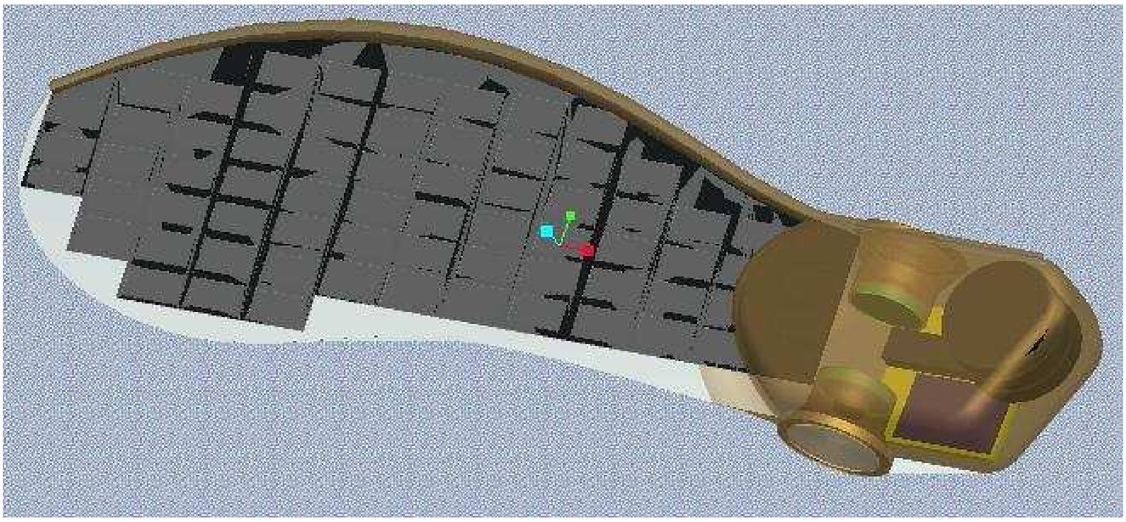
FAMU/ FSU College of Engineering
Mechanical Engineering Department
Senior Design

Maple Seed Sensor Housing for Desert Reconnaissance



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1 Executive Summary

The Maple Seed Sensor project is sponsored by Harris Corporation. The working concept behind these sensors are maple trees whose seeds use auto-rotating flight to disperse themselves over a large area. The seeds have a single wing attached to them which allows for auto-rotating flight. The same flight characteristics can be used for battlefield sensors. These sensors could be dropped from a height using an Unmanned Air Vehicle, use auto-rotation to descend slowly, and upon landing safely provide useful information on enemy vehicles or personnel locations. Using this method of detection keeps soldiers out of harm but still allows for reconnaissance.

The design is directly modeled after a maple seed as a specification from our sponsor. Modeling our sensor housing to behave similar to a maple seed in flight was our first objective. Designs were made in Pro-Engineer/Wildfire 3.0. Using a Fused Deposition Modeling (FDM) printer, small scaled versions were created. Drop tests were done on these designs. Following an analysis of the properties of each of our designs such as terminal velocity, seed weight to wing weight ratio, and wing area, a final shape design was chosen.

After the shape and flight characteristics were confirmed, the sensors and electronics had to be implemented into our design. As specified by Harris Corporation, we were to use at least one vibration sensor and infrared sensor to detect enemy presence. The sensors and electronics will have to draw very small amounts of power, be miniature in size, and survive desert conditions. While they are actively sensing, data will be sent by a wireless transmitter to central computer a safe distance away. All these systems will be powered by one or two batteries that will be recharged by small solar cells embedded within the wing. The electronics in the seed will also be embedded using a form of Shape

Deposition Manufacturing (SDM) polyurethane. This allows for the design to be free of attachment points for the electronics within the seed.

We will begin our build during the spring semester of 2009. Tests will be done on all the electronics to make sure the system is operational before applying the polyurethane housing. Field tests will be done on the completed housing to verify the final design meets all of our expectations.

2 Introduction

Reconnaissance has always been a valuable aspect of warfare. Receiving that information safely has become a commodity in today's military. Methods for achieving this include receiving information from planes that are either unmanned or positioned at a safe altitude. The problem is that the information obtained only spans a short amount of time. What if an area of interest could be monitored twenty-four hours a day using sensors with no risk to human life? This is a goal that our senior design group hopes to achieve by the end of the spring 2009 school semester.

A maple seed design for the sensor housing was specified to our group. The main advantages to a maple seed design are the flight and the dispersal characteristics. The auto-rotating flight allows the sensors to fall to the ground at a safe velocity. The wide dispersal of the sensors will help cover a larger area of interest. A maple seed can be seen below in **Figure 1**.

Figure 1: Maple Seed

After landing on the ground, sensors will relay any presence of vehicles or persons in the vicinity of each seed. When the sensors are not relaying information they will remain dormant, thereby reducing the amount of power consumed. Solar cells positioned within the wing will help recharge the battery during daylight hours.

During our initial research on maple seeds, a scholarly journal article was discovered with research on maple seed flight. The American Journal of Botany had published an article of scientific analysis on maple seed flight characteristics. Terminology from that paper was adopted by our group and will be used for this paper. The term seed refers to the entire body, wing and seed. The head refers to the seed itself, and the wing is just called the wing.

A working prototype will be created by the end of the spring 2009 semester. Our largest obstacles at this time are wiring the electronic circuit and the process of embedding the components in SDM material.

3 Problem Definition

The project goal is to create a sensor housing in the likeness of a maple seed that will duplicate auto-rotating flight, detect the presence of people or vehicles once on the ground, and survive adverse weather conditions. The concept of duplicating auto-rotating flight has already been verified by our research and initial models which can be seen in the Design and Analysis section of this paper. All the components within our maple seed sensor design are specified by their manufacturers to withstand the impact force generated when landing and the extreme temperatures of desert conditions. Our objective is to now have a wired maple seed sensor that will still mimic auto-rotating flight. We expect to have a working prototype of our design by April 2009.

4 Background

The principles of flight at work for a maple seed are not that much dissimilar to that of an airplane wing. As the seed begins to fall, air rushes over the wing. The leading edge of the wing causes the air to divide so that some of the air flows over the top and some of the air flows under the wing. This leading edge acts as the front of an airfoil causing the air flowing on the top to travel faster than the air flowing underneath. This creates a low pressure above the wing. Since the pressure below the wing is greater than the pressure above the wing, a force pushing upward is created. This force is lift. The wing rotates about the center of gravity which lies closer to the head. This is why a maple seed spins as it falls.

Previous work done on the subject of maple seed inspired sensors is very limited. The most prominent attempt came from Lockheed Martin in 2006. They attempted to develop a self propelled maple seed reconnaissance device that could be remote controlled and also produce lift using a jet thruster. It was also designed to complete missions of twenty minutes in duration, have a range of a kilometer, and drop a 2 gram payload. They called it an NAV or Nano Air Vehicle. **Figure 2** shows a model of the NAV. The project was quietly cancelled in 2008.

Figure 2: Lockheed Martin NAV with maple seed

Helicopters use auto-rotating flight during power or engine failures. The pilot can control the pitch of the rotor blades so the airflow generates blade rotation. The rotation then creates enough lift to allow the helicopter to glide to the ground safely.

Any other work on this subject is rare. Maple seed inspired sensors are not that common making this project a very unique one.

5 Design and Analysis

5.1 Concept Generation and Selection

Our design is directly taken from a maple seeds shape which was specified. Alternate shape designs were considered such as a double wing configuration. The single wing configuration was quickly decided upon due to its' ability to naturally maximize rotation speed and angle of attack (AOA) during flight based on total weight and wing area. Using the double wing design restricts both of these parameters. The AOA is the angle at which the wing is rotated about an axis parallel to the wing length from the horizontal position for winged aircraft. For the maple seed, the AOA also can be described by the angle at which the entire seed is offset from the horizontal plane. With the double wing design the wings will not be free to converge to an acceptable AOA for continuous flight. The angle of attack will be restricted to whatever is chosen during the design process. This predetermined AOA will also constrain the rotation speed. Rotation speed is a parameter that is highly dependent on the AOA and the total weight. The single wing design is very different with respect to this matter of predetermined parameters. While experiencing autorotation, the seed seeks an equilibrium position. If the same geometry is used but the mass is increased, the seed automatically increases the speed at which it rotates which is determined by a new AOA**.**

An article on maple seeds written in the American Journal of Botany was referenced in deciding wing shape. This article provided in depth analysis on six different wing shapes. Properties researched included wing weight, head weight, wing area, wing loading, descent rate, and dispersal area ratio. We decided to use the quillpen wing shape because of its large wing area, slow descent rate, and dispersal area ratio.

The quillpen seed shape is displayed in **Figure 3** below. All other general wing shapes that were considered are available in **Appendix 8.1**.

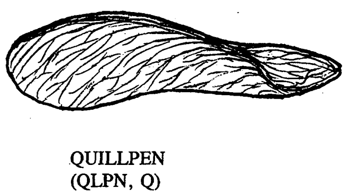


Figure 3: Quillpen maple seed morphology

Sensor type was also specified by our sponsor. Vibration sensors and infrared sensors are to be the devices used for detection. Theoretically the vibration sensors will be able to pick up vehicle movement or human footfalls from vibrations transmitted through the ground. The infrared sensors should detect changes in heat signature within their ranges.

Using a screening matrix, our group listed all the possible concepts for the subsystems of our prototype. Topics listed included design shape, sensor type, manufacturing material, power source, and transmission type. These concepts were weighted with the project criteria specified by our sponsor. A rank to each concept was calculated and our design concepts, as follows, were chosen. The screening matrix is located on the following page in **Table 1**.

A rechargeable battery will be the main power source. The battery will be recharged by miniature solar cells positioned within the wing. An A to D converter will be used to convert the analog signal to digital so it can be easily transmitted. A wireless transmitter will send out the signal using Zigbee (radio frequency) communication protocols. All of these systems will be fixed in place using Shape Deposition Manufacturing techniques. A polyurethane material, high in durability and strength properties, is poured into a wax mold and dried. This material is ideal for the environmental conditions and allows us to embed all the electronics in the head.

Table 1: Screening Matrix

			Concepts													
			Flight		Sensors					Material			Power		Transmission	
		Weight Factor	Single Wing	Double Wing	Sonar Sensor	Vibration Sensor	IR Sensor	Micro phone	Acceler ometer	FDM	SDM	Carbon Fiber	Solar Charged Battery	Solar Charged Capacitor	Wi-Fi	Radio
CRITERIA	Fall slowly	3	+	+	0	0	0	0	0	0	0	0	0	0	0	0
	Spread	2	+	+	0	0	0	0	0	0	0	0	0	0	0	0
	Detect Stationary Vehicle	3	0	0	-	+	+	-	+	0	0	0	0	0	0	0
	Detect Moving Vehicle	2	0	0	+	++	+	+	+	0	0	0	0	0	0	0
	Detect Stationary Human	3	0	0	-	-	++	+	-	0	0	0	0	0	0	0
	Detect Moving Human	2	0	0	+	++	+	+	+	0	0	0	0	0	0	0
	Sensor Range	2	0	0	-	+	-	+	+	0	0	0	0	0	0	0
	Durability	3	0	0	--	-	-	-	-	+	+	+	+	+	0	0
	Lightweight	2	+	--	+	++	+	+	+	+	+	++	+	+	+	+
	Strength	3	+	++	0	0	0	0	0	-	+	+	0	0	0	0
	Transmission Range	1	0	0	0	0	0	0	0	0	0	0	0	0	-	+
	Cost	1	+	+	+	-	+	-	+	++	+	-	+	--	+	+
	Sum of +		11	12	8	17	16	11	12	7	9	10	6	5	3	4
	Sum of -		0	2	14	7	5	7	6	3	0	1	0	2	1	0
	Sum of 0		7	7	4	4	4	4	4	8	8	8	9	9	9	9
	Net Score		11	10	-6	10	11	4	6	4	9	9	6	3	2	4
	Rank		1	2	5	1	2	4	3	2	1	2	1	2	1	2
	Continue?		Yes	No	No	Yes	Yes	No	No	No	Yes	No	Yes	No	No	Yes

Correlation Rating Scale: ("++" = Very Good, "+" = Good, "0" = Not Applicable, "-" = Poor, "--" = Very Poor)

5.2 Design 1

The initial maple seed design was based purely on physical observation of the shape of a maple seed and was created while the project was focused only on flight characteristics. A very rough 3-D model was made in Pro-Engineer/Wildfire 3.0 and was printed using Fused Deposition Manufacturing. This model was an attempt both to discern whether or not the flight characteristics of a maple seed were inherent to the exact shape of a maple seed and to see if a shape only roughly similar to a maple seed would still auto-rotate and create lift in the same way. This first maple seed prototype, shown in **Figure 4** displayed none of the auto-rotating flight characteristics of a maple seed. When dropped from a height of 10 meters it simply fell head end first and crashed into the ground. This prompted several questions concerning why this happened.

Figure 4: Initial Design Shape

The first theory concerned the most likely aspect; the shape and size of the head in relation to the wing. Because overall size was a large concern, the initial designs had a head to wing ratio larger than that of naturally occurring maple seeds. This was an attempt to design for the as-yet-unknown size of the sensors that were eventually going into the seed without designing an absurdly large seed. The data from The American

Journal of Botany describe the average head weight to wing area ratio to be 2.512 kg/m^2, as defined in **Equation 1** below. This differed greatly from the original prototype design, whose head weight to wing area ratio was 1.678 kg/m^2, even without embedded sensors. This proved that the doubts about the size of the head were well-founded.

$$Ratio_{average} = \frac{Fruit\_weight_{average}}{Wing\_area_{average}}$$

Equation 1

Next, the shape of the head itself was examined. Natural maple seeds display a seed that is in the shape of a modified ellipse with an average ratio of a to b, defined in **Figure 5,** of 2.318. This again differed from the test prototype, whose spherical head had a ratio of 1. In addition, the relative thickness of the prototype's head was much larger than the relative thickness of the naturally occurring head. The naturally occurring maple seeds have an average relative thickness, as defined in **Equation 2** of approximately 318, while the test prototype had a relative thickness of approximately 21.

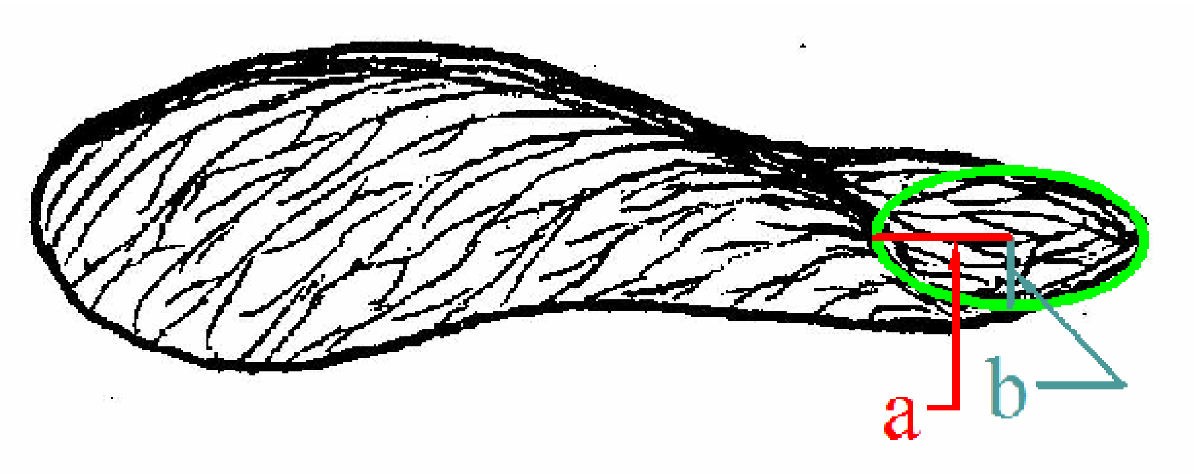


Figure 5: Elliptical Seed Shape Diagram

$$Thickness\_Ratio = \frac{Head\_Thickness}{Head\_Area}$$

Equation 2

Finally, the size and shape of the wing was analyzed. The test prototype seed had a wing which was thick at the spine and curved down smoothly to a thin bottom. This is similar to an actual maple seed in that the natural seed has a thicker spine and a thin wing, but in the prototype the thickness of the spine had been exaggerated to ensure strength, as had the thickness of the wing. This caused the head weight to wing weight ratio, which turns out to be one of the most important design characteristics, to be far too low. This ratio, defined in **Equation 3**, has an average value of 5.807 for actual maple seeds, while the first prototype seed had a ratio of 0.6. Too heavy a wing causes the seed to fall more horizontally and less vertically before auto-rotation, which results in a significantly longer delay before auto-rotating flight begins and can even result in the seed never entering auto-rotating flight.

$$Weight\_Weight\_Ratio = \frac{Head\_Weight}{Wing\_Weight}$$

Equation 3

The length of the wing was also found to be too short to provide sufficient lift for the seed. The lift calculation (**Appendix 8.3**) shows that the longer the wing, the higher the lift generated. This must be balanced with the head weight to wing weight ratio to ensure that the seed still auto-rotates and produces enough lift to slow the seed down.

5.3 Design 2

The second design iteration remained focused on flight characteristics. Based on the study by The American Journal of Botany, flight characteristics of six distinct seed shapes were analyzed to determine the shape most applicable for the sensor housing design. The “quillpen” morphology was chosen because it displayed the lowest average descent rate, 0.89 meters per second (Sipe and Linerooth, p. 1414). The projection of the seed shape was placed in AutoCAD and measured to determine size characteristics and was then drawn in Pro-Engineer/Wildfire 3.0 while adhering to the required shape characteristics discovered during the initial testing in the first design phase. A small, round spine more similar to a natural maple seed was added and the wing thickness was decreased significantly. The slope of the wing was removed and the wing shape became a simple thin sheet with a thickness of 0.39 millimeters topped by the spine, as shown in **Figure 6**Figure 6: Second Design Shape.

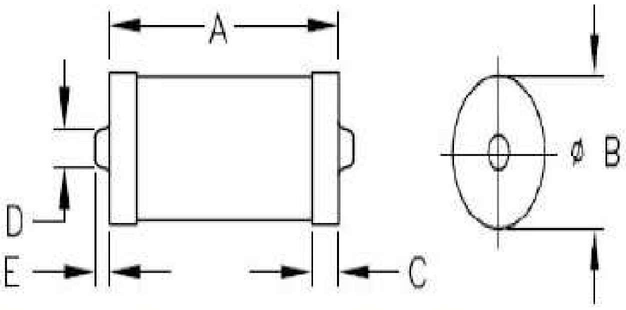
Figure 6: Second Design Shape

This design was a huge step forward. When dropped from the same height as the first design this seed entered auto-rotating flight after approximately two meters of free fall and glided down to the ground at a much slower speed. However, this design did have several faults. The spine of the seed did not connect all the way to the head, resulting in a section just behind the head where there were huge stress concentrations, leading to fracture both at the top and bottom of the spine. In addition, the spine itself was somewhat flimsy and bent too easily, feeling fragile and delicate when held. Because this seed is meant to be used in abrasive, rough environments and could be stepped on or collide with other objects during flight, this weakness was unacceptable.

5.4 Design 3

This stage in the design process began with a redefinition of the design parameters. While the first two designs were based on an emphasis only on the flight characteristics, this design temporarily abandoned flight and began with an extension into the realm of sensors and power systems. It was decided that the head would have to contain both a vibration and an infrared sensor and research showed that a pre-made circuit of the correct size would be very difficult to acquire and would likely bring the project beyond budget restrictions. Instead, the circuit would be designed and built in-house and this design focused purely on the design of that circuit.

A vibration sensor from SignalQuest, model SQ-SEN-200, was chosen. This sensor is perfect for the application because of its small size, low weight, and high sensitivity. It is able to pick up very low amplitude vibrations by using a small, omni-directional rolling ball switch which is at rest when stationary but chatters open and closed when vibrated. As shown in **Figure 7,** it is only 3.3 mm x 6.9 mm in size and weighs less than half of one gram. In addition, the SQ-SEN-200 can operate using only 0.25 μA. This allows more power to be used for the infrared sensor and transmitter.



SYMBOL	DESCRIPTION	MM	TOLERANCE
A	Length	6.8	±0.25
B	Diameter	3.3	±0.1
C	Terminal Width	0.8	±0.25
D	Solder Nub Diameter	0.9	±0.25
E	Solder Nub Length	0.4	±0.1

Figure 7: Vibration Sensor

The vibration sensor range is highly dependent on the circuit in which the sensor is incorporated and the environment where is lies. As with sound, vibration travels best through dense mediums. The looser the soil is, the higher the level of difficulty will be in detecting vibrations effectively. Sand is a very difficult medium to detect in due to its high damping effect. More importantly though, is how the circuit can amplify those signals. The sensor is capable of detecting the smallest of vibrations, but without a method of interpreting those signals, all the capabilities of the sensor are lost. This is one of the purposes of the microcontroller. It will be capable of determining which signals are ambient vibrations, and which signals are of importance. Without the microcontroller being implemented in our circuit, the sensor is able to indicate vibrations after tapping on a table.

Straight line infrared sensors were considered for this design because of their availability in small sizes and fairly low power consumption options. It was theorized that four of these sensors, each facing outward from the seed and offset by 90 degrees from each other would provide adequate, though not ideal, coverage. The detection line would need to be crossed in order for the sensor to operate properly. If the disturbance was aware of the sensor presence, walking in a straight line towards the sensor would be an effective way to evade detection as shown in **Figure 8**. This consideration resulted in a change of design to passive infrared sensors for the final design.

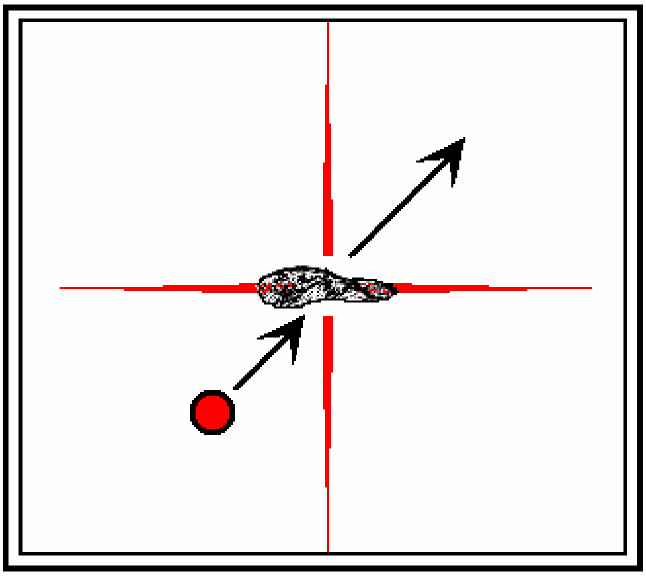


Figure 8: Straight Line Infrared Sensor

This design stage was also centered about transmitting via IEEE802.11g in the 2.4 GHz frequency. This is a good choice because IEEE802.11g transmitters are common and inexpensive and have an outdoor range of up to 2000 meters at 11Mbps.

While this range would be largely restricted by the power use restrictions placed on our sensors by the onboard power supply, this range would be more than adequate for this project. Unfortunately, IEEE802.11g transmitters are fairly large and would require a seed considerably larger than the target size. The smallest easily available IEEE802.11g transmitted available was fairly expensive at $149.99 from Rabbit and was 47mm x 72mm x 13mm. Shown in **Figure 9**, this was actually larger than the target total size of the seed. The lack of IEEE802.11g transmitters of a very small (less than 30mm square) size resulted in the choice to move away from IEEE802.11g transmission for future designs.

Figure 9: Wi-Fi Transmitter

Finally, a flexible solar cell was chosen for the wing of the seed. In order to run for a time period on the order of weeks and still remain within size constraints, the power source for the seed must be recharged. As shown in **Figure 10**, this was accomplished by item number 05-1284 from Silicon Solar. This incredibly durable solar cell can provide 9 Volts, measures 9 inches in length by 3 inches in width and fit nearly perfectly within the wing chosen for this design. In addition, it is made to be "suitable for rain, winds, and cold, [and] they can even be walked on” and is very lightweight. These characteristics make this type of solar cell perfect for this application.

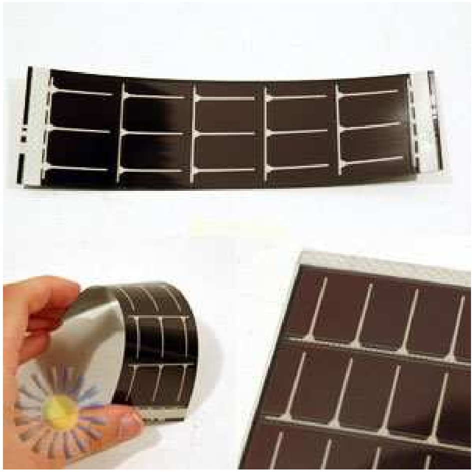


Figure 10: Flexible Solar Cells

5.5 Final Design

The final design iteration worked to combine the changes that were needed in the second and third design iterations into a final, viable design, shown in **Figure 11**. This current design consists of the SQ-SEN-200 Omni-directional Vibration Sensor from SignalQuest and a flexible solar cell from Silicon Solar, both of which were found to be very viable options during the third design iteration. Unfortunately, the straight line infrared sensor and the IEEE802.11g transmitter needed to be replaced with equipment which was both more useful and more practical.

Figure 11: Final Design Shape

A passive infrared area sensor was chosen to replace the straight line infrared sensor and required a slight redesign of the seed housing to account for the Fresnel lens covering the sensor. This sensor, model DP-001 from Glolab, is housed on a 19.05mm diameter round board, is only 9.6mm thick, and is capable of detecting "a moving human or animal both in daylight and at night." (http://www.glolab.com/dp-001/dp-001.pdf) This sensor, when equipped with a Fresnel lens also available from Glolab, is capable of detection at a range up to 27 meters. The sensor housing required a redesign to allow the Fresnel lenses to both face outward and not be covered by any of the housing material, and results in two small, circular faces on both sided of the seed.

These infrared sensors have the ability to detect movement of an infrared source such as people or vehicles. They do this by creating a two dimensional image of the wide angle which it is viewing. Whenever an object moves within that plane, either horizontally or vertically, that image changes and it sends an output signal corresponding to that disturbance.

IEEE802.15.4 communications protocol was chosen to replace the impractical IEEE802.11g standard which was dismissed in the third design step. IEEE802.15.4, commonly known as ZigBee, is a low-power, low bit-rate transmission protocol with a 100kbit/sec maximum speed. Similarly to IEEE802.11g, ZigBee operates in the 2.4GHz frequency, has an outdoor range up to 1000 meters (restricted in this case by power use) and is a very viable alternative. A ZigBee transmitter from Microchip, item number MRF24J40MA, was chosen and has a transmission range of up to 400 feet (122 meters).

Vibration sensor, infrared sensor, and transmitter in hand, a choice had to be made for the microcontroller to run this system. Attachment of the transmitter was the largest concern and became the defining factor for microcontroller use. Any of Microchip's PIC16 controller boards were sufficient for use with this transmitter, so a board was sought which had at least three built-in analog to digital channels and preference was given to those with a low power variant. The PIC16F726 from Microchip was chosen for its 11 channel 8bit analog to digital conversion, allowing for the addition of further sensors or inputs at a later date, and its 1.8 Volt – 3.6 Volt low power variant, PIC16LF726. The addition of this controller and the changes, above, resulted in the final design, shown in **Figure 12** and **Figure 13** with circuitry included. The Bill of Materials is included in **Table 2,** below.

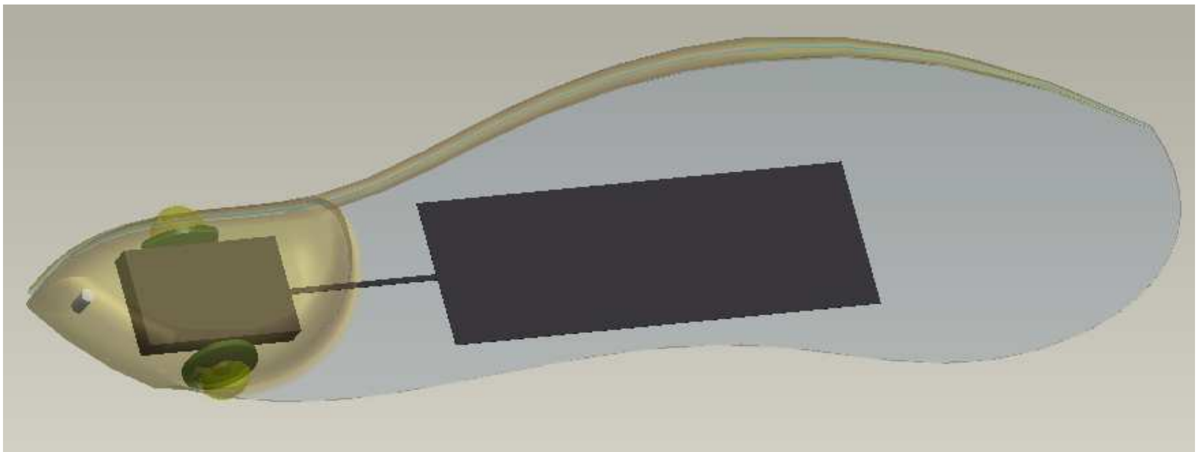


Figure 12: Pro-E Model of Final Design

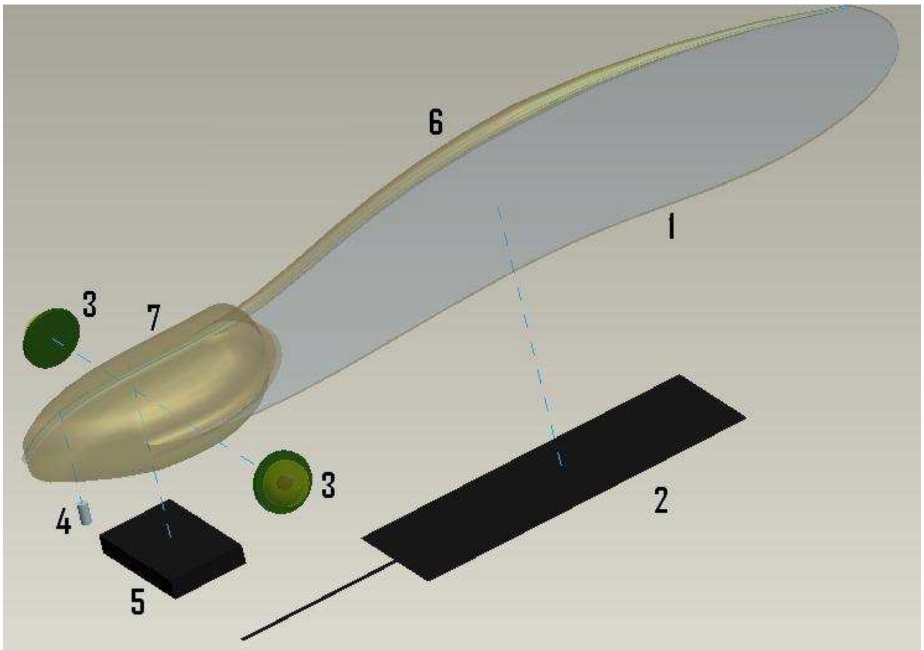


Figure 13: Exploded View of Pro-E Model of Final Design

5.6 Bill of Materials and Cost Analysis

Table 2: Bill of Materials and Cost Analysis

#	Company	Model Number	Function	Qty	Size (LxWxH) (mm)	Voltage (V)	Cost ($)
4	**SignalQuest**	SQ-SEN-200	Omni-directional Vibration Sensor	1	3.3x3.3x6.9	.5-12 (3 suggested)	$4.58
3	**Glolab**	DP-001	Infrared Sensor	2	19dia.x9.6	4.0-15.0	$22.95
5	**Microchip**	MRF24J40MA	802.15.4™ RF Transceiver Module	1	17.8x27.9	2.4-3.6	$8.99
5	**Microchip**	PIC16F726	Microcontroller	1	12x20	1.8-5.5	$1.99
2	**Silicon Solar**	05-1284	Flexible Solar Panel	2	114.3x38.1x~2.5	3	$5.50
5	**Sanyo**	RLITH-5	Battery	1	20x3	3	$9.99
5	**Panasonic**	EECS5R5H105	Capacitor	1	19x5	5.5	$5.07
1,7	**Innovative Polymers**	TP-4004	SDM Seed Body	NA	170x50x15	NA	$5.00
						Total Cost=	**$92.52**

5.7 Optimization

The material that was chosen to mold the seed was carefully considered. High density materials can increase the weight of the seed without having any improved strength characteristics over those of lower density composite materials. Some of the lower density materials lacked durability and the qualities required to withstand harsh environments for a long period of time.

The internal components greatly affect the weight of our final product. The solar panel, micro-processor, battery, transmitter, infrared and vibration detectors all have a relatively low mass. We have found that when you combine those items, the resulting mass has a very significant impact weight of the maple seed. As a result, we have chosen the smallest parts possible and limited the number of components to the absolute bare minimum.

Virtually every design has a common parameter that cannot be overlooked. As in the case of our project, size plays a large role in the design process and is a part of our design specifications. The size of our maple seed will not greatly affect its ability to fly, as our design can be scaled to any reasonable value and still maintain auto-rotation capability. Similar to the weight issues, finding internal components that are as small as possible was a seemingly never ending task. The size of the components was what ultimately decided the scale of our final design.

A detail of our design that was not obvious to us at first was the location of the center of gravity for the seed. Optimizing this parameter was the pinnacle of obtaining auto-rotation. We learned by trial and error what did not work and from that information, discovered what needed to be done to maintain flight. The center of gravity needs to be just past the wing inside of the head so the wing can rotate around that point as shown in

Figure 14. If the center is somewhere on the wing, the seed will rotate around that point and lose any available lift that portion of the wing could produce.

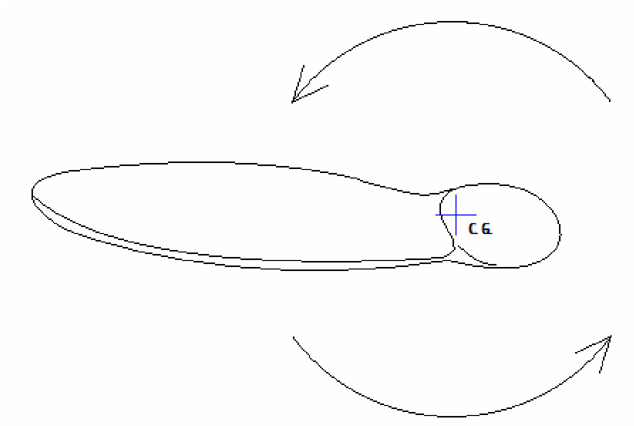


Figure 14: Rotation of Maple Seed in Flight

5.8 Prototypes

In any design process, creating prototypes can help to guide your design as well as provide an excellent visual aid for the customer. The first prototypes were made from card board and paper as seen below in **Figure 15**. These were produced to help us understand some of the fundamental characteristics of the maple seed. The thicker spine coupled with a thin wing was found to be an essential design requirement.

Figure 15: Cardboard Maple Seed Designs

The purpose of the next prototype was to test the 3-D printing capability as well as produce a first rough draft for what the seed would ultimately look like shown below in **Figure 16**. This version did not achieve auto-rotation due to its unbalanced head to wing weight ratio of 0.6. Which means the wing was heavier than the head. From this we learned to set the ideal head to weight ratio to 6.0.

Figure 16: Initial Design Shape

The second FDM prototype met the head to wing weight ratio but revealed a very important detail that was obtained by testing this prototype. What was learned was to avoid stress concentrations that are produced by sharp angles where two perpendicular surfaces meet. These sharp angles caused the wing to crack as seen below in **Figure 17.** We found that creating rounds in these locations greatly increased the strength and flexibility of the seeds.

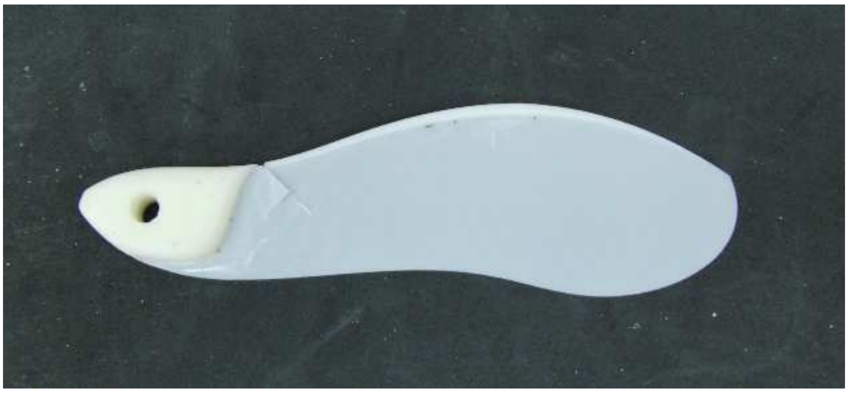


Figure 17: Second Design Shape

Our final prototype met the previous requirements and proved to be a successful model for the type of flight we were trying to achieve. This model released from 35ft and reached auto-rotation after about 20ft. The terminal velocity was determined using video and was found to be 3.6m/s (8mph). The weight of the prototype at this length (6.75") was 0.35oz. The rounded edges performed as expected against numerous impacts with hard tile flooring. After experimentation and data analysis, the decision was that this would be the basic blue print for our final product. This final shape design can be seen in **Figure 18**.

Figure 18: Final Design Shape

5.9 Material Selection

As discussed in the optimization portion of this report, weight and durability are of the utmost importance. The only material that needed to be considered was the body of the maple seed. All of the other parts are pre-assembled electrical components. The material that we would choose needed to satisfy a few criteria. It had to be light weight to maintain auto-rotation. Flexibility became an apparent requirement after prototype testing. Since the solar cells are to be mounted inside the wing, translucence was necessary to allow sunlight to reach the panels. Temperatures will exceed 140 deg F in the environment which the seeds will be operating, so the material needed to be impervious to that range of heat. The last characteristic of the chosen material was the ability to keep out water and moisture. The sensitive internal components would need a dry environment to function properly.

Our original selection was VA-273 SDM material. After careful consideration, it was determined that the final product would be too brittle and could easily fracture. The decision was made to use a stronger material of the same type TP-4004 SDM material

6 Design Changes

The aspects that were changed from our original design were the size of the wing, the wing and head construction method, and the circuit that was used to implement the sensors. These changes were made with much consideration and with the original project scope in mind.

The overall weight of the components and housing was greater than what was expected. To compensate for this, the length of the wing was increased by 30% and the width of the wing was increased by 60%. The lengthening of the wing helped to increase the wing tip speed and the widening helped to increase the effective area of the wing. This final design deviated from the original template, but proved to provide maximum lift and the slowest decent rate. The only down side to this design is the lack of perfect resemblance to our original inspiration of the quillpen maple seed. The new wing is shown below in **Figure 19.**

Figure 19: Final Wing

The original design used a CNC to manufacture the head and spine of the maple seed. After several attempts, this method was avoided due to damages that occur during the milling process. The head was found to be very unstable in the machine while material was being removed. Instead, it was decided to create a molding system using Fused Deposition Modeling (FDM) so the head could be poured around the circuit and sensors and removed from the mold. This method proved to be very effective in creating consistent models while limiting the potential damage during manufacturing.

Given the size of the new wing, pouring the wing out of polyurethane proved to be difficult to build and overly fragile. The method that was adopted was using thick, clear laminating sheets to make up the entire wing surface area. This was chosen in order to simplify the issue that was discovered when trying to embed the solar cells into the wing. This created a clear layer for the light to easily pass to the solar cells. Rubber tubing became the spine material with a thin metal rod inserted for support. Cutting and reforming the wing proved to become very simple with the laminating sheets, as well.

The head of the maple seed was too small to accommodate the focal length of the Fresnel lenses that are required by the IR sensors in order to increase their sensing range. To accommodate the focal length of the lenses, the size of the head was increased. The added weight to this design will be counterbalanced by the entire circuit being embedded in lightweight insulating foam. The insulating foam will take up volume in the maple seed while reducing the amount of weight added to the seed by the larger head. The new maple seed head can be seen in **Figure 20.**

Figure 20: Final Maple Seed Head

The final and possibly the most impacting change that was made to our final design was the circuit that was implemented. After many programming issues that were encountered when attempting to incorporate the micro-processor, a simple hardware only circuit was designed and created to demonstrate the concept of the entire operation. A blue LED was decided upon to represent that transmission of data when a sensor was activated. This circuit does not include any processors or chips, only switches and a relay which activate a blue light after detecting a disturbance which is displayed in **Figure 21**, the circuit diagram below.

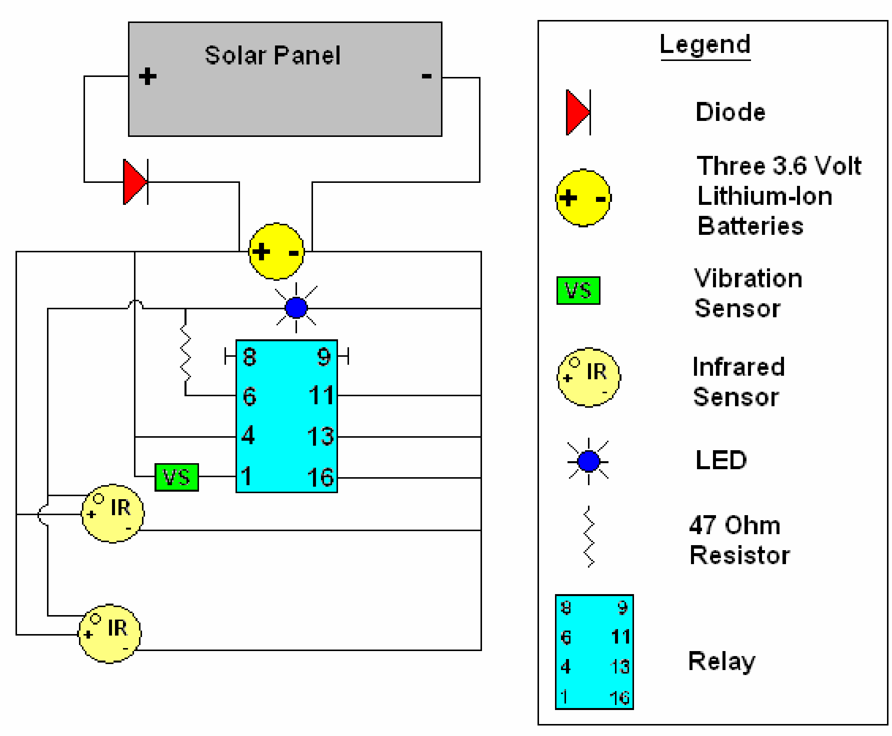


Figure 21: Circuit Diagram

7 Manufacturing and Assembly

The first step in the manufacturing process consisted of creating the circuit and incorporating the sensors. If a light were connected to the output of the vibration sensor, it would always be on and would only turn of when a vibration is detected. A relay was installed to reverse this process. The infrared sensors act as a switch that are always off and turn on when movement is detected. This method of operation is consistent with the desired output so no changes were made to its inherent operation. The vibration sensor and the two IR sensors were connected in parallel to have a common output of a blue LED. The batteries were connected in parallel with the solar cells and sensors. A switch was installed to the sensor half of the circuit so the unit would not use power when it is not required to. This was done for presentation purposes only. A diode was attached in between the solar cell and batteries so that the batteries would not discharge at night. The wing was the next item that was assembled in the process. Clear rubber tubing used for the spine was cut to the proper length and sliced lengthwise to allow insertion of the solar cell wires, supporting rod, and the laminate wing. The solar cell package was inserted into the laminate and the laminate was sealed using a household iron. The laminate was then trimmed to the desired size and the wires were soldered to the ends of the solar cells. After inserting the supporting rod, the wing was inserted into the rubber tubing and sealed with polyurethane material injected from a syringe.

With the wing and circuit assembled, the head was ready to be poured using the mold created with the Fused Deposition Modeling process. Clay was used to position the wing. Three holes were punched in the portion where the wing meets the head. This was done so that polyurethane could flow through the wing to insure a secure bond. The mold was closed and sealed using modeling clay to ensure there were no leaks. The polyurethane was then poured through a hole in the top of the mold and left to set for one hour. After removal, all clay covers and seals were removed from the head and the Fresnel lenses were installed on the IR sensors.

8 Testing and Data Analysis

After production of the maple seed, flight and sensor tests were conducted and the actual final dimensions and weight of the seed were recorded. The seed was filmed during autorotation using a high-speed camera and an in-frame scale was used to determine terminal velocity. In addition, this footage was analyzed to determine the angular velocity of the seed during steady-state autorotation. The infrared sensors were tested to determine the range at which they picked up moving human-sized infrared signatures in ambient temperatures of approximately 21 degrees Celsius. Finally, the resistance and power usage of the circuit were measured and recorded. The results of these tests are shown below in **Table 3**.

Table 3: Testing Results

Terminal Velocity (Steady state)	3.24 m/s
Angular Velocity (Steady state)	26.96 rad/sec (257.4 rpm)
Total weight	0.277 kg
Total length	0.41275 m
Wing area	0.03888 m^2
Infrared Sensor Range	15.24 m
Circuit resistance	160 Ω
Circuit power usage	784 mW

9 Final Cost Analysis

In total, the production cost of each maple seed is $125.93. This cost does not include labor, but should be fairly accurate when considering the reduced cost of larger-scale production which must include labor. The itemized Bill of Materials is shown below in **Table 4** and includes prices, dimensions, and voltages of all components of the seed.

Table 4: Bill of Materials and Cost Analysis

Company	Model Number	Function	Qty	Size (LxWxH) (mm)	Voltage (V)	Cost ($)
SignalQuest	SQ-SEN-200	Omni-directional Vibration Sensor	1	3.3 x 3.3 x 6.9	.5-12 (3 suggested)	$4.58
Glolab	DP-001	Infrared Sensor	2	19dia. x 9.6	4.0-15.0	$22.95
Silicon Solar	05-1293	Flexible Solar Panel	1	254 x 149.86	7.2	$35.95
GMBPower	LIR3048	Rechargeable Battery	3	30.5dia. x 5.5	3.6	$5.50
Innovative Polymers	TP-4004	SDM Seed Body	N/A	N/A	N/A	$10.00
Glolab	FL40	Fresnel Lens	2	25.4dia. x 0.4	N/A	$4.00
Great Stuff	Big Gap Filler	Foam insulation	1	N/A	N/A	$5.00
					Total Cost=	**$125.93**

10 Acknowledgements

- Matt Christensen – Harris Corporation
    - For valuable advice during this semester

- Dr. Jonathan Clark – FAMU/FSU College of Engineering
    - Use of the STRIDe lab
    - Valuable advice during this semester

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12 Appendix

12.1 Maple Seed Morphology

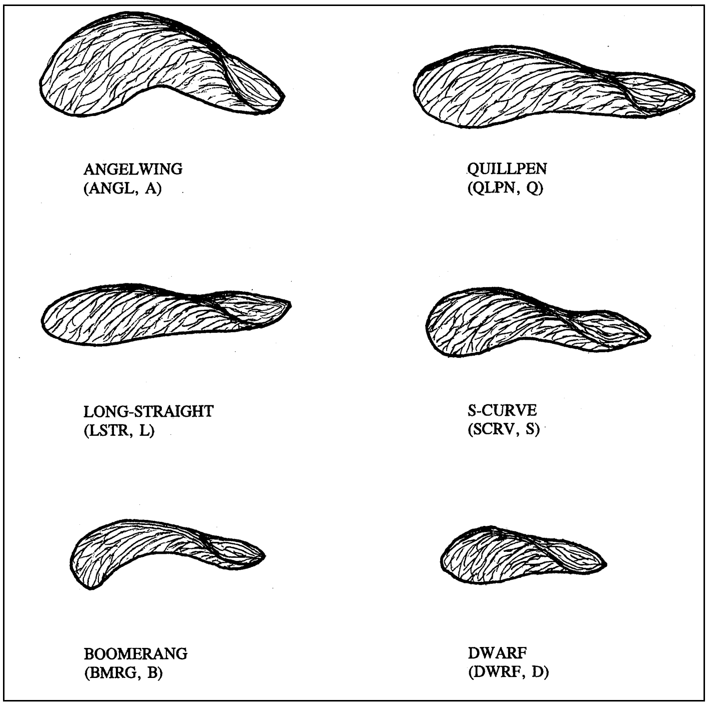


Figure 22: Maple seed morphologies

12.2 Ratio Calculation

$$Seed\_weight_{average} := 130.6\,10^{-6}kg$$

$$\rho := 731.883\frac{kg}{m^3}$$

$$Wing\_area_{average} := 52mm^2$$

$$thickness_{natural} := 3.5mm$$

$$Weight\_Area\_Ratio_{average} := \frac{Seed\_weight_{average}}{Wing\_area_{average}}$$

$$Weight\_Area\_Ratio_{average} = 2.512\frac{kg}{m^2}$$

$$ab\_ratio := \begin{pmatrix} \frac{1.1585}{0.4474} \\ \frac{1.0938}{0.5696} \\ \frac{1.1684}{0.4797} \\ \frac{1.2573}{0.5637} \\ \frac{0.9822}{0.3512} \\ \frac{0.9334}{0.4819} \end{pmatrix}$$

$$mean(ab\_ratio) = 2.318$$

$$Diameter := 30mm$$

$$Projected\_Area_{proto} := \frac{\pi \cdot Diameter^2}{4} \qquad Thickness_{proto} := Diameter$$

$$relative\_thickness \equiv \frac{Thickness}{Projected\_Area}$$

$$relative\_thickness_{proto} := \frac{Thickness_{proto}}{Projected\_Area_{proto}} \qquad relative\_thickness_{proto} = 42.441 \frac{1}{m}$$

$$Thickness\_Ratio \equiv \frac{Head\_Thickness}{Head\_Area}$$

$$Thickness\_Ratio_{natural} := \frac{3.5mm}{11mm^2} \qquad Thickness\_Ratio_{natural} = 318.182 \frac{1}{m}$$

$$Thickness\_Ratio_{proto} := \frac{15.25mm}{\pi \cdot (15.25mm)^2} \qquad Thickness\_Ratio_{proto} = 20.873 \frac{1}{m}$$

$$Head\_Weight_{ave} := mean\left[\begin{pmatrix} 118.7 \\ 134.6 \\ 120.5 \\ 79.8 \\ 122.0 \\ 92.8 \end{pmatrix} mg\right] \qquad Head\_Weight_{ave} = 1.114 \times 10^{-4} kg$$

$$Wing\_Weight_{ave} := mean\left[\begin{pmatrix} 25.0 \\ 23.9 \\ 20.1 \\ 15.4 \\ 18.0 \\ 12.7 \end{pmatrix} mg\right] \qquad Wing\_Weight_{ave} = 1.918 \times 10^{-5}\, kg$$

$$Weight\_Weight\_Ratio := \frac{Head\_Weight_{ave}}{Wing\_Weight_{ave}} \qquad Weight\_Weight\_Ratio = 5.807$$

$$Head\_Weight_{proto} := (0.2501374 - 0.1562901)in^3 \cdot \rho \qquad Head\_Weight_{proto} = 1.126 \times 10^{-3}\, kg$$

$$Wing\_Weight_{proto} := 0.1562901in^3 \cdot \rho \qquad Wing\_Weight_{proto} = 1.874 \times 10^{-3}\, kg$$

$$Weight\_Weight\_Ratio_{proto} := \frac{Head\_Weight_{proto}}{Wing\_Weight_{proto}} \qquad Weight\_Weight\_Ratio_{proto} = 0.6$$

$$Wing\_Area_{proto} := 1.04in^2$$

$$Weight\_Area\_Ratio_{proto} := \frac{Head\_Weight_{proto}}{Wing\_Area_{proto}} \qquad Weight\_Area\_Ratio_{proto} = 1.678\, \frac{kg}{m^2}$$

12.3 Lift Calculations

C.1 is the area factor
L is the overall length
W is the width of the wing at its widest point

$A = C_1 \cdot L \cdot W$

$C_2(L, W) := \frac{L}{W}$ => $W = \frac{L}{C_2}$

C.2 is the ratio of total length to seed width

$\mathrm{Area}(C_1, L, C_2) := C_1 \cdot \frac{L^2}{C_2}$

$\frac{L}{W} = C_2$

$C_1(A, L, C_2) := \frac{A \cdot C_2}{L^2}$

Point 1

$L_1 := 9.35\,in$

$W_1 := 2.68\,in$

$\mathrm{Area}_1 := 13.8058\,in^2$

$C_2(L_1, W_1) = 3.489$

$C_1(\mathrm{Area}_1, L_1, C_2(L_1, W_1)) = 0.551$

Point 2

$L_2 := 18.71\,in$

$W_2 := 5.37\,in$

$\mathrm{Area}_2 := 55.2233\,in^2$

$C_2(L_2, W_2) = 3.484$

$C_1(\mathrm{Area}_2, L_2, C_2(L_2, W_2)) = 0.55$

$C_{1con} := 0.55$

$C_{2con} := \frac{3.489 + 3.484}{2}$

$C_A := \frac{C_{1con}}{C_{2con}}$

$C_A = 0.158$

$\mathrm{Wing\_Area}(\mathrm{Length}) := C_A \cdot \mathrm{Length}^2$

$\mathrm{Area}(L) = 0.158 \cdot L^2$

$\mathrm{Lift} = \frac{Cl \cdot \rho \cdot (\omega \cdot L)^2 \cdot A}{2}$

$C_{lift} := 1.7 \qquad \omega := \frac{50}{s} \qquad \rho_{air} := 1.2\frac{kg}{m^3} \qquad Lift = Weight$

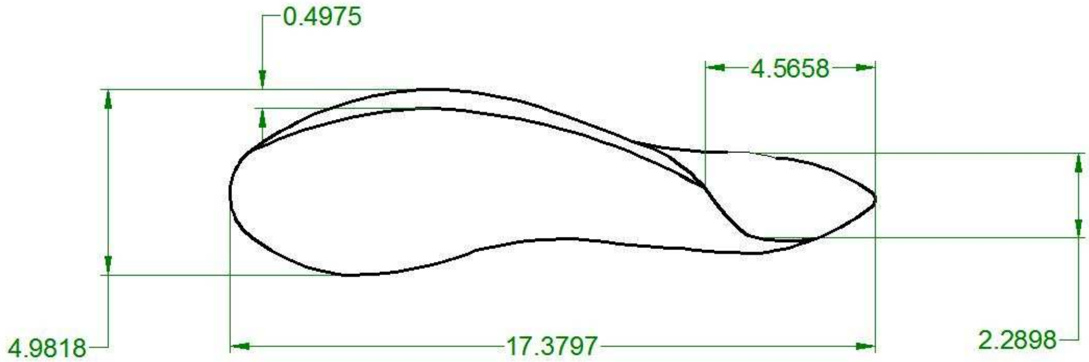
$Length := 2in, 4in .. 16in$

$Wing\_Area(Length) := C_A \cdot Length^2$

$$Lift(Length) := \frac{C_{lift} \cdot \rho_{air} \cdot (\omega \cdot Length)^2 \cdot Wing\_Area(Length)}{4} \qquad Lift(L) = \frac{Cl \cdot \rho \cdot \omega^2 \cdot 0.158 \cdot L^4}{4}$$

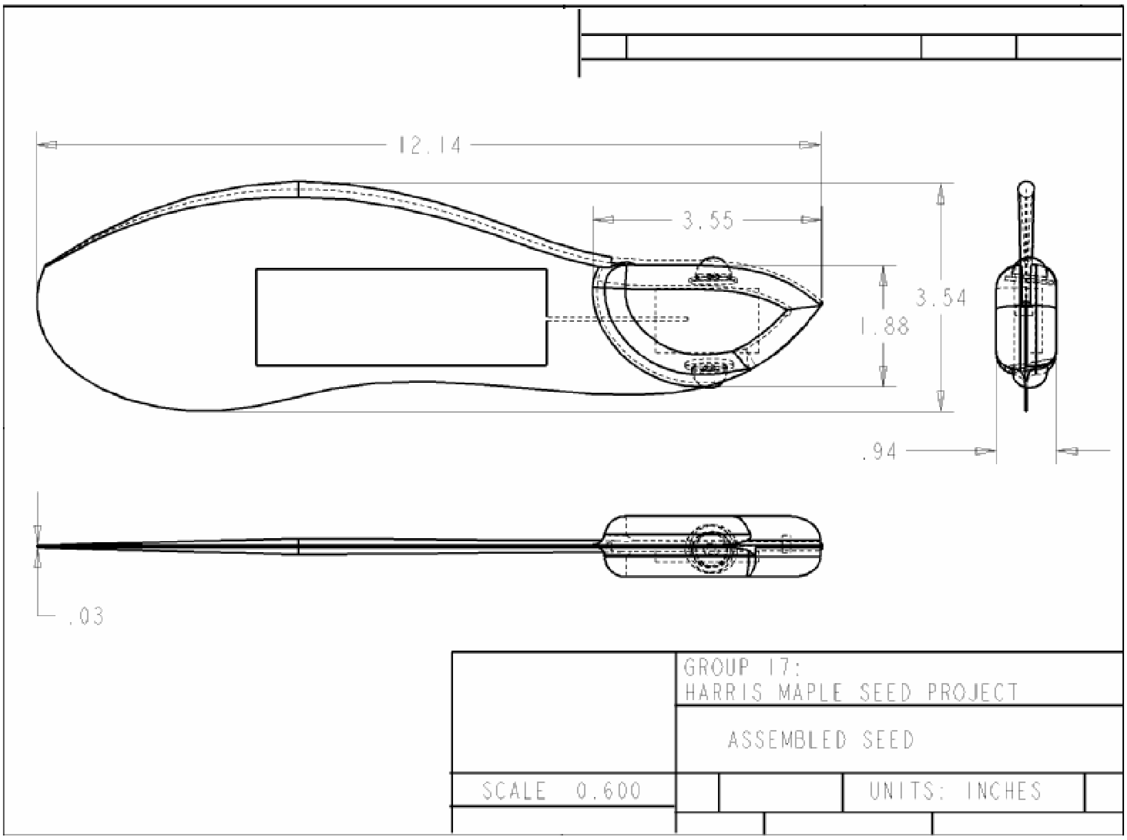
Length = (in)	Lift(Length) = (lbf)
2	$3.011 \cdot 10^{-4}$
4	$4.818 \cdot 10^{-3}$
6	0.024
8	0.077
10	0.188
12	0.39
14	0.723
16	1.233

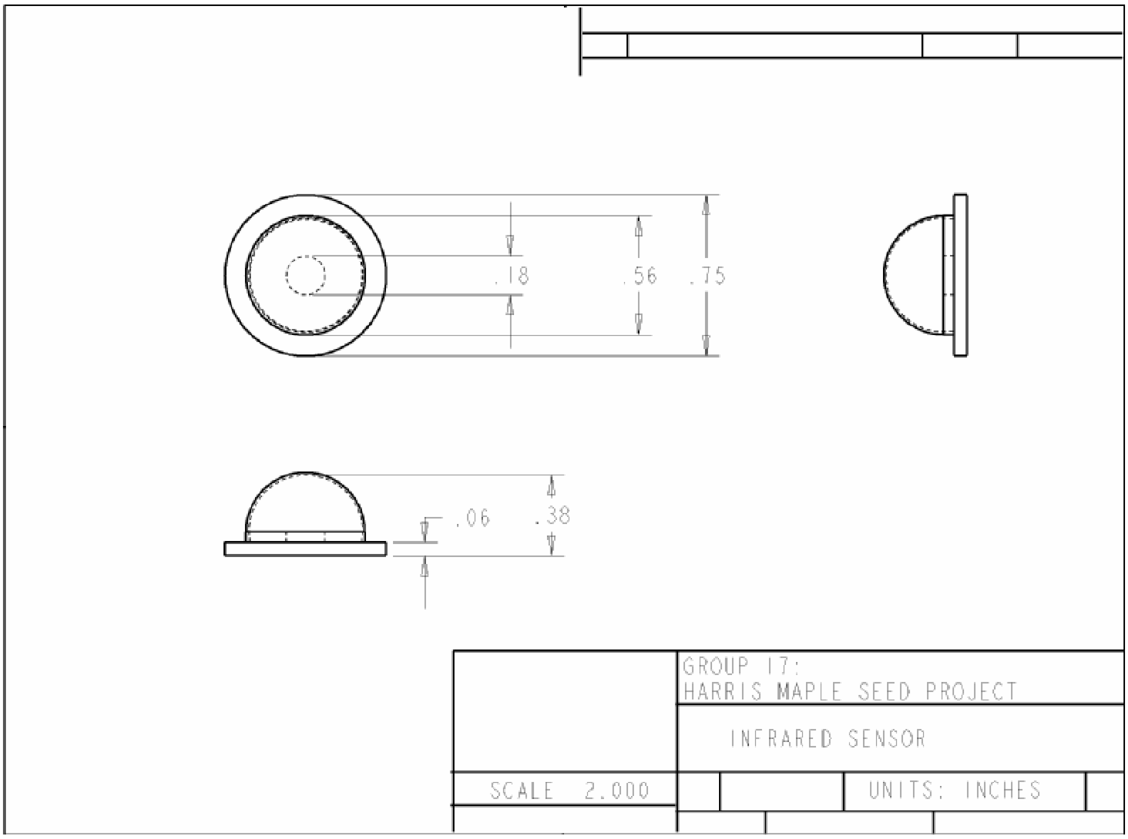
12.4 Natural Maple Seed Dimensions

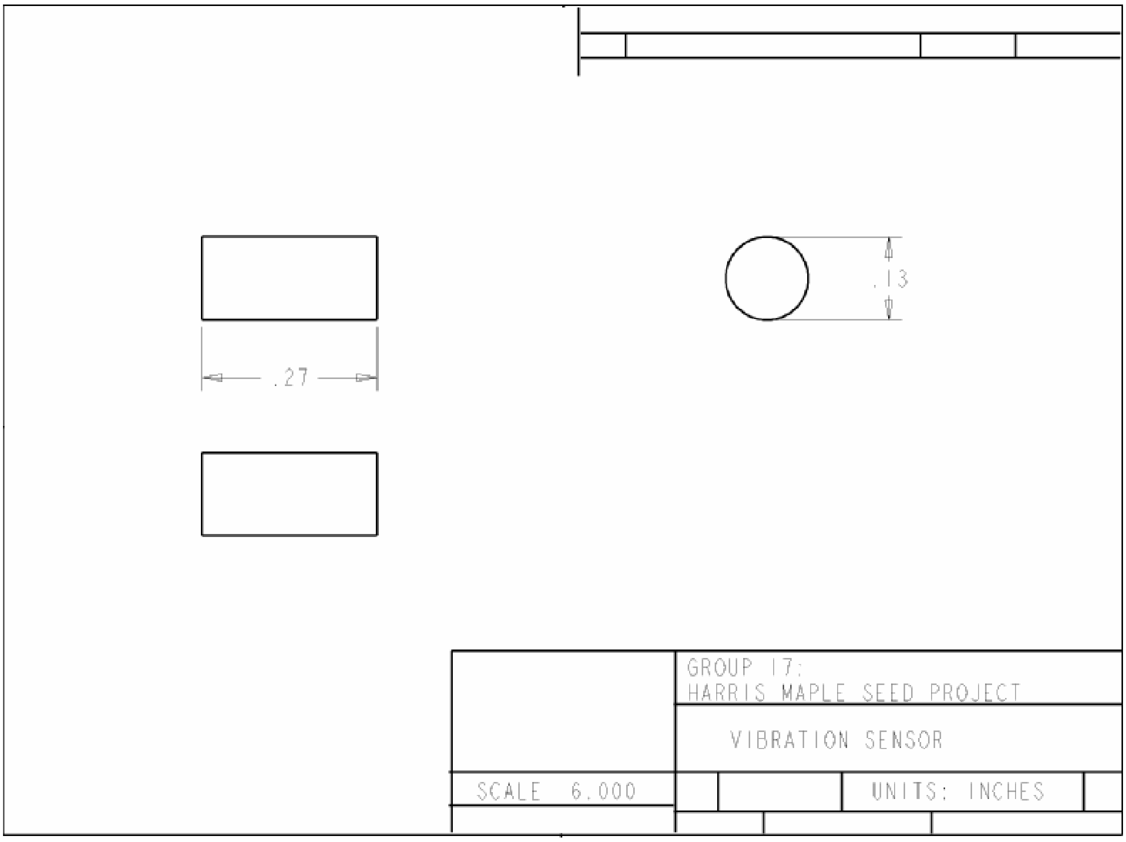


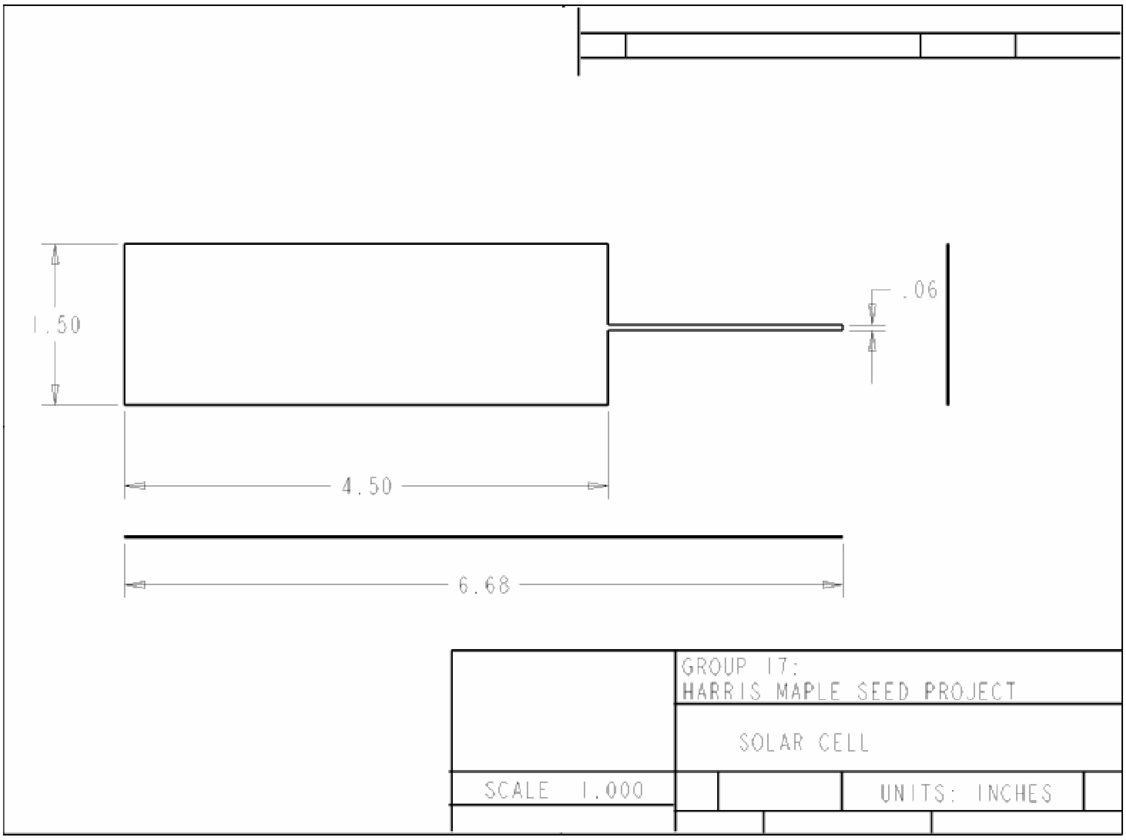
Dimensions in millimeters

12.5 Pro-E Drawings



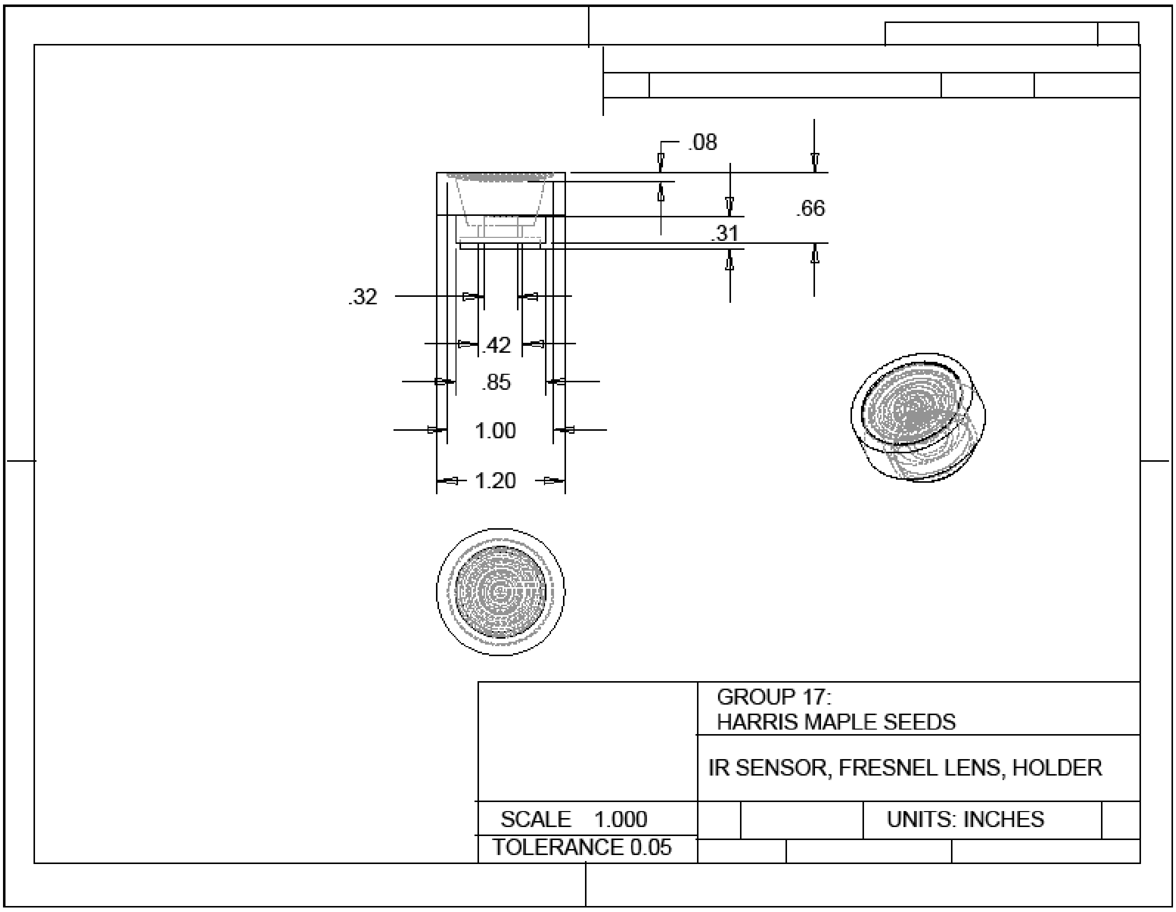

.18
.56
.75
.06
.38
GROUP 17:
HARRIS MAPLE SEED PROJECT
INFRARED SENSOR
SCALE 2.000
UNITS: INCHES

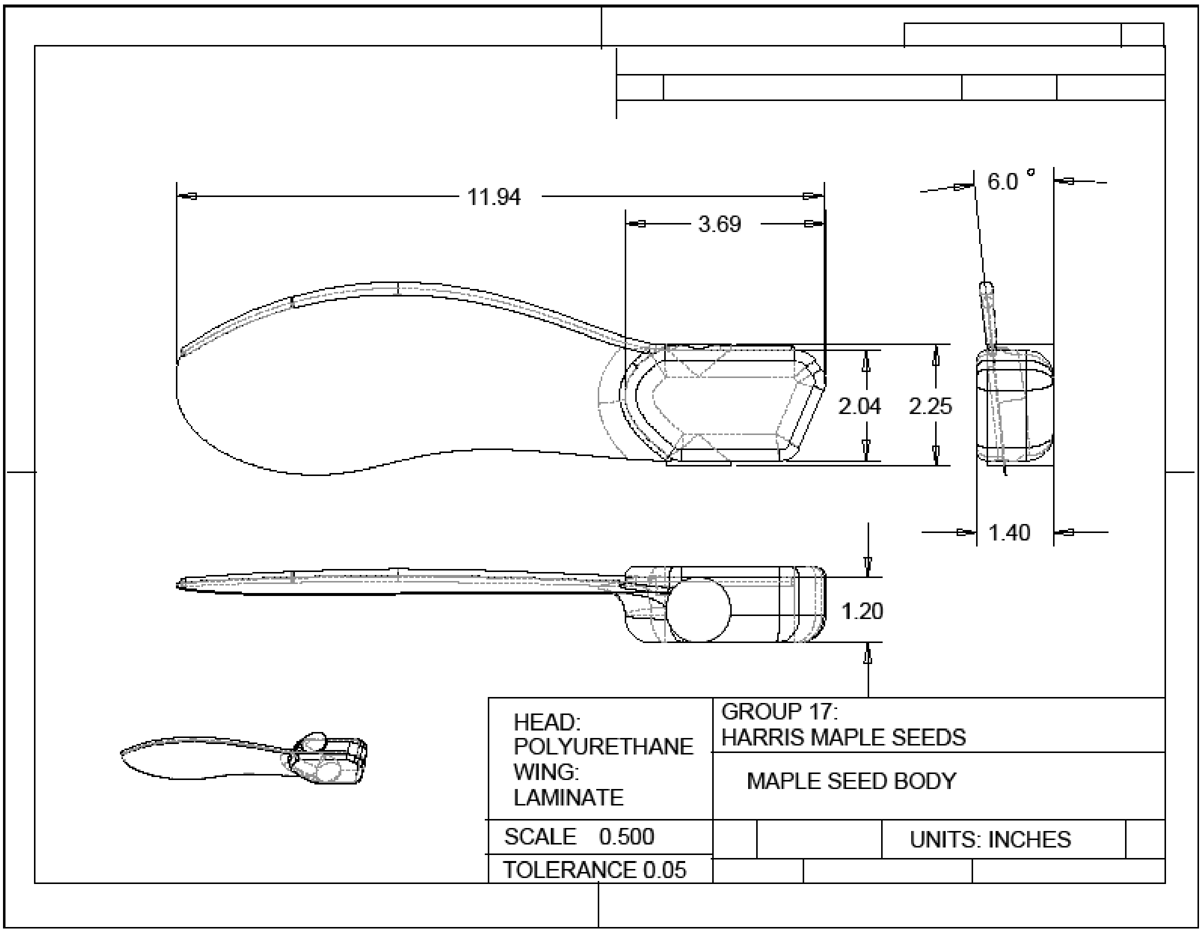

.27
.13
GROUP 17:
HARRIS MAPLE SEED PROJECT
VIBRATION SENSOR
SCALE 6.000
UNITS: INCHES



1.50
.06
4.50
6.68
GROUP 17:
HARRIS MAPLE SEED PROJECT
SOLAR CELL
SCALE 1.000
UNITS: INCHES

12.6 Final Product Pro-E Drawings




11.94
3.69
6.0 °
2.04
2.25
1.40
1.20
HEAD:
POLYURETHANE
WING:
LAMINATE
GROUP 17:
HARRIS MAPLE SEEDS
MAPLE SEED BODY
SCALE 0.500
UNITS: INCHES
TOLERANCE 0.05