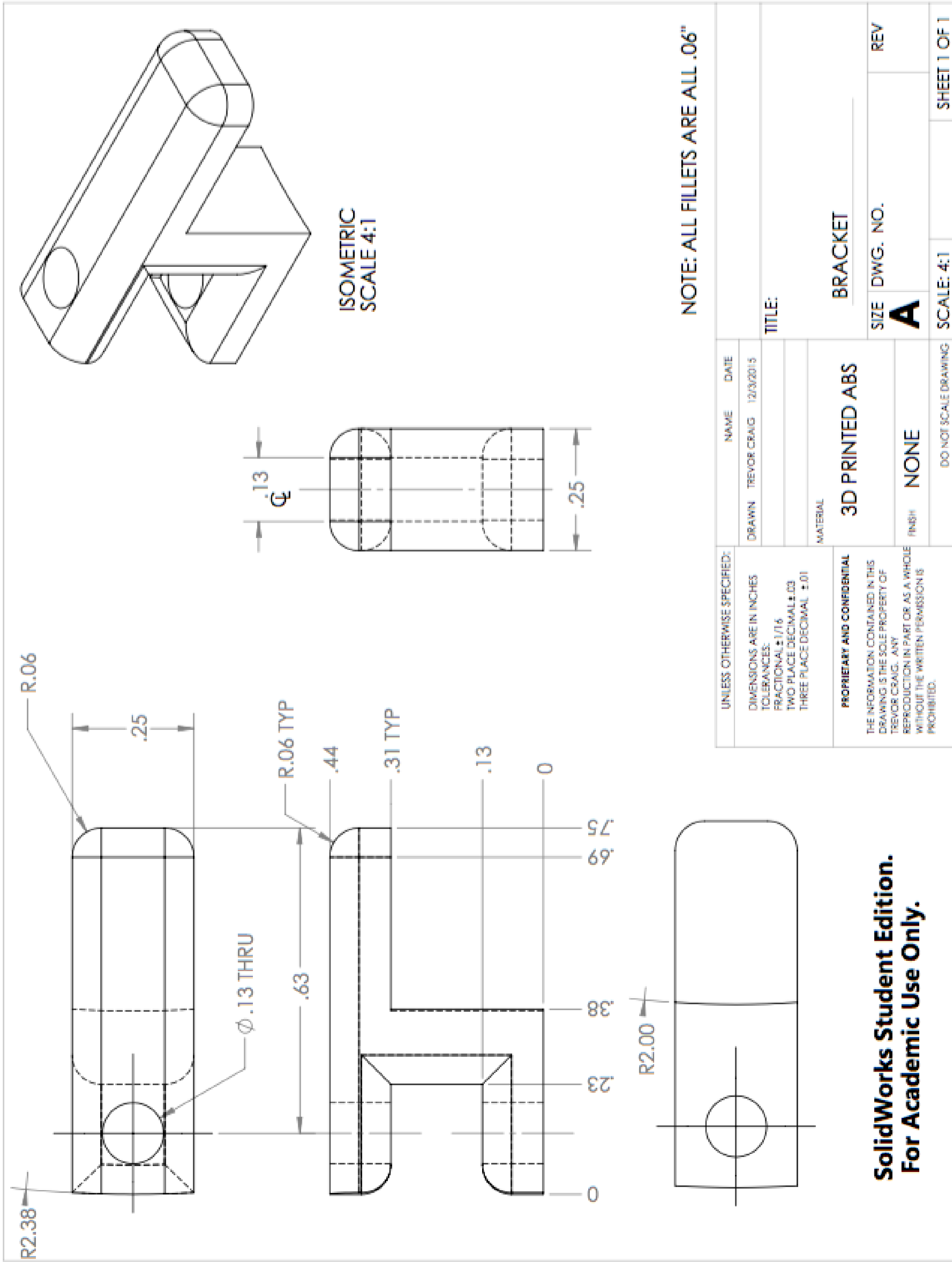
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R.06 TYP
.44
.31 TYP
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.75
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.63
Ø.13 THRU
.38
.23
R2.00
R2.38
.13
.25
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ± 1/16
TWO PLACE DECIMAL ± .03
THREE PLACE DECIMAL ± .01
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TREVOR CRAIG
12/3/2015
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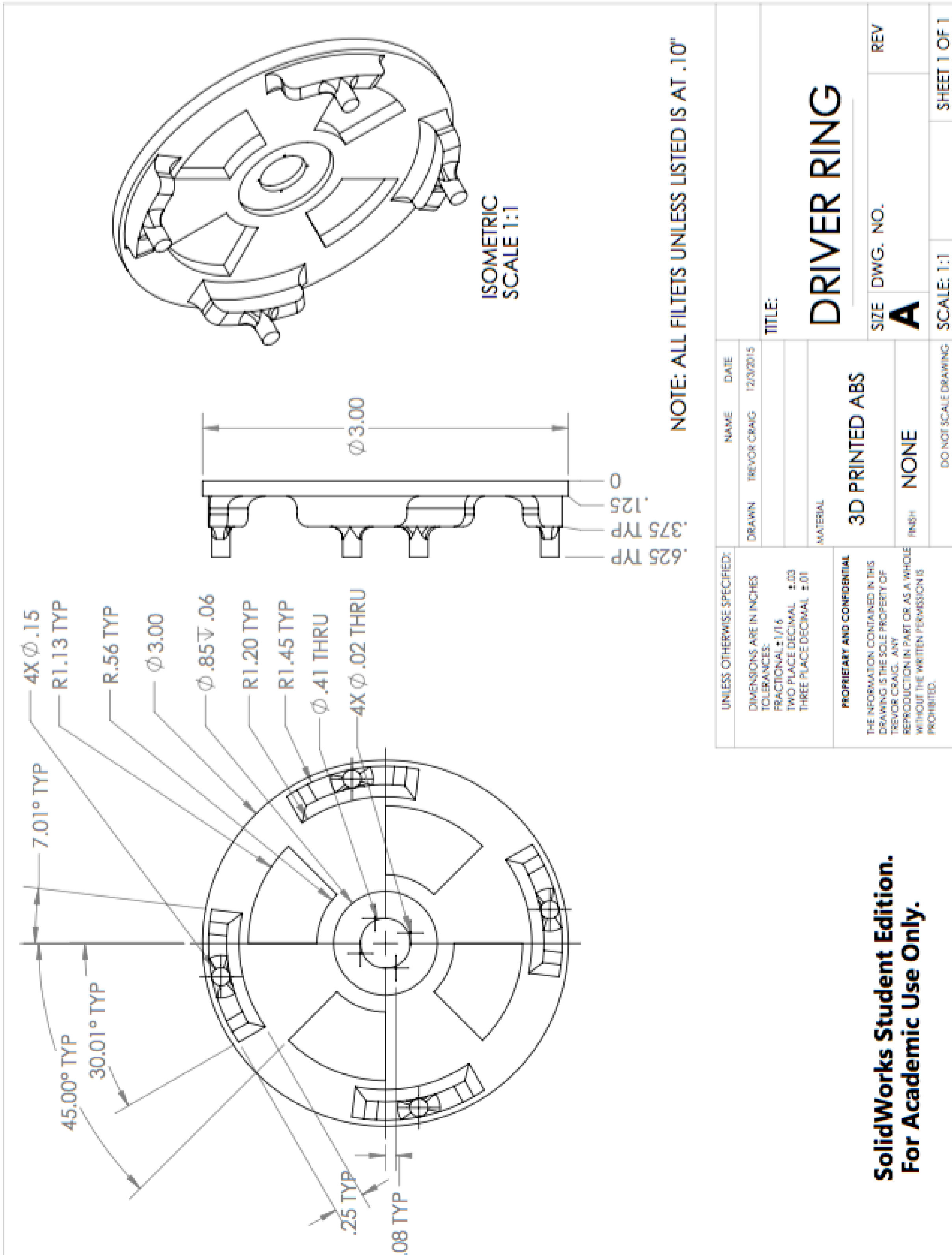
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45.00° TYP
30.01° TYP
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.08 TYP
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R1.13 TYP
R.56 TYP
Ø3.00
Ø.85 ↧ .06
R1.20 TYP
R1.45 TYP
Ø.41 THRU
4X Ø.02 THRU
Ø3.00
0
.125
.375 TYP
.625 TYP
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TOLERANCES:
FRACTIONAL ± 1/16
TWO PLACE DECIMAL ±.03
THREE PLACE DECIMAL ±.01
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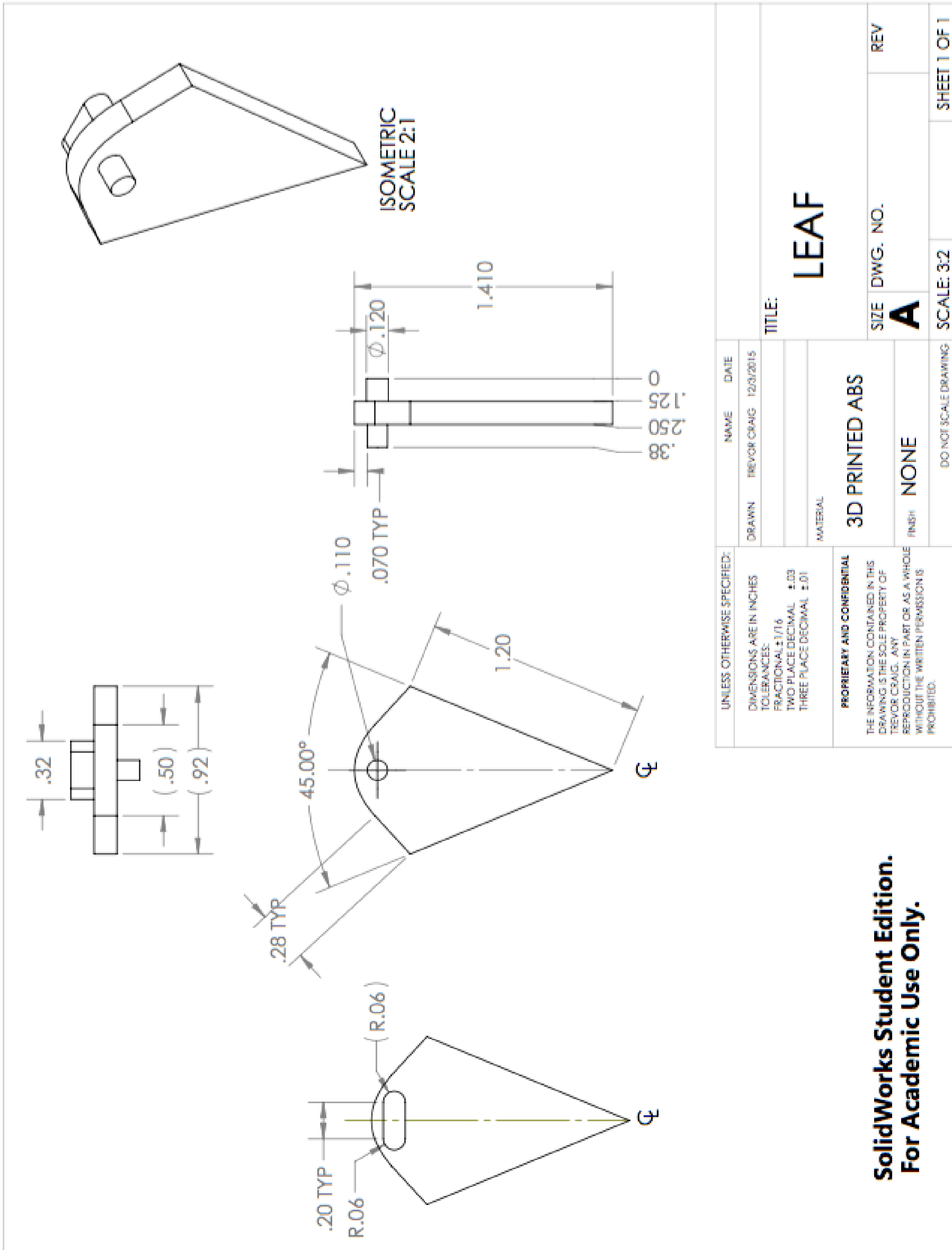
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∅.110
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(.50)
(.92)
.20 TYP
R.06
(R.06)
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±1/16
TWO PLACE DECIMAL ±.03
THREE PLACE DECIMAL ±.01
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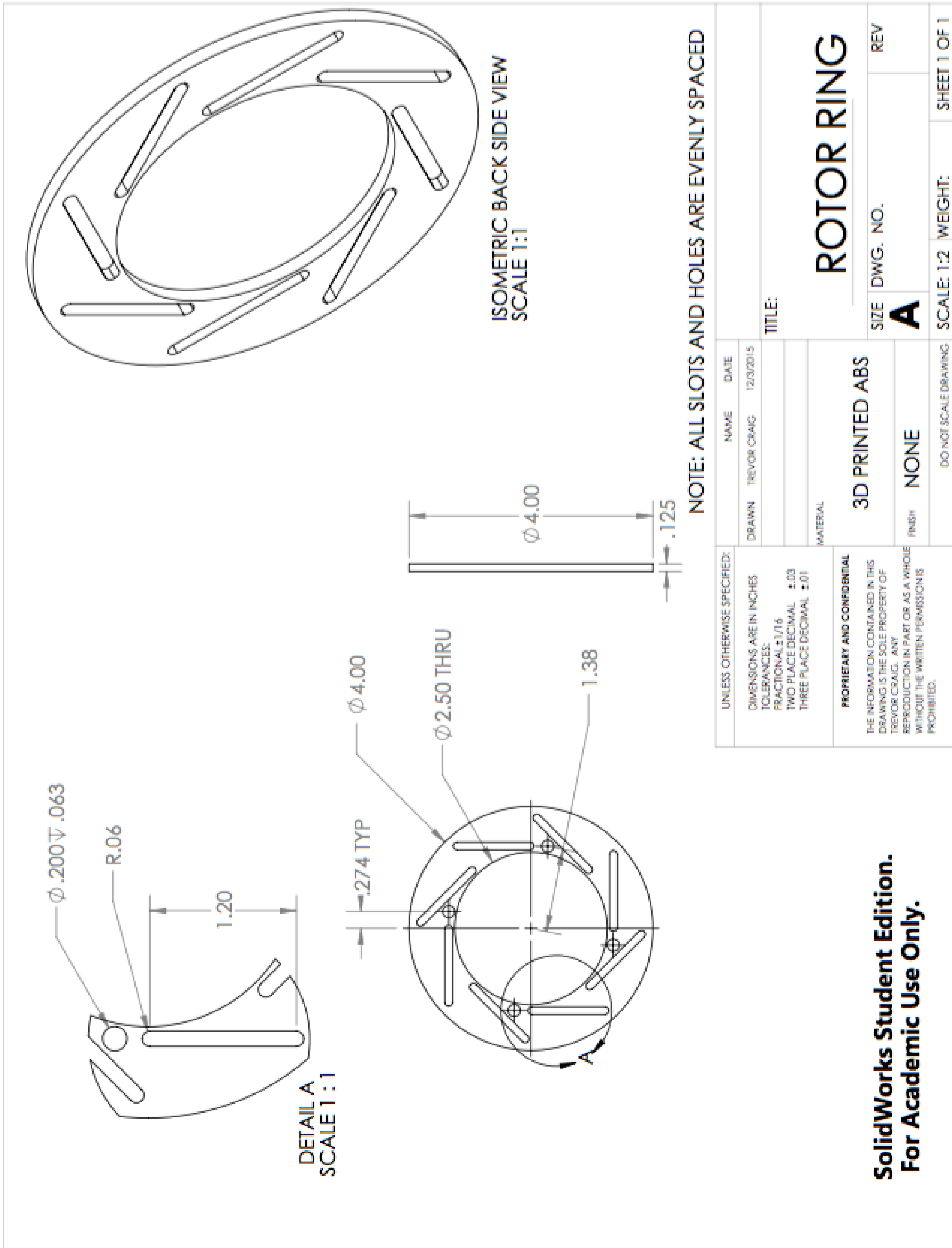

ISOMETRIC BACK SIDE VIEW
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Ø .200 ⊽ .063
R.06
1.20
.274 TYP
Ø 4.00
Ø 2.50 THRU
1.38
A
DETAIL A
SCALE 1 : 1
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ± 1/16
TWO PLACE DECIMAL ±.03
THREE PLACE DECIMAL ±.01
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MATERIAL
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FINISH
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TITLE:
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WEIGHT:
SHEET 1 OF 1
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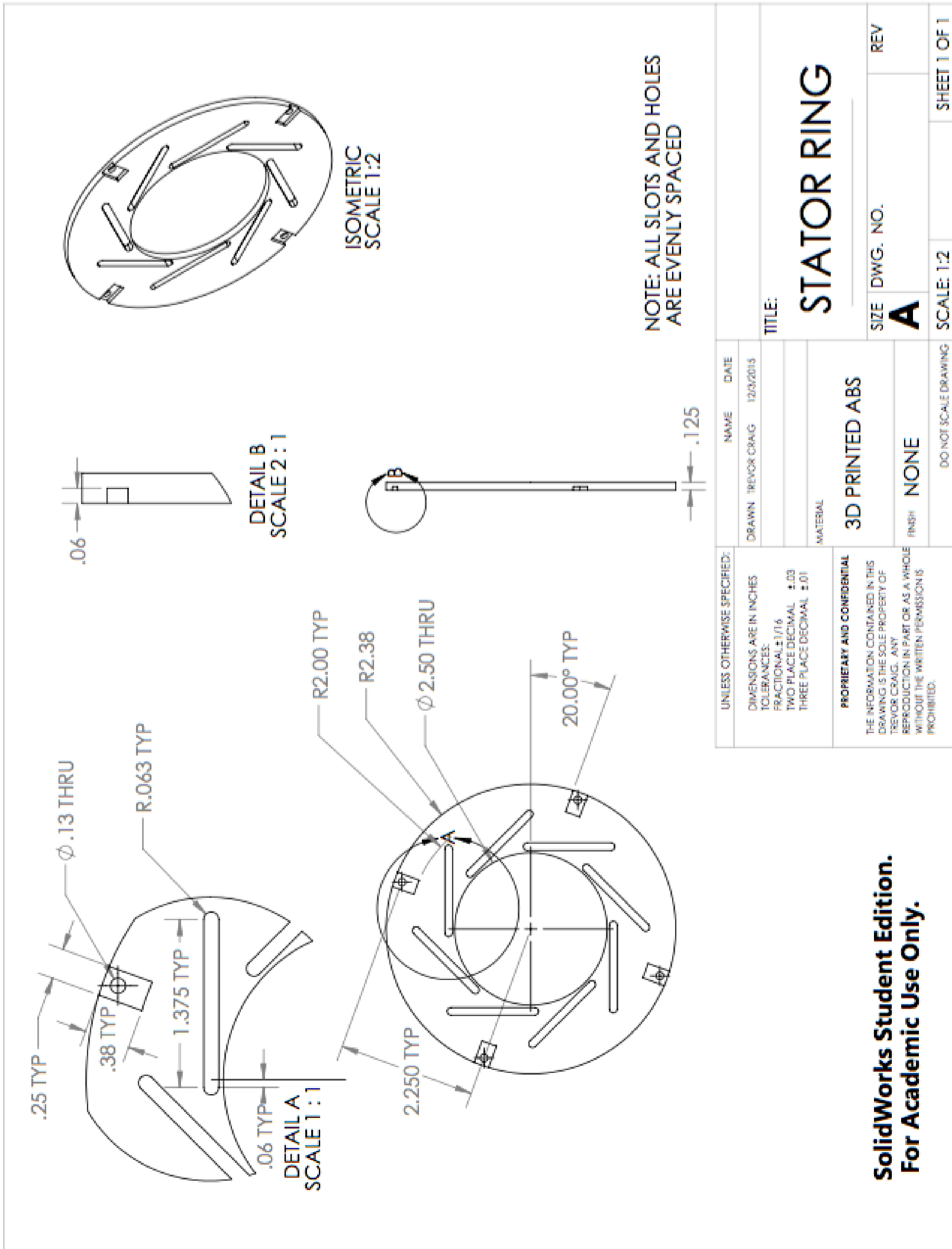
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ISOMETRIC SCALE 1:2
DETAIL B SCALE 2 : 1
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.125
B
DETAIL A SCALE 1 : 1
.25 TYP
.38 TYP
1.375 TYP
.06 TYP
∅.13 THRU
R.063 TYP
R2.00 TYP
R2.38
∅2.50 THRU
20.00° TYP
2.250 TYP
A
UNLESS OTHERWISE SPECIFIED:
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TOLERANCES:
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TWO PLACE DECIMAL ±.03
THREE PLACE DECIMAL ±.01
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FINISH
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SIZE
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DWG. NO.
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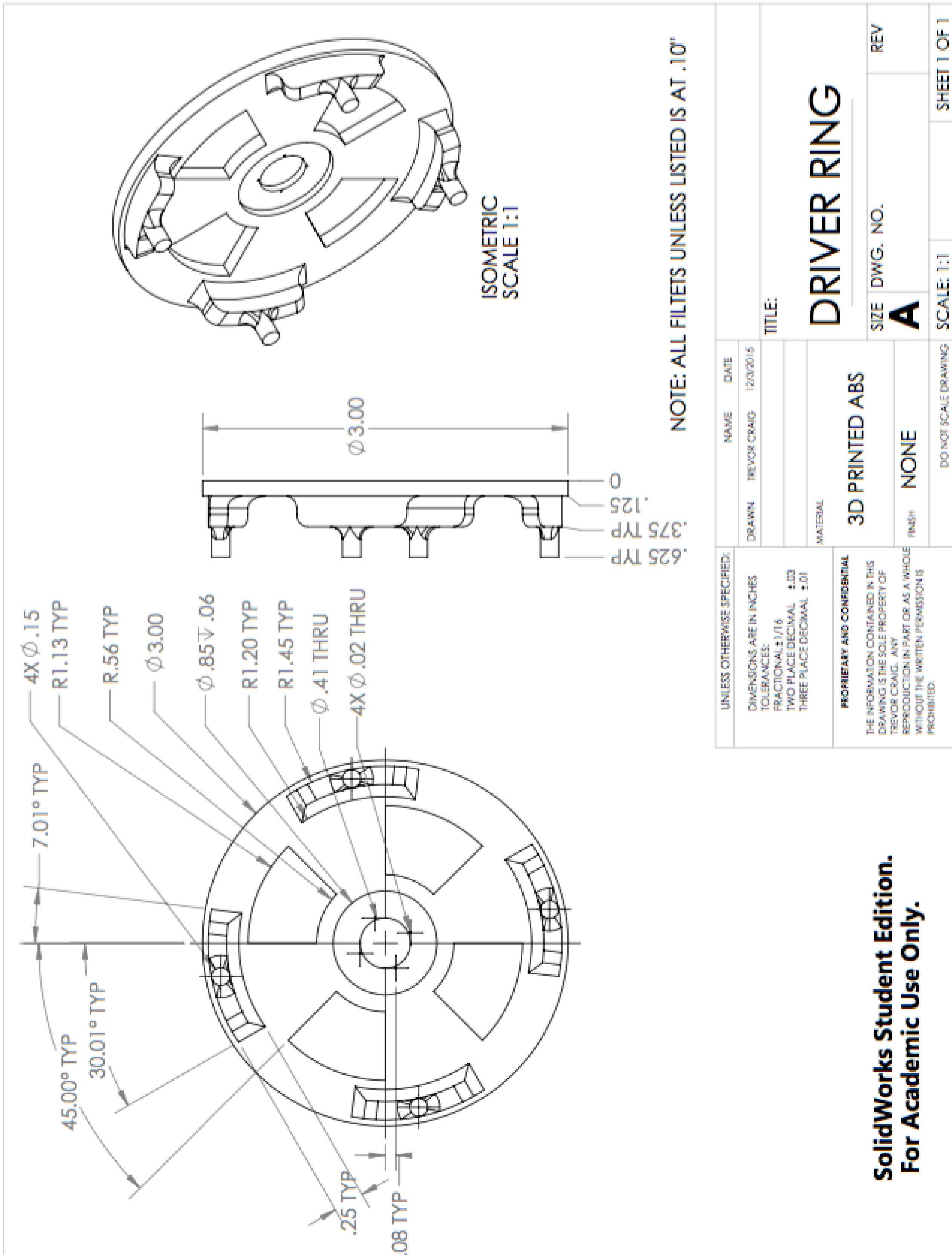
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R.56 TYP
Ø3.00
Ø.85 ↧.06
R1.20 TYP
R1.45 TYP
Ø.41 THRU
4X Ø.02 THRU
7.01° TYP
30.01° TYP
45.00° TYP
.25 TYP
.08 TYP
Ø3.00
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.375 TYP
.625 TYP
ISOMETRIC
SCALE 1:1
NOTE: ALL FILTETS UNLESS LISTED IS AT .10"
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TOLERANCES:
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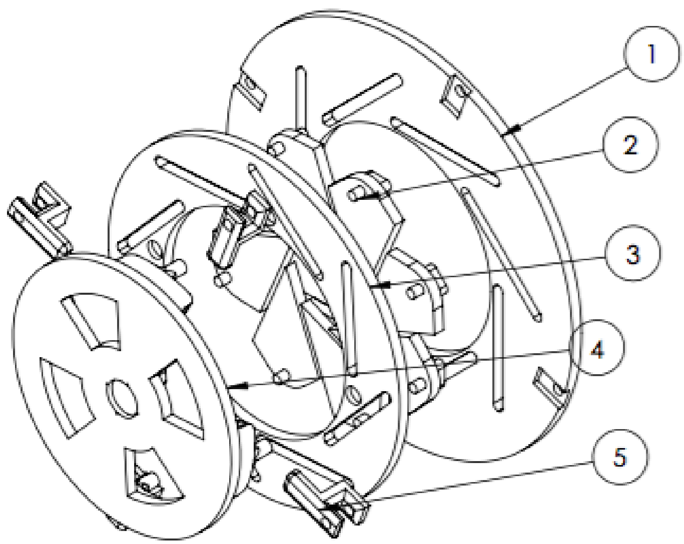

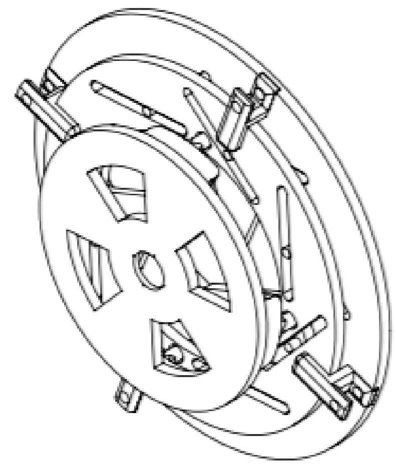

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2	LEAF	8
3	ROTOR RING	1
4	DRIVER RING	1
5	BRACKET	4

UNLESS OTHERWISE SPECIFIED:

DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL±1/16
TWO PLACE DECIMAL ±.03
THREE PLACE DECIMAL ±.01

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MATERIAL: 3D PRINTED ABS

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TITLE:

SUB ASSEMBLY

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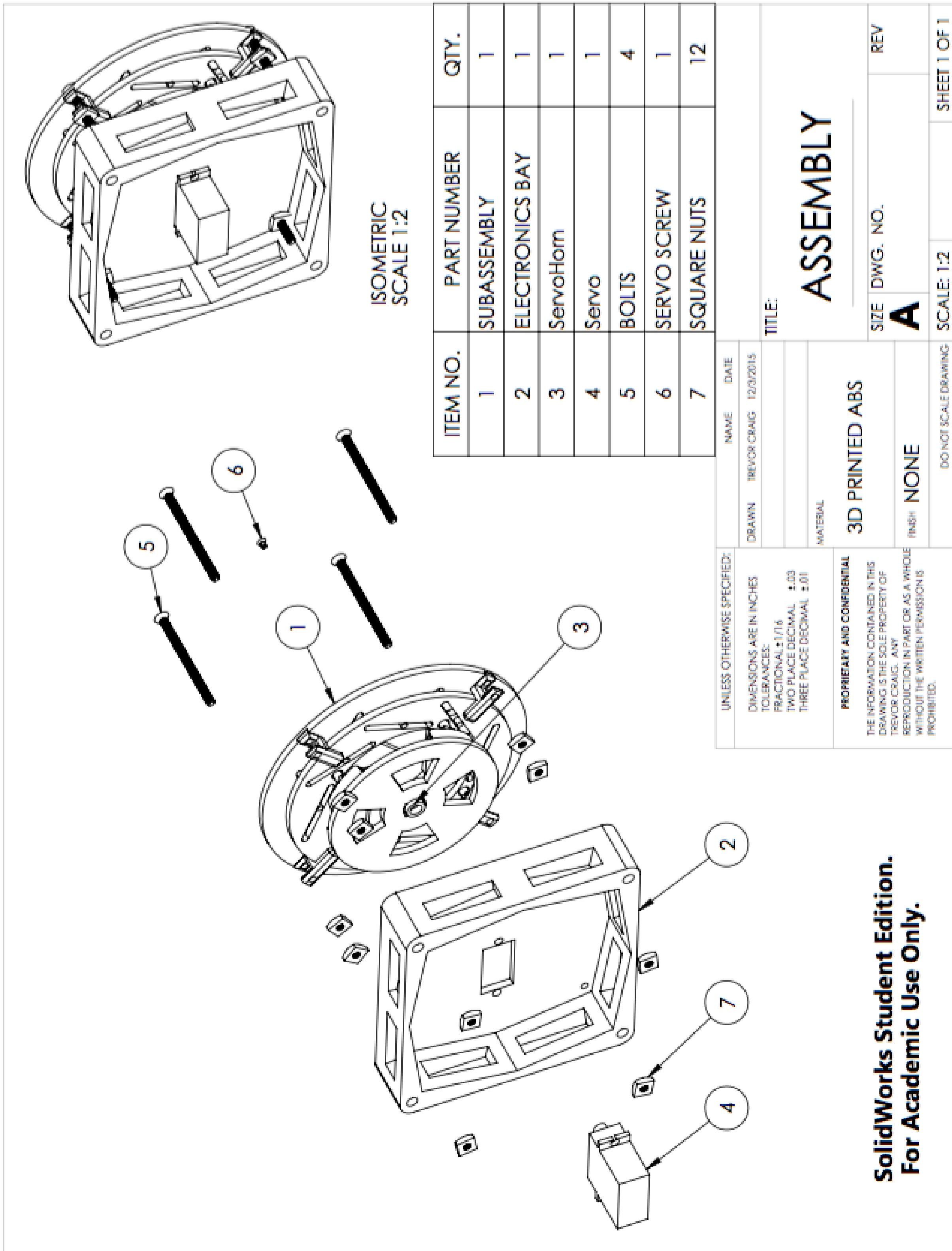


ITEM NO.	PART NUMBER	QTY.
1	SUBASSEMBLY	1
2	ELECTRONICS BAY	1
3	ServoHorn	1
4	Servo	1
5	BOLTS	4
6	SERVO SCREW	1
7	SQUARE NUTS	12

Appendix 7 – FMEA

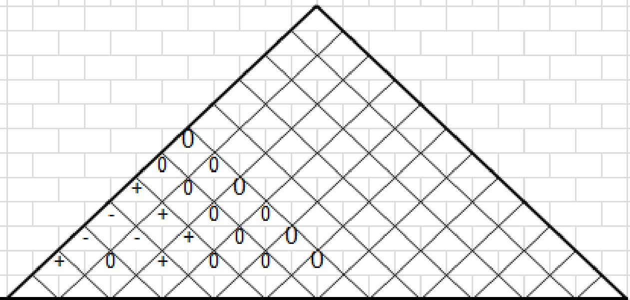
Process / Product
Failure Modes and Effects Analysis
(FMEA)

Process or Product Name:	Drone Coupler	Prepared by: Senior Design Team	Page __1__ of __1__
Responsible:	Senior Design Team	FMEA Date (Orig) _11/5/2015____________ (Rev) ____________	

Process Function	Potential Failure Mode	Potential Effects of Failure	SEV	Potential Cause(s)/ Mechanism(s) of Failure	OCC	Current Process Controls	DET	RPN	Recommended Action(s)	Responsibility and Completion Date	Action Results: Actions Taken	Action Results: SEV	Action Results: OCC	Action Results: DET	Action Results: RPN
The highest value process steps from the C&E matrix.	In what ways might the process potentially fail to meet the process requirements and/or design intent?	What is the effect of each failure mode on the outputs and/or customer requirements? The customer could be the next operation, subsequent operations, another division or the end user.	How Severe is the effect to the customer?	How can the failure occur? Describe in terms of something that can be corrected or controlled. Be specific. Try identify the causes that directly impacts the failure mode, i.e., root causes.	How often does the cause or failure mode occur?	What are the existing controls and procedures (inspection and test) that either prevent failure mode from occurring or detect the failure should it occur? **Should include an SOP number.**	How well can you detect cause or FM?	SEV x OCC x DET	What are the actions for reducing the occurrence, or improving detection, or for identifying the root cause if it is unknown? **Should have actions only on high RPN's or easy fixes.**	Who is responsible for the recommended action?	List the completed actions that are included in the recalculated RPN. Include the implementation date for any changes.	What is the new severity?	What is the new process capability?	Are the detection limits improved?	Recomputed RPN after actions are complete
1	Servo Jams due to friction	If servo jams, the drone will not be able to deliver sensor	7	Friction in 3D parts	4	Testing Prototypes	10	280	Low friction parts	12/4/2015	Acetone bath for 3D printed parts	6	2	8	96
2	Power brown outs	Brown outs can cause malfunction of servos and loss of communication	9	Electrical Malfunction	3	Testing Prototypes	10	270	Voltage sensor	12/4/2015	Added voltage sensor	7	2	8	112
3	Faulty Assembly	This could lead to the assembly falling apart during operation	4	Assembled Incorrectly	3	Accurate Drawings	2	24	-	-	-	4	3	2	24
4	Irregular shaped sensor target	Makes it difficult to grab sensor	6	Sensor altered In the field	4	Not Preventable	4	96	-	-	-	6	4	4	96
5	Electronics communications issues	This could lead to servos malfunctioning	5	Software/Hardware issues	2	Testing Prototypes	1	10	-	-	-	5	2	1	10
6	Over - weight	Drone will not be able to fly very well	9	Sensor has gained mass from atmospheric effects	6	Prototype Weight	1	54	-	-	-	9	6	1	54
7	Center of gravity - changes	Sharp changes can make flying difficult	5	Untrained operator	4	Trained Operators	3	60	-	-	-	5	4	3	60
8	Stress on parts such as pins/leaves	Could lead to the sensor node falling	10	Heavy Sensor	5	Stress Testing	10	500	Stress Analysis/Factor of Safety	12/4/2015	Performed stress analysis on parts/ improved FOS	8	4	8	256
9	Dead Battery	Could lead to the sensor node falling	8	Electrical Malfunction	3	Testing Prototypes	10	240	Voltage sensor	12/4/2015	Added voltage sensor	7	2	8	112
10	Sensor node breaks	This will affect picking up the sensor node	6	Environment	5	Not Preventable	2	60	-	-	-	6	5	2	60
11	Friction between the 3D printed parts	This could cause servo jams	6	Low Tolerances	4	Prototype	4	96	-	-	-	6	4	4	96
12	Drone Surviving impact	What would happen if drone falls.	4	Untrained operator	4	Trained Operators	5	80	-	-	-	4	4	5	80

Figure 44: FMEA

APPENDIX 8 – QUALITY FUNCTIONAL DEVELOPMENT



Goal (Up/Down)	D	U	D	D	U	U	U	Competitive Evaluation			
Customer Needs	Price	Reliability	Weight	Power	Strong Assembly	Performance	Repairablitiy	Priority (1-5)	Improvement ratio	Importance	Weight
Low Profile	1	1	3		3	1	3	4	2.5	10	0.47
Holding Force	9		9	9	3			3	2.5	7.5	0.35
Analog Input								1	1	1	0.05
Assembleable	3						9	2	1.5	3	0.14
										0	0
										0	0
										0	0
										0	0
Technical Evaluation								Σ		21.5	1
Absolute importance	4.0	0.5	4.5	3.1	2.4	0.5	2.7	17.7			
Relative importance (%)	23	3	26	18	14	3	15	100			
Target Value	< $250	N/A	600 grams	5 volt	FOS = 4	N/A	Time < 15min				

Figure 45: QFD

APPENDIX 9 – DESIGN FOR MANUFACTURING

Design for Assembly Chart

Part	Retrieve			Handle			Insert						# Parts	Assembly Index	Part Required
							AL = alignment difficult; NTD = not top down; HIP = hold in place			OB = obstructed; RES = resistance					
	Small <12mm (+1) <2mm (+2)	Tangled (+2)	Flexible (+2)	No end symm (+2)	No insert symm (+2) (+1) if clear	Heavy or tools needed (+2)	AL (+2)	OB (+2)	NTD (+2)	RES (+2)	HIP (+2)	FASTEN Twist (+1) Screw (+3)			
Electronics Bay	0	0	0	0	0	2	0	2	0	2	2	0	1	2	1
Servo attachment ring	0	0	0	0	0	2	2	0	0	0	0	0	1	2	1
Driver ring	0	0	0	0	0	0	0	0	0	0	2	0	1	2	1
Leaves	0	0	0	0	0	0	2	0	0	2	2	0	8	16	8
Large ring	0	0	0	0	0	0	0	0	0	0	0	0	1	2	1
Bracket	1	0	0	2	0	0	0	0	0	0	2	0	4	8	4
3" bolt	0	0	0	0	0	2	0	0	2	0	0	1	4	8	4
Servo horn	1	0	0	0	0	2	0	0	2	0	2	3	1	2	1
Fasterner	2	0	0	0	0	2	0	2	0	2	0	1	8	16	4
Servo	0	0	0	2	0	0	2	0	0	2	0	0	1	2	1
2.5" bolt	0	0	0	0	0	2	0	0	2	0	0	1	4	8	4
												Total	34	68	30
Goal: minimize assembly index and parts count								Part required if:		relative motion; different material; (dis)assembly impossible without			Parts reduction:		4

Figure 46: Design for manufacturing

APPENDIX 10 – COMPUTER PROGRAM

The programming for this project was done in Arduino and consisted of both a sender and a receiver. The sending program reads a potentiometer and then scales the analog input to be the full spin of the servo. The analog input pins can be seen in the figure <> below, and are listed as A0, A1, A2, A3, and A4, and A5 are above A2 and A3. Totally up these analog inputs provides 6 analog inputs at 10 bit precision meaning it can read 1024 unique values. These values are scaled to the values found in testing and calibration for the required motion. These values will vary for each servo and for each configuration. Some initial calibration is required before using this program. The values sent to the servo was between 100 and 110 degrees for the set up used in this design. To send the data over xbees it needs to be sent over the serial line. This is done by translating the value to be an integer and using a print library to allow multiple prints if desired. There then needs to be a delay to allow the xbee to send the data. This delay is extremely important, without this delay the xbees will not connect long term or at a distance. The minimum delay is 20 ms this should not be used in situations where the drone could be moving at a fast speed. By using 50 ms the human body does not seems to recognize the delay, it uses less battery power, and sends more consistent values at a baud rate of 9600. This value can and should be adjusted with the baud rate to be optimized for the scenario for which it is used in. The code is actually fairly simple and can be seen below.

The receiving side of the code contains a library for easy interaction with the servo. In order for the receiver code to work properly the servo needs to be attached to a pin with PWM, in this design that was pin 9. For the Arduino pro mini the PWM a small circle around the hole indicates pins. The Arduino Pro Mini supports PWM on pins 3, 5, 6, 9, 10, and 11. The Pro Mini has an 8 bit PWM output meaning it can do 256 different values. The information needed to know where to move the servo is read in through serial over the XBee. This program then prints the value it received to serial. This allows the user to plug the Arduino into the computer and watch the serial monitor to see if it receiving the values accurately. Another advantage of printing on the receiving side is you can print to the sender to double check the value send was what was intended for error checking. The next step of the program is to write to the servo the required position that was received over the serial. And the final step is to add a small delay. This delay is to help the servo not have too much vibrations as it attempts to get the values specified. This delay may be reduced as there is also a delay on the sender but this needs to be changed and calibrated for each user. Where it stands now there is a small delay but it is not very noticeable to the user and is more than satisfactory to avoid servo jerk, and twitching.

```
////////////////////////SENDER\\\\\\\\\\\\\\\\\\\\\\\\
#include "ARDPRINTF.h"
int potpin = 0;  // analog pin used to connect the potentiometer
int val;    // variable to read the value from the analog pin
void setup() {
  Serial.begin(9600);
  // put your setup code here, to run once:
}
void loop() {
  //while(Serial.available()){
   val = analogRead(potpin);            // reads the value of
the potentiometer (value between 0 and 1023)
   val = map(val, 0, 1023, 0, 180);     // scale it to use it
with the servo (value between 0 and 180)
   val = map(val, 0, 180, 100, 110);
   //Serial.println(val);
   ARDPRINTF("%d", val);
   delay(50);//to give time to send
  //}
}
```

```
               ///////////////RECIEVER\\\\\\\\\\\\\\\

#include <Servo.h>

Servo myservo;  // create servo object to control a servo

int servopin=9;

void setup() {

  Serial.begin(9600);

  myservo.attach(servopin);  // attaches the servo on pin 9 to
the servo object

  //Serial.println('Starting...');

}

void loop() {

  //if(Serial.available() >0){//The amount of data read in

    int x = Serial.parseInt();

    Serial.println(x);

    myservo.write(x);                  // sets the servo
position according to the scaled value

    delay(15);                           // waits for the servo
to get there was 15

   // }

}
```