Nevada Dynamics
Spatial Delivery

May 6, 2015

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UNIVERSITY OF NEVADA RENO

THE HONORS PROGRAM

We recommend that the thesis prepared under our supervision by

Daniel T. Ferguson and Harrison A. Gray

entitled

Nevada Dynamics: Spatial Delivery

be accepted in partial fulfillment of the requirements for the degree of

BACHELOR OF SCIENCE, MECHANICAL ENGINEERING

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May, 2015

Executive Summary

Nevada Dynamics has designed an adaptable Unmanned Aerial Vehicle (UAV) charging station that is capable of safely charging Lithium Polymer batteries through copper contacts while simultaneously allowing for a package to be housed below the UAV. The UAV industry is rapidly growing; however, there are strict regulations of their use due to safety concerns. If companies could ensure that their UAV's battery is charged so that important safety features remain on, the regulations may begin to lessen. While there are multiple UAV charging stations on the market currently, none of the existing designs allow UAV's carrying packages to charge their batteries without human interaction. Nevada Dynamics' final charging station completes the goal of expanding the UAV industry by allowing delivery UAVs to recharge without damaging the package housed below the UAV. By analyzing the competition, the team was able to define the remaining key functions required for the charging station to be a success. Building upon the key functions, several designs were considered, and each design iteration was analyzed to create the optimal design seen in Figure 1.

Figure 1: Final Prototype Design

Several potential designs were generated in the preliminary design work for the charging station that were then translated into 3D models. Converting the conceptual designs into simplistic 3D models solidified the customer requirements, which were then converted into engineering specifications. The final hoop and contact design was selected based on the results of the engineering analysis, budget constraints, and time constraints. The main concern with the hoop and contact design centered on how the theory of electrical contacts transfers to real world application. These concerns were combated by building a proof of concept that focused on the application of copper contacts. The data from the proof of concept affirmed the theory that copper contact points would provide a strong enough connection to charge a Lithium Polymer battery. The final design combines the copper contacts with 3D printed parts to create the main portions of the charging station. The final design parts were printed partly in Nevada Dynamic's lab with a 3D printer and the team's mentor, Andrew Smith, printed the remaining parts. Once the 3D printed parts were complete, the team built the remaining portion of the station and built the hexacopter frame that was used for testing. The tests performed involved checking the copper contacts and establishing a method of checking the alignment of the UAV on the station. Overall, the testing of the final prototype revealed that Nevada Dynamics' charging station design met all the engineering specifications created by the team.

Nevada Dynamic's work over the past two semesters has proven worthwhile with the creation of a fully functioning UAV charging station. The station is able to detect if the UAV is aligned, can charge a Lithium Polymer battery using copper contacts, and allows room for a package below the UAV. Additionally, by building the hexacopter frame, it was proven that a UAV can fly with the copper contacts and additional hardware that the charging station requires.

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Design Problem and Objective

As the Unmanned Aerial Vehicle (UAV) industry expands to include new businesses and clients, there is a need for a charging station to increase the range over which delivery UAVs can travel. Nevada Dynamics has designed a sturdy Lithium Polymer (LiPo) battery charging station that is adaptable and allows for a payload to be housed below the UAV during charging. The objective of the station is to recharge a UAV during a mission in order to increase the distance it can travel while increasing the opportunities for delivery UAVs. The market for increasing UAV travel is currently a hot topic. Regulations are expected lessen, and UAV usage in civilian airspace will soon become commonplace. A safe, reliable, and durable charging station will be needed to further expand the range of cover for companies integrating UAVs into everyday operations.

One device capable of extending the range of a UAV is a battery swapping station. A few companies and research teams have accomplished the task of designing and building such a device; however, each product involves a high level of sophistication and an equally large budget. A research group from MIT and a company by the name of Skycatch are two groups trying to perfect battery swapping. The MIT platform connects with the UAV and switches out the spent battery for a fresh one prior to releasing the vehicle, which achieves the goal of increasing the range. The device, however, is only compatible with a particular UAV design. Additionally, the charging station does not allow for a payload to be placed below the vehicle, thus limiting its usefulness. As with the MIT research team, Skycatch has developed a base station that can autonomously swap batteries out of a UAV. Skycatch's station is specific to their UAV (Fig. 2); however, their station has a bowl like shape which is a step toward allowing room for a package. This means that their station extends the range of UAVs, increases flight time, and expands upon their customer base.

Figure 2: Skycatch battery swap station [1]

Figure 3: Skysense inductive charging station [2]

While the battery swapping stations reduce the amount of down time for the UAV, they depend on the area below the battery being exposed. Skysense has attempted to free the platform of the station from moving parts by creating an inductive charging station that is sleek and can be used with various UAVs (Fig. 3). This design extends the range and broadens the uses for the vehicle, but it also increases the amount of time that will be spent charging the battery. The major limitation of this design is the fact that the UAV must contact the surface, which eliminates the possibility of housing a payload underneath the vehicle. While these designs are fully functioning, they do not meet all customer requirements.

The concerns of both companies and recipients had to be considered when creating the design because recharging stations affect everyone involved in the UAV industry. From analyzing the customer surveys completed at the beginning of the term, a number of customer requirements and engineering specifications were developed and laid out in Table 1. Customers called for same day delivery, so the maximum charging time was determined to be an hour and a half. The charging station must also allow for charging of a larger battery, specifically a 6S, 5000mAh, 22.2V battery. The charging station had to accommodate a package size of 16”x16”x12”. For the product to be more appealing to a variety of customers, the charging station had to accommodate a variety of UAV sizes and configurations. Lastly, the charging station had to balance charge the LiPo battery and keep the autopilot operating in order to ensure that the UAV could complete its mission.

Table 1: Customer requirements developed into engineering specifications from the Product Design Specifications (PDS) laid out in Appendix B.

Customer Requirements	Constraints	Engineering Specifications
Same day delivery	Charge time	Maximum charging time of 1.5 hours
Expand range with larger battery	Weight	Charger must be able to accommodate a 6S, 5000mAh, 22.2V battery
Package accommodation	Size	Minimum package size of 16"x16"x12"
Adaptable to various UAV designs	Adaptability	Easily able to manipulate orientation of contact points
Product safety	Safety	The LiPo battery must be balance charged
Midflight charging	Safety	UAV autopilot must remain on during charging process
Sufficient power to charge the battery	Power	Charging station will draw power from a large source

The final prototype charging station had to satisfy the four main objectives listed in Table 2 in order to be considered for production. First, it had to safely accommodate a package. Neither the merchandise, UAV, nor the charging station could experience damage in any manner by the charging process. Space for a package separates this charging station from every other charging stations on the market. Prior to initiating the charging process, the UAV had to properly align with the charging station. This prevents short circuits, damage to any equipment or merchandise, and incomplete loops. In order to increase the market size, the charging station had to be adaptable to several different sizes and types of UAVs. This could have been accomplished by either building one design that accommodates all UAV designs or by maintaining a cost effective design that could be adapted and produced for different UAVs. Above all, the purpose of the charging station was to safely charge the battery on the UAV. Constant monitoring and balancing of the LiPo battery was required in order to accomplish this. LiPo batteries can be dangerous if they are not charged properly, so the station had to make safe charging a top priority.

Table 2: Design objectives that will all contribute to satisfying the corporate and civilian needs.

Design Objectives	
Safely Accommodate Package	The station must provide ample space for the package to rest during the charging process.
Safely Align UAV with Charging Station	The UAV must be aligned properly in order to charge correctly and prevent damage to both the UAV and its payload.
Adaptable to Several UAVs	The station design must be easily produced to accommodate different sizes and types of UAVs
Safely Charge Battery	The charge must be autonomously monitored to ensure the batteries are not overcharged or damaged.

Overview of Design

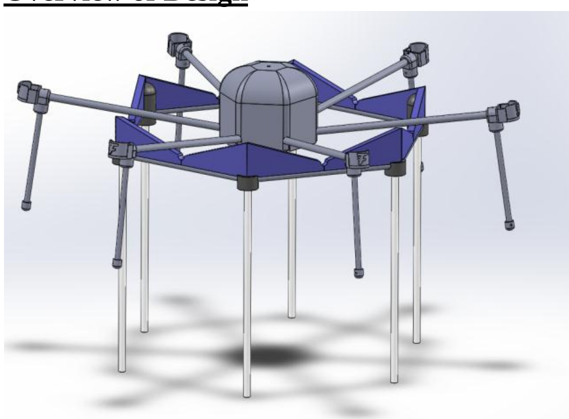


Figure 4: Hex Hoop design shows as a 3D rendering in Solidworks

The final Hex Hoop and contact charging station design chosen by Nevada Dynamics encompassed all the design objectives and performed all the necessary design functions to charge a UAV. The hoop and contact charging station is hexagonal in shape with sloped ridges (the blue components) that align with a six-armed UAV upon landing to ensure that a proper connection is made (Fig. 4). The function for the sloped ridges allow the arms of an incoming UAV to slide down into the exact charging position. The 3D printed hexagonal hoop easily accommodates for a package during the docking, charging, and undocking phases because it keeps the charging station components clear of the area under the UAV. This ensures that a package remains unobstructed while the UAV is in contact with the station. This design can be easily adapted to match a variety of sizes and types of UAVs. The Hex Hoop supports are located under the blue components in the figure and their function is to increase the strength of the station. The legs provide clearance for the package housed beneath the UAV, as well as raise the UAV off of the ground to reduce the turbulence produced by the propellers. The length of these legs can be altered easily. The components that make up the Hex Hoop have tabs designed in them to allow for easy assembly.

Once the UAV lands on the hoop, the arms fit into the copper contact notches as seen in Figure 5. The copper notches create a greater surface area for charging and fix the UAV in place during the charging process. In addition to fixing the UAV arms in place, the copper contacts function as the connecting mechanism through which the UAV is charged. A small copper contact module is placed on the arm of the UAV and connects with that on the charging station. This completes the circuit and allows the charging station to provide power to the battery on the UAV. Switches are placed on two of the notches missing a copper contact to ensure that the UAV is level and to announce to the station that the UAV has connected by lighting up an LED light.

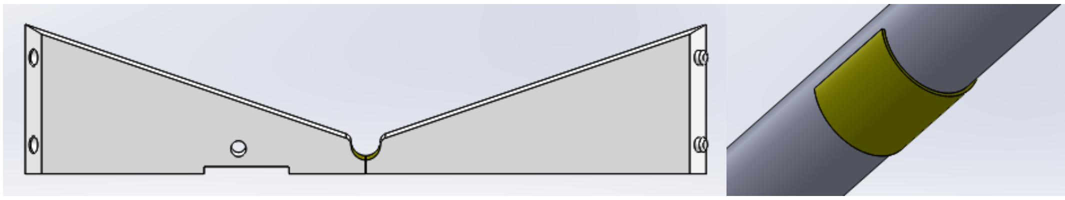


Figure 5: One portion of the sloped arms that will make up the hexagonal hoop with a notch in the middle that will house the copper contact for charging, and one arm of the UAV showing the copper contact that will be applied.

As a safety precaution, a cell balancer was required when charging a LiPo battery. For the charging station this was done via a third party balancer that connected directly to the battery instead of working as part of the battery charger. This increased overall life of the battery as well as prevented it from catching on fire. The station had to ensure that the UAV was properly aligned with the copper contacts and check the status of the battery prior to initiating the charge in order to prevent a fire from occurring. Battery fires can start from electrical arcing or lack of balancing with a bad battery cell. Since the charging station is gravity driven, misalignment is expected to be rare. Additionally, a fireproof bag must be placed around the battery on the UAV to prevent a fire from creating major system loss should a problem occur with the LiPo battery cells during the charging process.

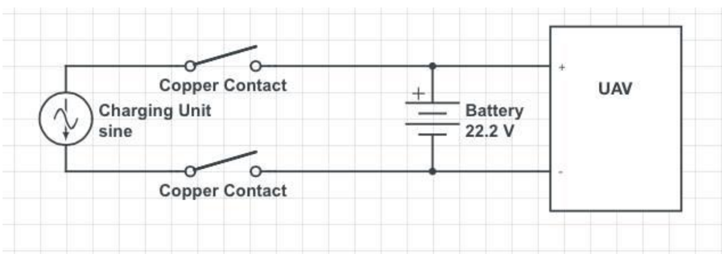


Figure 6: Electrical circuitry between the charging unit, battery and UAV electrical components

The station would only allow the LiPo battery charger to supply power to the battery charging circuit once communication had been achieved. A status light is set to turn from red to green when the UAV connects. The wiring schematic shown in figure 6 charges the battery while keeping the autopilot powered. This meets the critical function of keeping the UAV autopilot on while charging to allow for a continuation of the mission. The splicing was done with a "connection piece" so that the customer can remove the added splice when not operating the UAV with the charger. The autopilot can remain on, but the motors must still turn off when connected to the charger to prevent significant power from being drawn while charging.

The charger is housed in a box below and to the side of the hoop and contact arrangement with wires feeding through the legs of the station. Such an arrangement protects the charger from the weather and maintains space for a package to sit below the UAV during the charging process.

Detailed Design Documentation

Engineering Analysis

Nevada Dynamics analyzed each of the original design concepts to determine which one best meets the design engineering specifications. The final design must effectively recharge the LiPo battery on the UAV, be easy to manufacture, be durable for hazardous weather conditions, and be easy to service and repair. To best meet these objectives, a design made up of inexpensive replaceable parts is required. The modular design of the Hex Hoop fit this category well. It is easy and inexpensive to manufacture, as well as quick and simple to repair and replace any defects. The copper contact surfaces are easy to replace since the Hex Hoop can be assembled and disassembled in parts. The Hex Hoop included ⅝ inch diameter cylindrical copper contacts that transfer power from the charger to the UAV battery. Due to the success of the proof of concept, Nevada Dynamics assumed that the contact surfaces have the ability to adequately transfer up to five amps of current without creating a hot spot. Engineering calculations determined that the surface area of the contact points needed to exceed 0.245 in^2 (Table 3). A minimum wire size of 14 gauge was needed to withstand the maximum supplied current of 5A while charging. Through experimentation, the team determined that no additional force, other than the weight of the UAV, needed to be applied to the contact surface. Since the contact pressure was sufficient, the final design was simplified so that no additional mechanical device, such as a clamp and motor was needed.

Table 3: Required values determined by engineering analysis.

Tabulated Engineeing Analysis Results	Required Value	Designed Value	Satisfy Conditions?
Surface Area Required to Transfer Energy	.245 in^2	.39 in^2	Yes
Wire Thickness	10 gauge	14 gauge	Yes
Input Voltage to Charger	120V	Power Grid	Yes

The design specifications also required that the copper contact surfaces properly align between the station and the UAV frame. The vertical saw-tooth design of the Hex Hoop solved this issue by allowing a large landing tolerance and a gravity induced alignment procedure. The UAV arms land on and slide down the saw-tooth ramps onto the contact area creating the connection. A communication link needed to be established between the UAV and the charging station. The charging station incorporated the use of switches that the UAV arms compress upon landing; these switches notify the charging station that the UAV is docked and ready to be charged.

The ability of Nevada Dynamics to create a fully autonomous UAV charging station that interacted with UAVs and required no human interaction relied heavily on cross disciplinary work with a computer science team. Nevada Dynamics was able to create the charging station and outfit a UAV to be compatible with the charging station, but to achieve true autonomous charging; the computer science group needed to successfully program a communication link.

DFX and Human Factors

Nevada Dynamics created the final design of the Hex Hoop platform because it meets all of the design requirements for manufacturability, testability, versatility, and safety. Most of the components that make up the platform can be 3D printed and fastened together. The others can be purchased at a local hardware store. The design makes testing the electrical resistance in the circuit easy, which reduces the complexity to troubleshoot possible errors. The vertical saw-tooth design of the Hex Hoop allows the station to accommodate a large variety of UAV sizes, and allows for a landing tolerance.

Manufacturability: The parts were printed using Nevada Dynamic's 3D printer which allowed the team to manufacture the majority of the components in house. By taking control of production, including the timeline, Nevada Dynamics ensured that the parts are procured in a timely manner and at a low cost. The raw materials for the necessary printed parts were already purchased and prepared for manufacturing. The team 3D printed the majority of the components in house while the remaining parts were printed by the team's mentor, Andrew Smith. The Hex Hoop supports and each side of the Hex Hoop took over 100 minutes to produce. On a larger scale, a different method of producing the parts, such as injection molding, would be needed to complete the parts in a timely manner.

Testability: The design can be tested in the factory prior to release using a modified hexacopter frame and a multimeter. This eliminates the complexity of using a fully assembled UAV model outfitted to be compatible with the charging station. The modified hexacopter used to test is a bare bones UAV frame with a battery, copper contacts, and similar weight distribution which is perfect for testing the station in the field. A technician will be able to use a multimeter to test the resistance in the copper contacts to ensure that they are suitable for charging the battery on the UAV frame.

Versatility: An important design feature on the Hex Hoop is the vertical saw-tooth shape which allows for the arms to self-align onto the contact points through the use of gravity. This increases the error tolerance when landing in hazardous conditions and eliminates the need for a mechanical alignment device. Another added benefit of the saw-tooth shape of the design is the ability to accommodate a number of similar UAV models without having to modify the size of the charging station. Nevada Dynamics is capable of easily modifying the size of the charging station to fit different UAV platforms by printing smaller or larger parts. The design of the electrical schematic will not need to be changed based on size.

Safety: The charging station begins to initiate charge once landing confirmation is sent to the charger via multiple pressure points on non-charging contact points located on the hoop of the charging station. With the hexacopter frame, the charging station has four available points after the positive and negative terminals occupy two contact points. The pressure switches located on several of these empty contact points prevent false charging from a bird or other potential triggers. The size of the electrical contact surface was designed to minimize the amount of exposed live surface area. For commercial application, the charging station would be housed inside a closed fence to prevent the opportunity for people to accidently get shocked or cut by messing around with the charging station or the UAV.

Manufacturing and Assembly Process

3D printing the Hex Hoop components was the main focus of the manufacturing process. Nevada Dynamics printed a portion of the parts in house using a Solidoodle printer with ABS plastic. The team mentor, Andrew Smith, printed the rest to ensure that the team met the preset deadlines for the final prototype. The station legs and supports were cut from wooden dowels which then secured into the 3D printed leg supports with Gorilla Glue.

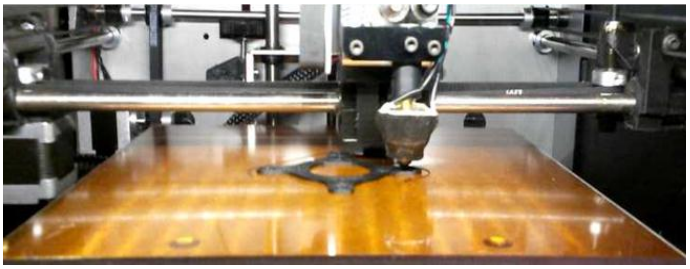


Figure 7: Solidoodle 3D printer used by Nevada Dynamics in the Edgington Engineering garage

The main improvement to the manufacturing process for the final prototype included increasing the accuracy and precision of the copper contacts. The team used the metal roller in the machine shop to create a smooth curved shape. The shape was important because any high spots could have better contact and overheat from increased current flow. Copper tabs were attached to the copper contacts to make soldering easier. After soldering, the copper contacts were fixed to the station in the proper orientation so that the wires could run down the station legs to connect to Molex connectors which then connected to the charger that Nevada Dynamics had purchased. The battery on the UAV was spliced so that upon landing, the positive connected to the positive copper contact directly and the negative connected directly to the negative contact. The LED lights that indicate proper alignment of the UAV were also wired to the two single-pole single-throw switches and were placed in a protective casing on the side.

Figure 8: Manufacturing process of the added components for the UAV to charge

Figure 9: Station Legs being installed to the station leg supports

The last portion of the manufacturing and assembly process involved building the Tarot hexacopter frame which was used to test the charging stations' effectiveness. The first phase included securing a motor and electronic speed controller (ESC) to each of the six arms. Wire extensions were added to the ESCs and were soldered to the frame, which acts as a power distribution board (PDB). A power module, to monitor the current, was wired in between the PDB and the battery. Each ESC also has a UT15 servo wire that plugs into the APM autopilot. All of the wires from the ESCs run through the hollow arms of the frame. A Spektrum receiver was also wired to the APM using the same servo wires. Each wire controls the yaw, roll, pitch, and thrust commands that the DX7i transmitter relays for manual flight testing. A 3DR telemetry unit was attached to the APM and communicated wirelessly to the ground station Mission Planner software. This completed the base hexacopter platform. Six modules were secured under the arms of the frame near the motors to make the hexacopter compatible with the charging station. Two opposing modules held the copper contacts that connected to the station while the rest helped align the UAV.

Cost Analysis and Bill of Materials

The total estimated As-Built cost for the charging station from the fall semester was $2,044.14. This cost included components that are required to test and manufacture the product but would not be included in the final product sold to a customer. Table 4 outlines the updated budget after completing purchasing for the parts. The majority of the additional cost is to outfit the modified UAV frame with the components necessary to fly. The class budget includes the UAV frame that allowed the team to outfit it with the necessary charging components.

Table 4: Nevada Dynamics Budget

Nevada Dynamics Budget		
Project Components		
Item	*Actual*	*As Build*
Proof of Concept Parts	$172.14	$172.14
PowerLab 6 Batery Charger	$179.49	$179.49
Wood Dowels	$6.52	$6.52
Batteries	$50.32	$50.32
Switches/Electrical Components	$19.98	$19.98
Blinky Battery Balancer	$65.80	$65.80
Carbon Fiber Frame	$119.99	$119.99
IR Transmitter/Reciever	$49.95	$49.95
Wire	$20.00	$20.00
Alloy Copper Rolls	$27.62	$27.62
LiPo Battery Guard Bag	$11.13	$11.13
3D Printer Fillaments	$77.97	$77.97
Total Funds Costs		$800.91
Nevada Dynamics Sponsored Materials		
Item	*Actual*	*As Build*
Stepper Shield*		$20.00
Assembled UAV Components		$500.00
Clamps		$34.00
Arduino*		$30.00
Electrical Connectors		$7.00
Glue		$22.14
Wire*		$5.00
Connectors*		$7.00
3D Printer		$650.00
Total Sponsored Costs		$1,275.14
Construction Labor Estimates		
Item	*Hours*	*As Build*
Total Man Hours @ $20/hour	140	$ 2,800.00
Full Project Costs (less Labor)		$2,076.05
Full Project Costs		**$ 4,876.05**

The total fall estimated cost for developing the spring prototype and building the proof of concept that will be funded by the class is $782.14. The total cost excluding the proof of concept for the prototype came to $628.77. When the cost of last semester's proof of concept is added, the estimated total cost for Nevada Dynamics is $800.91, which is nearly spot on the $800 limit (class funds) and within 10% of fall semester's estimated cost. Full project costs for the project came to $4,876.05 which included labor. The primary difference in the cost estimate from the previous budget was glue to assist in assembly, the addition of the Blinky battery balancer, and removal of the two raspberry pi units which became irrelevant with the on board battery balancer. The cost variations gave the team a roughly 3% overall increase in estimated price and was well within the acceptable standards for this project.

Cost considerations impacted the design by demonstrating that 3D printing the parts in house would be more cost effective than ordering custom parts. While this is not the best option for mass production, it does provide the most cost effective solution for prototyping. The required electrical components such as the charger made it difficult to cut costs in all areas because of the firm price with few replacement options (Appendix D). The electrical charger is one of the few chargers that enabled the computer science team to control the charger autonomously without having to open the box and tamper with the internal circuits. Another cost consideration was to use copper instead of silver for the contact points despite the fact that silver has better long term properties.

Proof-of-Concept

The main goal of the Proof of Concept (PoC) was to determine if copper contacts could be used to charge the LiPo battery on the UAV. To accomplish this, the team constructed one of six sides of the final designed station. The PoC was comprised of eleven different parts including a charger, LiPo battery, Arduino UNO, clamp system with a stepper motor, and copper contacts. The Hex Hoop arm simulated the station portion where the UAV lands. The contact points on the UAV arm and the charging station were formed from copper shim stock. The stepper motor combined with the clamps and clamp rod held the UAV arm in place but provided minimal additional contact pressure. The Arduino UNO with the stepper motor shield and battery was used to program the stepper motor. The total cost of the proof of concept was $172.14 and the cost breakdown of the charging station can be found in Appendix H.

During testing, the team checked for numerous faults that would lead to inefficiencies and failures in the final design. The main failure concern was the inability to charge the battery. To test if the contact points would be capable of charging the battery, the complete charging loop for the battery was constructed with a contact point between the charger and the battery. Some of the other failures that the team looked for included insufficient amperage to the battery, effectiveness of the stepper motor, and burn marks at the contact point. The complete list of test specifications is included in Appendix H. Throughout the testing process, the amperage going to and from the battery was at a max. There were no burn marks or heat produced at the contact point; this led to the conclusion that the connections used in the PoC were sufficient and could be implemented in the final design. The stepper motor was completely ineffective in supplying additional pressure to the contact area which caused the team to remove the motor from the final design. This saved the team time programming the motors, decreased the mechanical and electrical complexity of the system, and saved money since the motors are relatively expensive compared to the rest of the station. Fortunately, all other concerns were either minimal to the extent that they had no effect on the charging process or worked without error.

The PoC eased many fears about the effectiveness of the final charging station. The contact points worked without fault which is why they remained in the final design. Special effort was put toward making sure the contacts points were free of defects for the final design. The team decided to use switches on two points on the hoop to ensure alignment of the UAV prior to charging since the motors were no longer considered to hold the UAV in place.

Laboratory Test Plans and Results

To verify that the final prototype met all of the engineering specifications, testing the charging stations capabilities was done in three stages. For the first phase, the hexacopter was manually placed on the charging station to test the connection of the electrical circuit and verify the dimensions of the Hex Hoop. Upon placing the UAV on the station, the landing lights changed from red to green and the battery charger was able to detect and begin charging the LiPo battery. Both of these results showed that the charging station was able to align the UAV properly and charge the LiPo battery without issue. The stand-alone battery balancing unit connected directly to the battery of the UAV also displayed the proper light arrangement that corresponded with active balancing of the LiPo battery cells. This fulfilled the engineering specification that the battery be balance charged by maintaining the same voltage and current across each cell to prevent battery fires. Additionally, the fact that the UAV was able to be placed on the station with the extended legs proved that a 16”x16”x12” packaged could be accounted for. The results of the final prototype testing comparing the abilities of the station to the engineering qualitative and quantitative specifications are listed in table 5.

Table 5: Final prototype testing results separated by qualitative and quantitative testing parameters

Qualitative Testing		
	Specification or Objective	Testing Result
1	Charger supports a 6S, 5000mAh, 22.2V battery	Success
2	Station supports package size of 16"x16"x12"	Success
3	Easily able to change orientation of contact points	Success
4	Charger communication with battery	Success
5	Autopilot remains on	Success
Quantitative Specifications		
	Specification or Objective	Testing Result
1	Max charging time of 1.5 hours	Average charging time of 1.16 hours

Figure 10: Testing the landing capabilities by manually landing hexacopter on the station

The second phase of testing incorporated hand launching the UAV and manually landing it on the charging station using the remote control. The UAV was then allowed to charge and then takeoff. This stage of testing was performed in the Applied Research Facility (ARF) High Bay on the University of Nevada, Reno campus. Because of current regulations on UAV usage, the team could only fly the UAV indoors for testing. This test was performed to determine if the autopilot would remain on while the battery was charging. The results of the test proved that the autopilot control on the UAV remained fully functional during the charging process because the remote never lost connection with the UAV. This is important because if the autopilot did not remain on, the UAV would not be able to complete its course after landing on the charging station.

Figure 11: Draining the battery of the UAV prior to testing how rapidly the battery could be effectively charged

The last phase of testing was created to test how quickly the LiPo battery could charge when connected to the charging station's copper contacts. The UAV was manually placed on the charging station with its battery drained to the point that it would not be able to carry a package anymore (22.9V). The results of the test showed that the charging unit was able to charge the battery from 22.9V to 25.2V at a current of 2.17A which took 69 minutes and 56 seconds. This meets the engineering specification of charging the UAV in 1.5 hours, though the team would have liked the charging time to have been less. The time to charge was not affected by the resistance created by the copper contacts but rather by the trickle charge function on the charger. Since the LiPo battery was not fully drained, the battery charger charged at a lower current to aid the balance charger in regulating the cells.

Figure 12: Final charging results showing well under the 1.5 hour maximum

Alternatives Considered

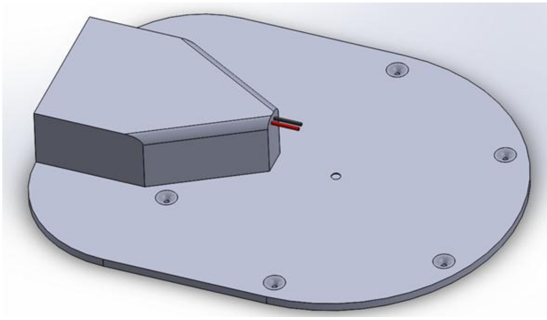


Figure 13: First alternative considered with the extruding pins

The team briefly considered two other design options for the final charging station; however, each had distinct disadvantages compared to the hoop and contact design that was finally chosen. The initial charging station design featured a landing platform that the legs of the UAV rested on while two pins extruded from the charging box to charge the battery (Fig. 13). This design had the advantage of having the entire charging system located on the charging platform which meant that no additional parts had to be added to the UAV; however, it required an impossibly high degree of accuracy in the landing procedure and placed too many limitation on the size of the package carried.

The hoop and tether charging station design was very similar to the hoop and contact charging station in that it used the hoop support and housed the charger in a separate portion of the station (Fig. 14). These both contributed to creating ample room for a package, which is why they were implemented in the final design. This hoop and tether station required that the UAV carry a heavy motor with a spool of wire on board so that a plug could be lowered once the UAV had landed on the hoop support. The funnel would catch the wire and guide it to connect with the station, but there was also a likely chance that the package would interfere with the wire and cause a misfire.

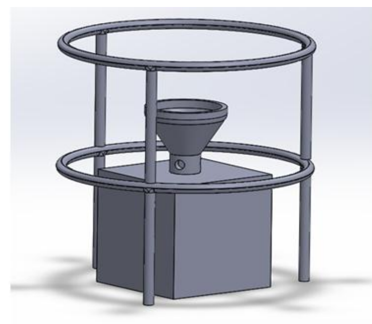


Figure 14: Second alternative considered

Though the hoop and contact charging station requires that copper contacts be added to the underside of two of the vehicle's arms, they are a fraction of the weight of a motor and wire spool. The hoop and contact design also counteracts the issues of inconsistent package size by moving the charging connection away from the package area. Lastly the hoop and contact design would decrease the time required to charge the battery because there are no mechanisms to lower or raise the UAV.

Ethical and Safety Concerns with Relevant Standards

As with any battery charging system, there are safety concerns and standards associated the Nevada Dynamics' final hoop and contact charging station. A full risk assessment was initially performed concerning the manufacturing, assembly, and usage of the station that revealed issues that were quickly combatted. Table 6 shows the top three concerns that arose out of the risk assessment along with the solution that was created to either prevent or contain the issue.

Table 6: Key possible failures and how the hoop and contact charging station prevents them.

Design Failure Mode Analysis		
Failure Mode	**Effects of Failure**	**Preventive Solution**
Fire	System Loss	Lipo bag, balanced charger, maintenance
Battery Swelling	System Damage	Acceptable without review
Damaged Components	System Damage	Sensors to indicate proper alignment of UAV

From the manufacturing and assembly portion of the design, there is the concern of personal injury resulting from human interaction with the high voltage supplied by the charging station. Personal injury could result from arcing due to improper copper contact connection or from a misconnection during the manufacturing process. Inputting switches into the station to ensure that there is only power being supplied when a UAV is properly aligned. At the very least, proper training and warning signs will be required in areas where humans might come into contact with the charging station.

Though personal injury may occur, it has a very low occurrence rate compared to the rate at which Lipo batteries fail. Many UAVs use LiPo batteries because of their light weight; however, they have the possibility of creating a fire if they are damaged or charged improperly. Because of this, ASTM has created standard F3005-14a which outlines that LiPo batteries used on UAVs must be balance charged to prevent battery failures [4]. A flame resistant enclosure is also required during the charging process in case of a battery failure during the charging process. The standard is a requirement if the UAV owner wants to fly in any nation's approved airspace. The team designed around these concerns and the standard by requiring the battery to be placed in a fireproof LiPo bag while at the charging station to contain the fire should one occur. Additionally, a balancer plugs directly into the battery to regulate the status of the cells during the charge. This ensures that the cells only receive power when it is required which will help prevent a fire from occurring. Each of these safety concerns was carefully considered by the team to ensure that the best solution was implemented.

Timeline and Team Management

A timeline was created to divide the project into manageable components and ensure that each assignment was completed on time (Fig. 15). Nevada Dynamics set a goal to have a preliminary draft of assignments done at least three days prior to the due date to allow time for review. During the fall and spring semesters, the team was successful in meeting the required deadlines and attributes this success to allocating extra time before the deadline. The timeline of the required tasks includes all major assignment due dates and build time estimates. To stay on track for building the final prototype, the team broke down the building process into. The timeline below shows when each component was started. During the first semester, the Nevada Dynamics CS and ME teams communicated much more frequently about each other's projects. However, after the spring semester started, it was apparent that there was much less overlap than was originally anticipated. The main aspect the computer science team brought to the Spatial Delivery project was consulting on various components that would aid in communication or safe and effective charging.

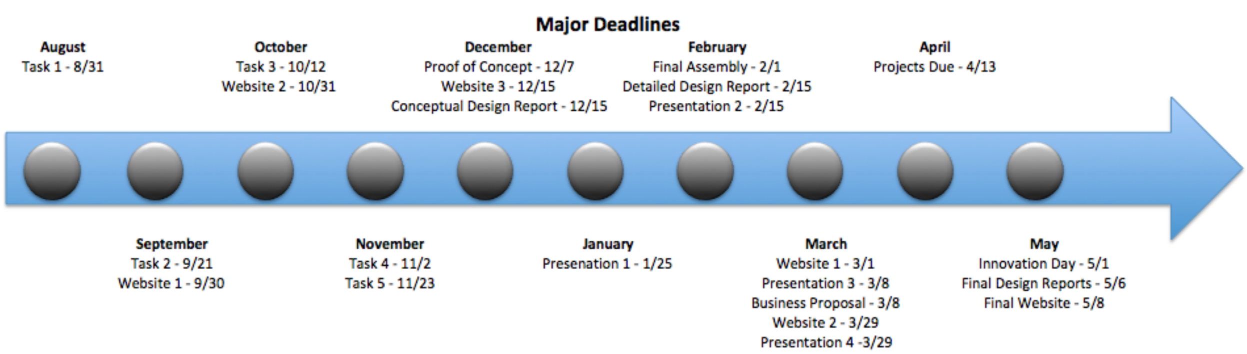


Figure 15: Layout of major deadlines from the past year

Table 7: Gantt Chart showing when tasks were completed throughout the year

The team was managed by dividing up the workload among the five members. At the end of each meeting, the team would go over the required action items before the next meeting and assign one member or multiple members to each action item. Although Nevada Dynamics did not initially lay out specific roles for each team member, as the term progressed, specific team members were continually assigned tasks that best fit their skills. The developed responsibilities of each team member are as follows:

Evan Autry: Designated procurement supervisor in charge of managing part orders, lead website developer, format editor for the design reports, and builder for the final prototype.

Erik Edgington: Budgetary manager, liaison to the computer science team, 3D printer production manager, and builder for the final prototype.

Daniel Ferguson: Designated lead designer in charge of all design components and 3D models, and UAV specialist in charge of flight tests with the final prototype.

Harrison Gray: Team leader in charge of organizing and leading team meetings, managing team members, submitting assignments, taking and writing meeting minutes, and building the final prototype.

Amanda Nelson: Member in charge of laying out the barebones design reports, poster designer, was not present for any aspect of the manufacturing or testing.

Conclusion

After careful engineering analysis, Nevada Dynamics choose the Hex Hoop UAV charging station for the final design of Spatial Delivery. The Hex Hoop charging station effectively incorporates all of the desired design objectives by balance charging the LiPo battery of the UAV carrying a package. The modular design of the Hex Hoop allows the station to be quickly repaired by replacing any damaged components with new ones. The design can accommodate various UAV sizes and shapes because of the way in which the charging occurs. The battery does not need to be accessed during charging and can be placed inside the UAV to protect it during flight. The drawback of the design comes with outfitting the UAV to be compatible with the station. In order for a UAV to use the charging station, it needs to be equipped with the copper contacts on the arms. Nevada Dynamics attempted to keep this as simple and inexpensive as possible. The copper contacts are an elegant way to safely and effectively charge any size battery that a UAV uses. The proof of concept proved that contact charging is a viable option for the charging process, and the final prototype testing proved that they even worked on a large scale effectively.

Nevada Dynamics' charging station could be improved by implementing higher quality 3D printed parts and machined components or by injection molding the parts to save on manufacturing time. The team would employ outside help in manufacturing the parts and use higher quality materials if more resources in the form of time and funding were available; however, the limited amount of resources that the team required for the final prototype can be seen as a positive aspect for the design. This required Nevada Dynamics to use the available resources as efficiently as possible and pack large value in the product design while keeping a reasonable price. Looking to the future, Nevada Dynamics would have to have an electrical engineer fully analyze the circuits in the charging station in order to present an ethical product to the public.

Acknowledgments

Nevada Dynamics has been able to complete the Spatial Delivery UAV charging station final prototype thanks to the advice and equipment provided by the following individuals and groups.
Andrew Smith
Dr. Emil J. Geiger
Dr. Eric Wang
Tony Berendsen
The Engineering Design Lab
The Mechanical Engineering machine shop

References

[1] Skycatch, Inc. (2014). *SKYCATCH* [Online]. Available: http://skycatch.com/
[2] Skysense Inc. (2014). *SKYSENSE* [Online]. Available: http://skysense.de/
[3] Bureau of Reclamation, "Electrical Connections for Power Circuits," US Department of the Interior, 1991, Vol 3.3.
[4] ASTM Compass (2015). F3005-14a Standard Specification for Batteries for Use in Small Unmanned Aircraft Systems (sUAS) [Online].
Available: http://0-compass.astm.org.innopac.library.unr.edu/EDIT/html_annot.cgi?F3005+14a.

Appendix A
Letter of Support

Dear Nevada Dynamics,

The Computer Science Team for Nevada Dynamics is excited to begin collaboration with the Mechanical Engineering Team. We intend to assist you with any programming to the best of our ability. We are confident that our skills will improve your project greatly.

Best Regards,

MacCallister Higgins

Nevada Dynamics

Computer Science Team Leader

Appendix B
Product Design Specifications

Product Design Specification: Nevada Dynamics UAV Charging Station

Product Identification

- UAV charging station that automatically charges a UAV system.
- Charging station will accommodate a package
- Contact points between the charging station and the UAV battery will allow for adaptability of the charging system to multiple UAV body designs

Key Performance Targets

- Able to charge up to a 6S, 5000mAh, 22.2 Volt battery in 1.5 hours.
- Able to accommodate a UAV of varying size from 24” to 48” wingspan
- Able to accommodate a package size of 12”x12”x8”
- Powered by a connection to the existing electrical grid
- Maximum added weight to UAV for charging station is 12 ounces

User Training Required: Autonomous except during service or repair

Service Environment:

- Outdoor: ~15 to 100°F
- Up to 100% humidity

Key Project Deadlines

- Four months to finalize design
- Four to five months to build
- Target advertising for Innovation Day

Physical Description

- Dimensions
    - 24” wide x24” deep x 18”tall
    - Control box located in a separate housing
- Material: To be determined (TBD)
- Weight Target: easily mobile by a single person

Manufacturing Specifications

- All framing will be printed with a Solidoodle 3D printer in house
- Suppliers: Various online resources such as McMaster-Carr, eBay, etc.

Market Identification

- Target market for this product will be mailing delivery companies or any other company that may require long range or extended use UAVs
- Initial Launch: May 1, 2014
- Initial Production: one unit for Innovation Day
- Competing products
    - Current products have a very mechanically complex design with multiple venues for mechanical failure
    - No products accommodate packages
- Brand Name: Nevada Dynamics

Financial Requirements

- Target manufacturing cost: $250
- Estimated Retail Price: $750
- Warranty Policy: N/A
- Expected financial performance or rate of return on investment: N/A
- Level of capital investment required: TBD

Life Cycle Targets:

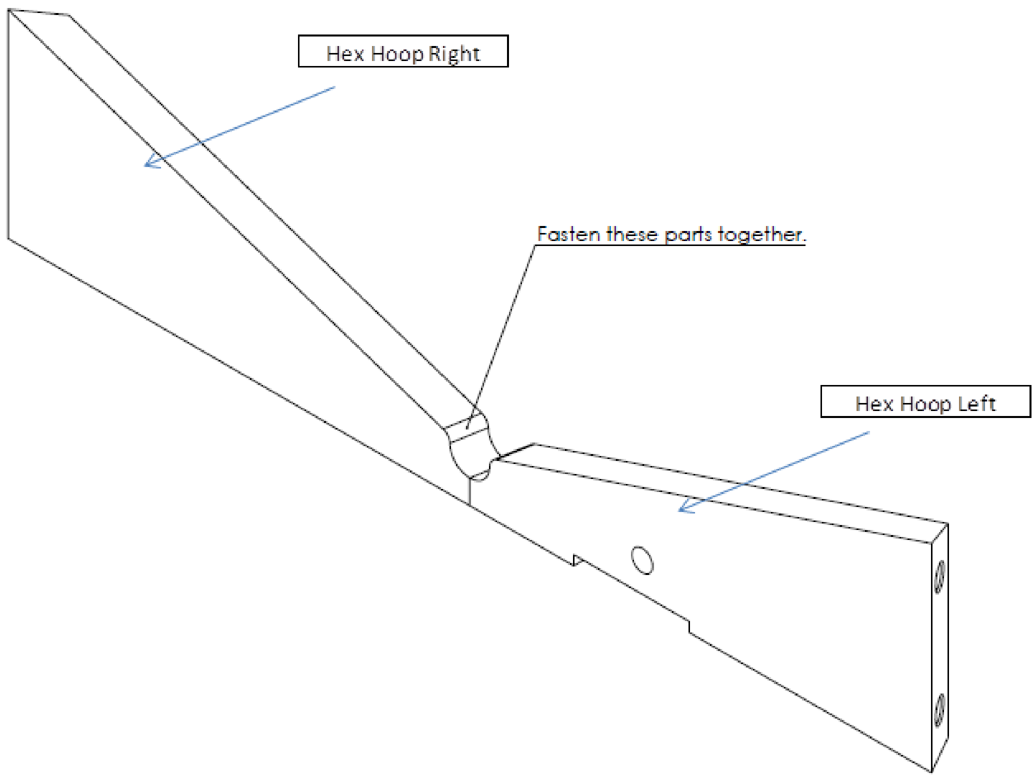
- Useful life 5 years and beyond
- Maintenance schedule: Every two months to maintain copper connection integrity
- Reliability: 5 years mean time to failure
- End of life strategy: Nevada Dynamics charging station will be recyclable with batteries requiring

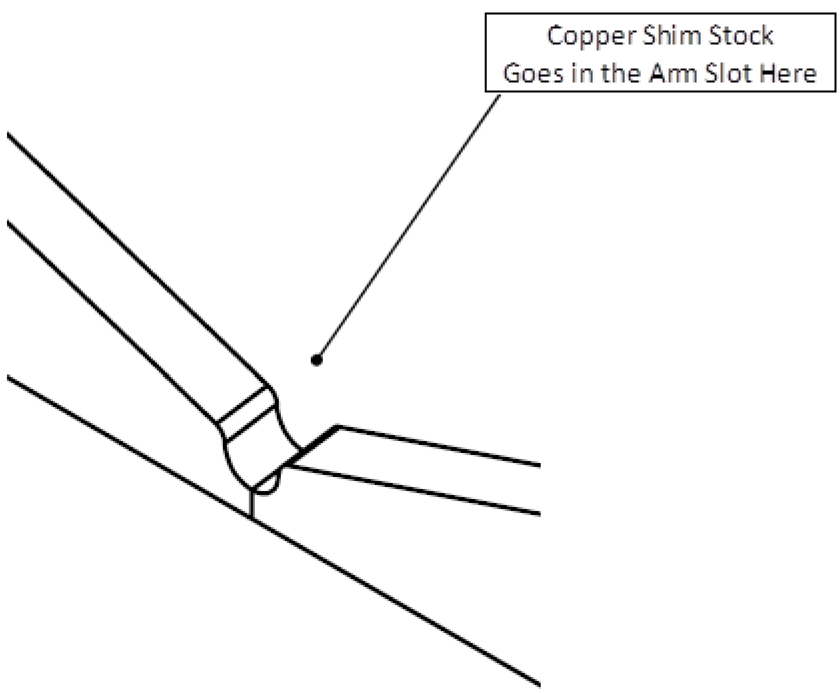
special disposal/handling

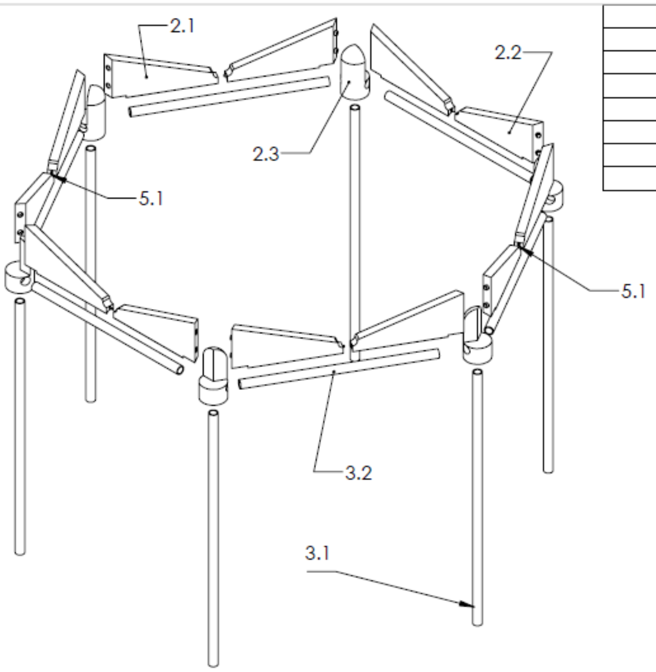
Social, Political, and Legal Requirements

- Safety and environment regulations will be followed
- Standards: Research federal regulations on autonomous battery operated systems
- Safety and product liability: the only safety aspects of the charging station is the unlikely potential of contact arcing or battery wear, both of which are minimized by the maintenance schedule
- Intellectual property: Will investigate patent potential

Appendix C
As-Built Assembly Models


Hex Hoop Right
Fasten these parts together.
Hex Hoop Left


Copper Shim Stock
Goes in the Arm Slot Here



Item No.	Part Number	Qty
1	Corner_Assembly	6
2.1	Hex_Hoop Left	6
2.2	Hex_Hoop Right	6
2.3	Legg_Support	6
3.1	Station Leg	6
3.2	Station Support	6
5.1	Copper Contact	2

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
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ANGULAR: MACH± BEND ±
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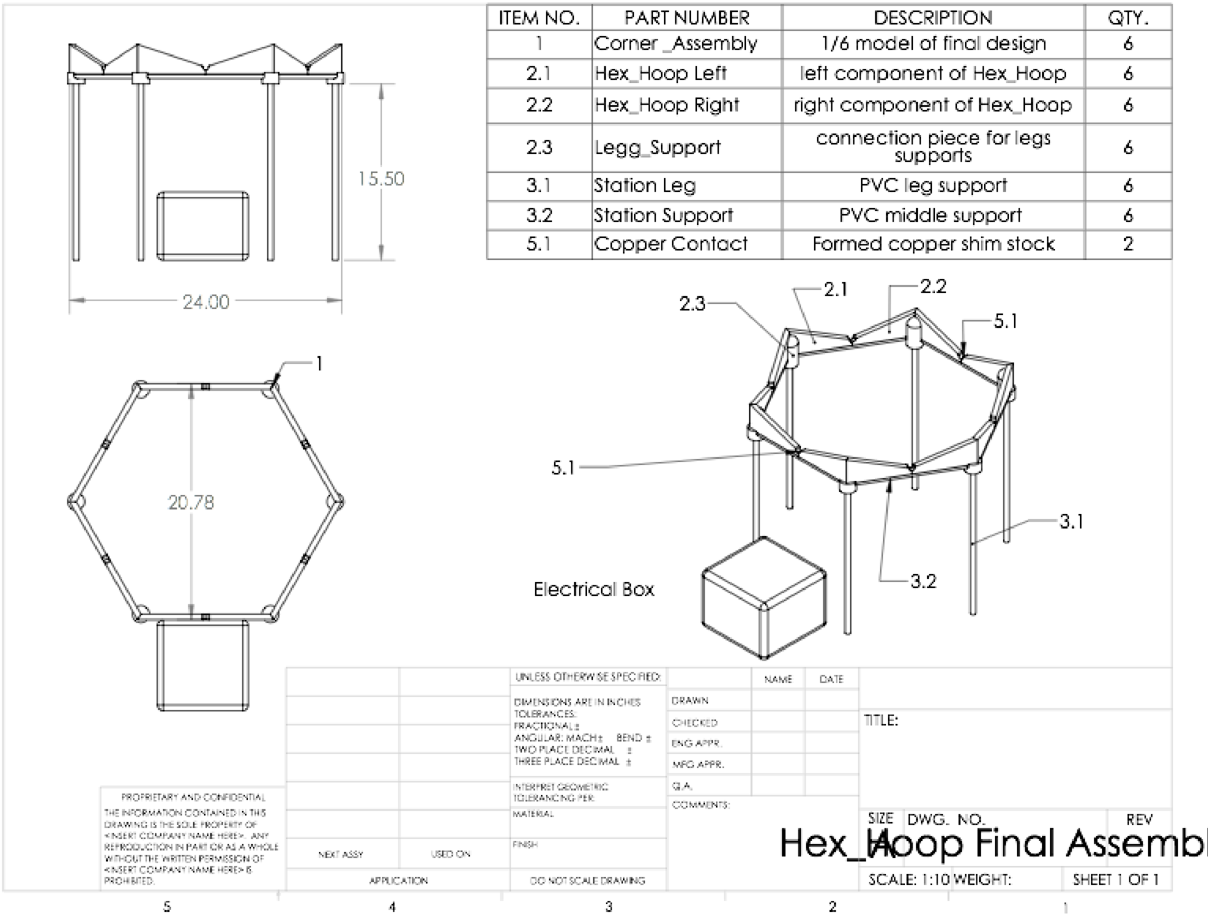
Appendix D
As-Built Bill of Materials

Bill of Materials

Nevada Dynamics

Purpose	Item #	Part Name	Quantity	Supplier	Part #	Part Cost	Shipping Cost	Total	Status
Station Build	1	PowerLab 6 Battery Charger	1	Amazon	B00CDA1ZKY	$174.99	$0.00	$174.99	Received
	2	3D Printer Filament - ABS Plastic	3	eBay	390853090209	$25.99	$0.00	$77.97	Received
	2.1	Hexhoop Left	6	Nevada Dynamics	2.1	$0.00	$0.00	$0.00	Manfucactured
	2.2	Hexhoop Right	6	Nevada Dynamics	2.2	$0.00	$0.00	$0.00	Manfucactured
	2.3	Leg Support	6	Nevada Dynamics	2.3	$0.00	$0.00	$0.00	Manfucactured
	3	Hardwood Dowel - .5" x 48"	4	Home Depot	12-4EDC	$1.63	$0.00	$6.52	Received
	3.1	Station Leg - 16"	6	Nevada Dynamics	3.1	$0.00	$0.00	$0.00	Manfucactured
	3.2	Station Support Beam - 12"	6	Nevada Dynamics	3.2	$0.00	$0.00	$0.00	Manfucactured
	4	Stranded Wire—300V AC	1	McMaster Carr	8054T17	$11.87	$0.00	$11.87	Received
	5	Alloy 110 Copper Rolls	1	McMaster Carr	9014K47	$27.62	$0.00	$27.62	Received
	5.1	Copper Contact	2	Nevada Dynamics	5.1	$0.00	$0.00	$0.00	Manfucactured
	6	Lipo Battery Guard Bag	1	Amazon	B007V9MN44	$11.13	$0.00	$11.13	Received
	7	Pololu IR Beacon Transceiver Pair	1	Pololu Robotics and Electrinics	702	$49.95	$0.00	$49.95	Received
	8	XT-60 Electical Connectors	1	eBay	B00D842CQA	$19.98	$0.00	$19.98	Received
Testing UAV	9	Tarot 680PRO HexaCopter Folding Frame	1	Hobby King	297000036-0	$119.99	$0.00	$119.99	Received
	10	Turnigy 5000mAh 6S 20C Lipo Pack	1	Hobby King	T5000.6S.20	$50.32	$0.00	$50.32	Received
	11	Blinky Battery Balancer	1	Tower Hobbies	LXMRZ9	$65.80	$0.00	$65.80	Received
							Total Cost:	$616.14	

Appendix E
As-Built Drawings for Fabricated Components



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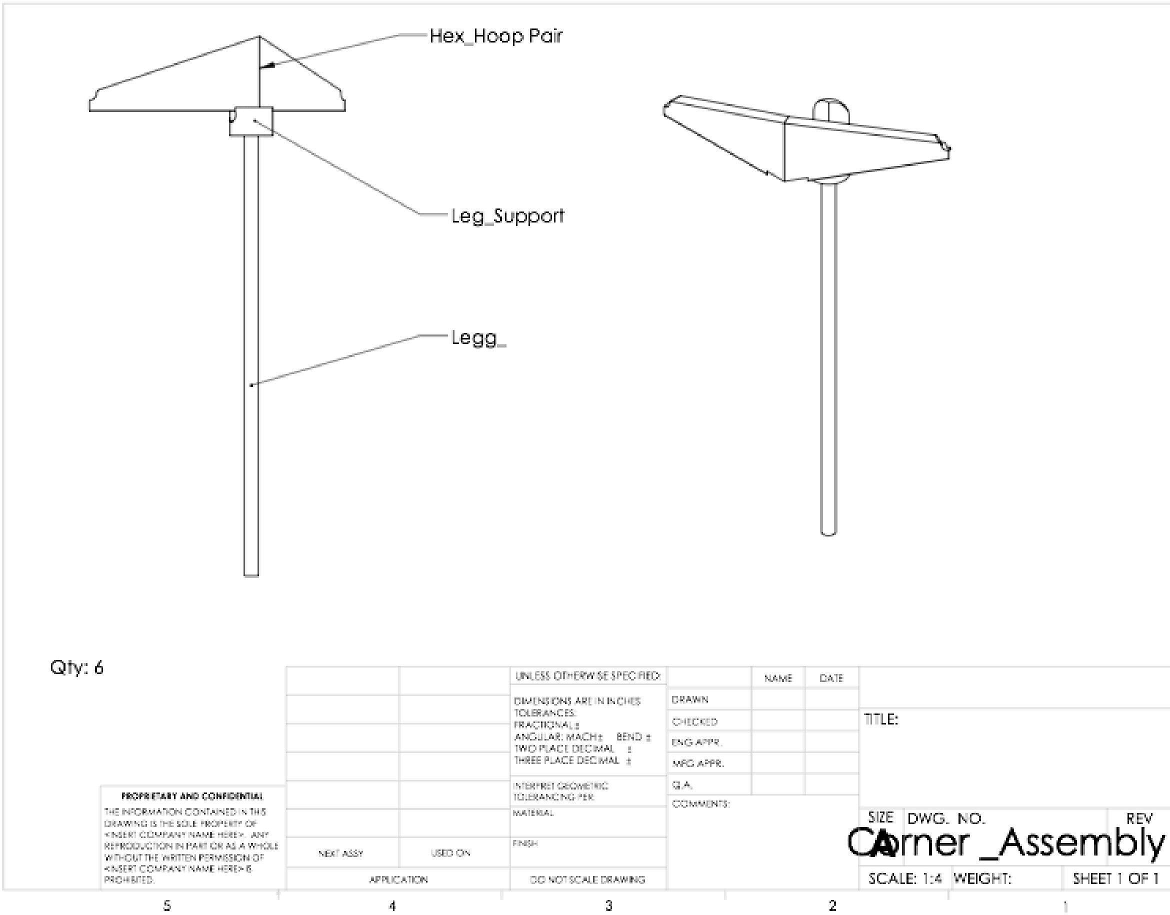
1	Corner _Assembly	1/6 model of final design	6
2.1	Hex_Hoop Left	left component of Hex_Hoop	6
2.2	Hex_Hoop Right	right component of Hex_Hoop	6
2.3	Legg_Support	connection piece for legs supports	6
3.1	Station Leg	PVC leg support	6
3.2	Station Support	PVC middle support	6
5.1	Copper Contact	Formed copper shim stock	2



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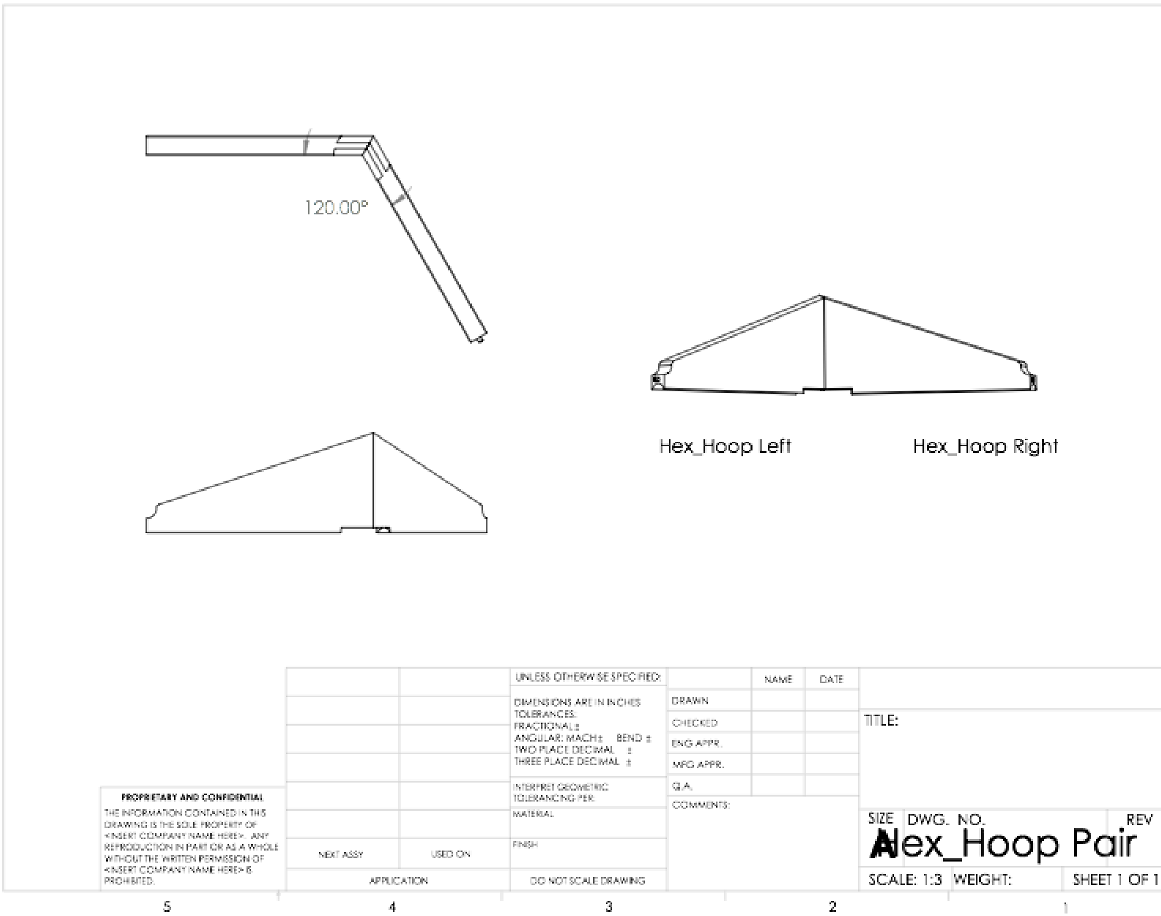
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Hex_Hoop Left
Hex_Hoop Right
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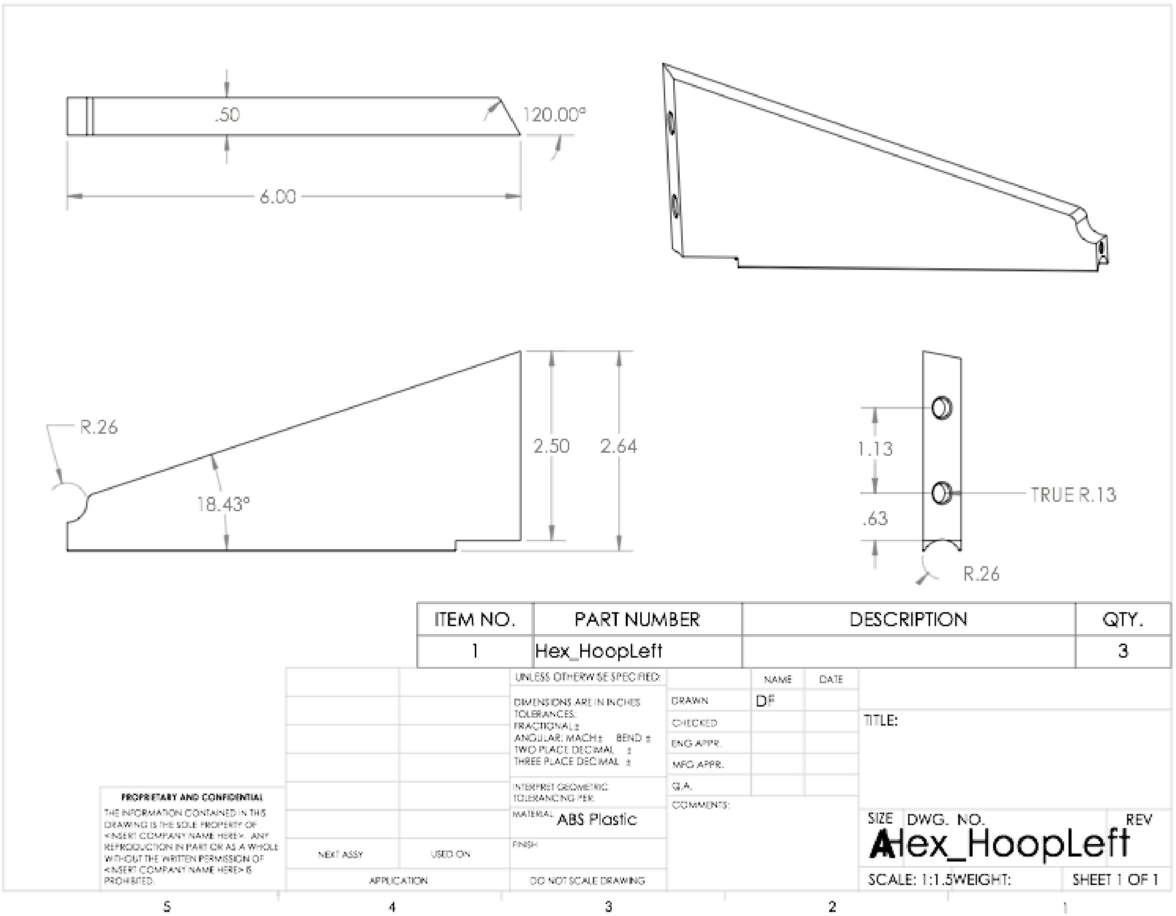
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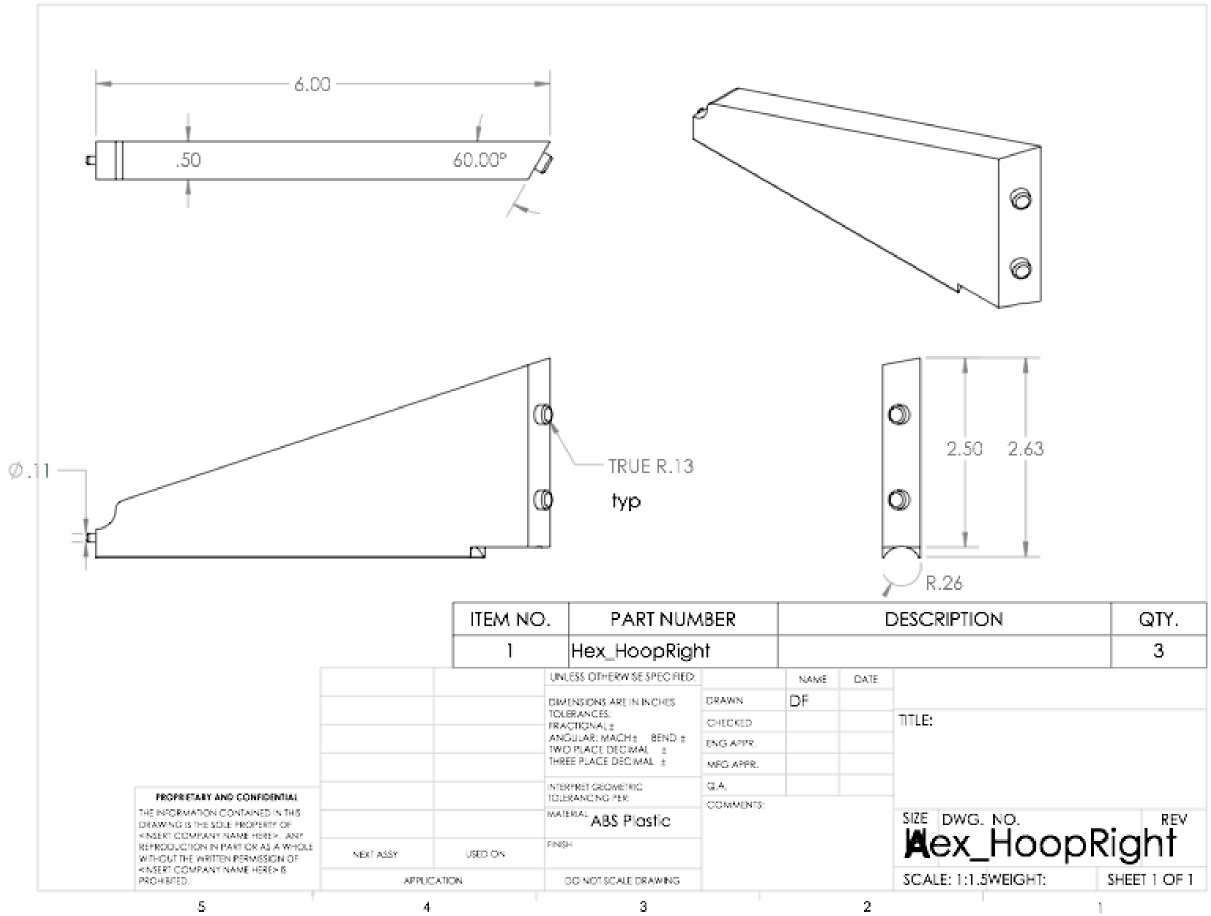
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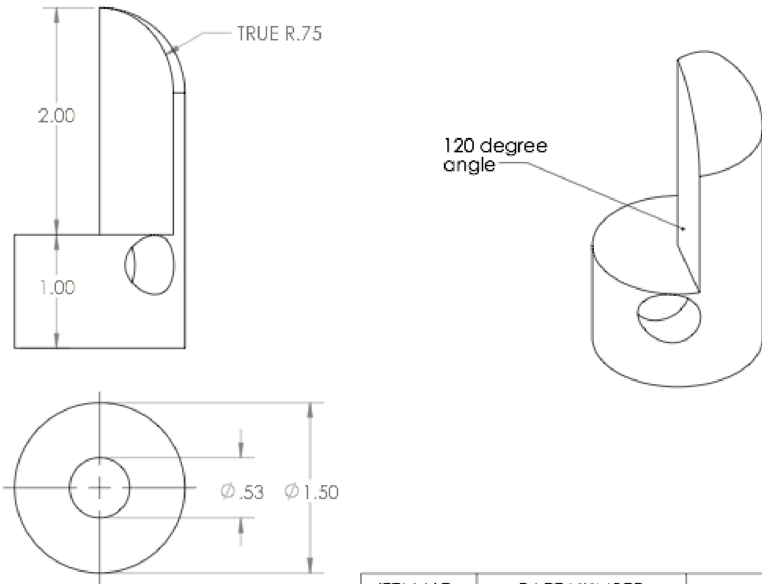

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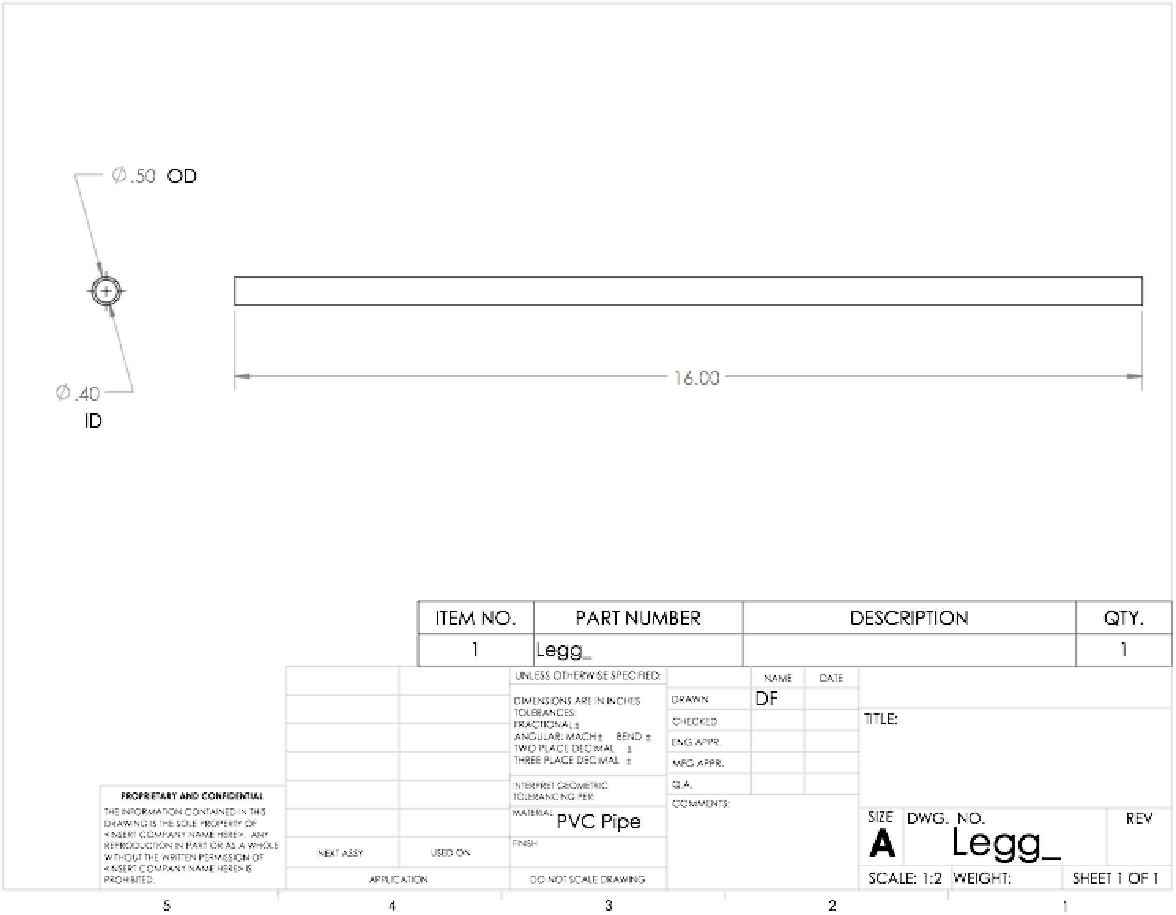

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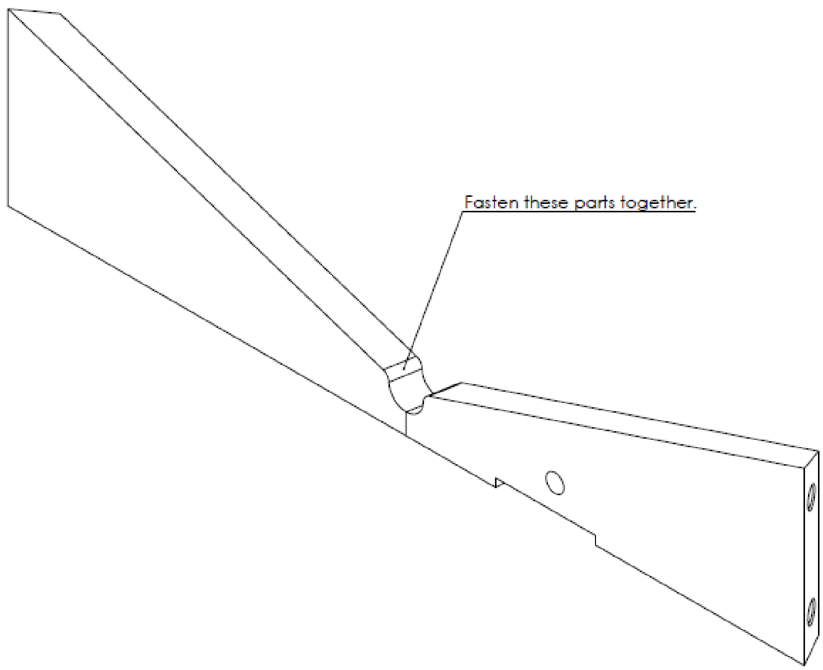
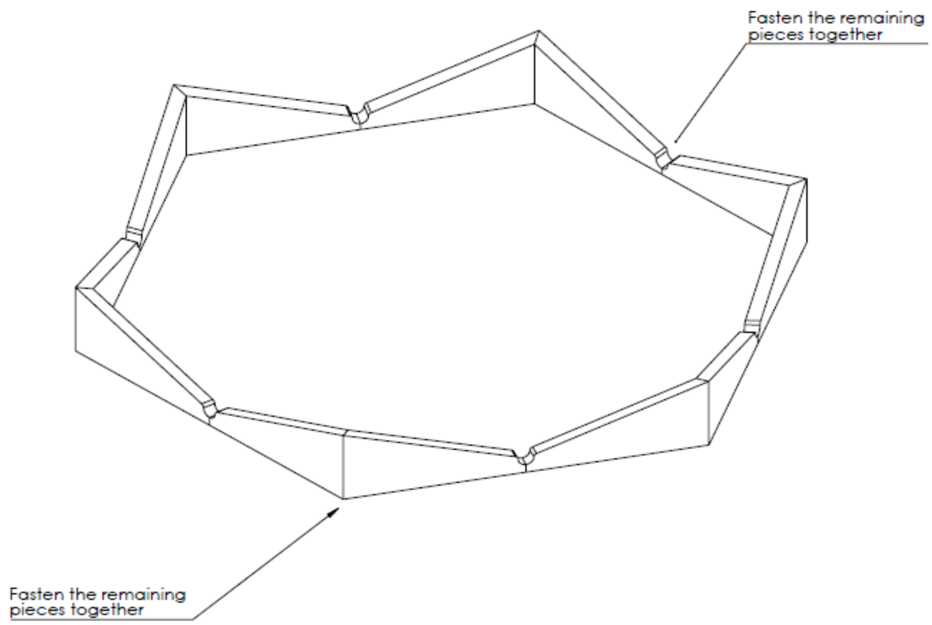
Appendix F

As-Built Manufacturing and Assembly Instructions

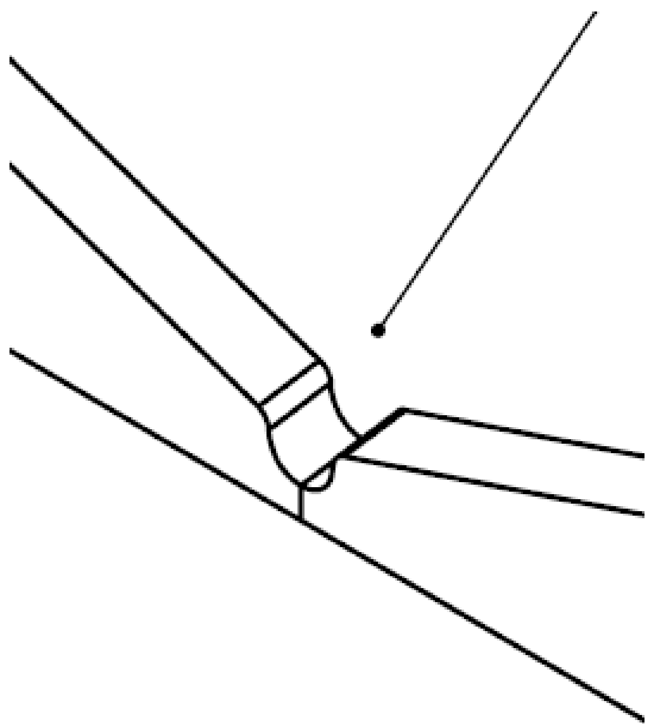
1. 3-D print six right Hex Hoop and six left Hex Hoop pieces
2. Purchase legs, leg supports, and copper shim stock
3. Fasten the left Hex Hoop to the right Hex Hoop (x6)



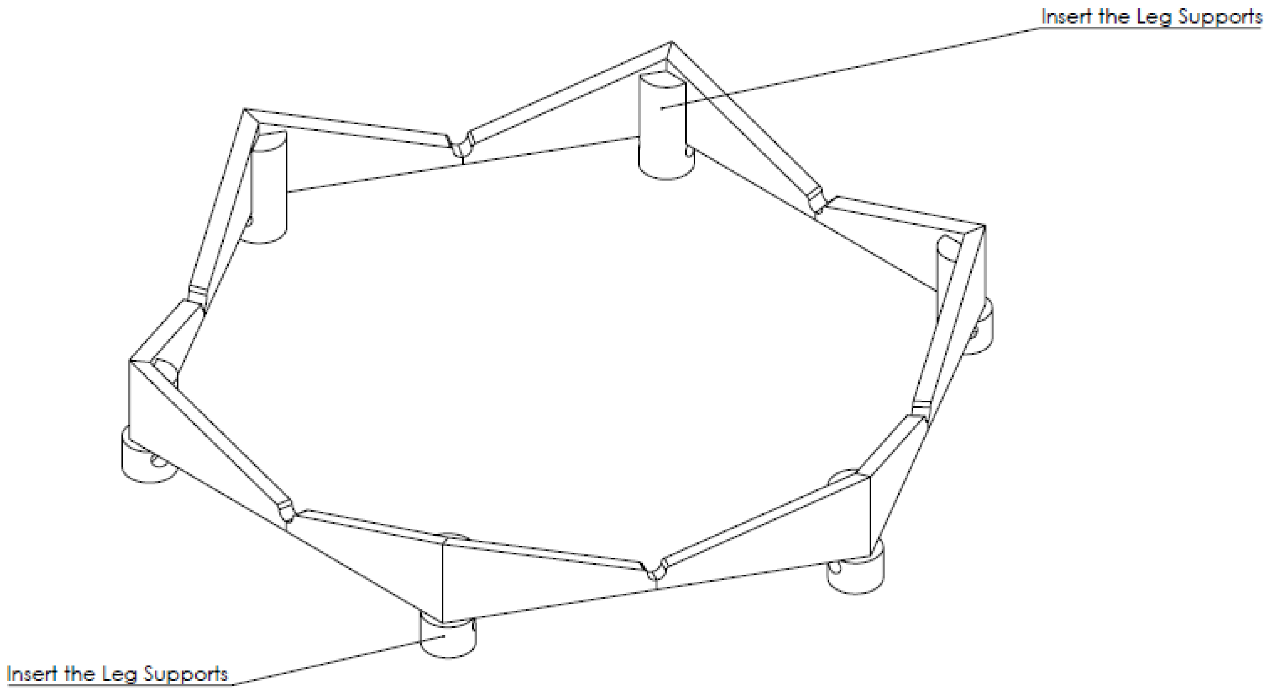
4. Fasten the six Hex Hoop assemblies together so the form a hexagon



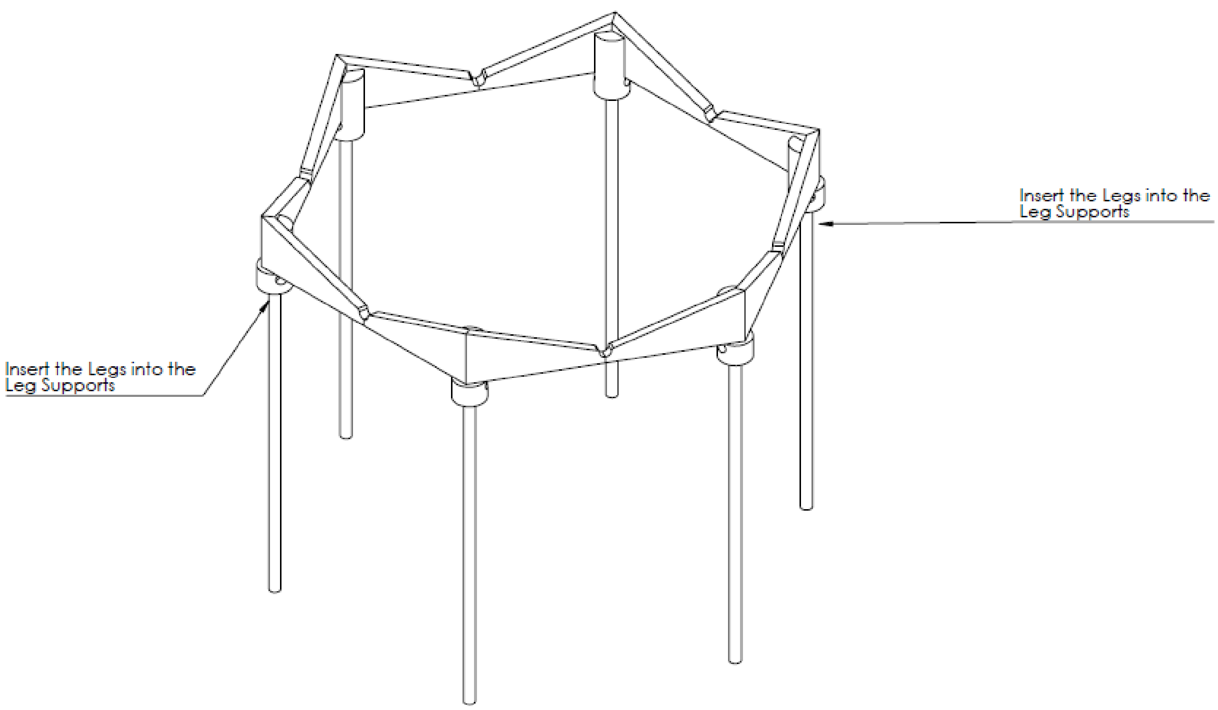
5. Attach copper shim stock to two opposite arm slots



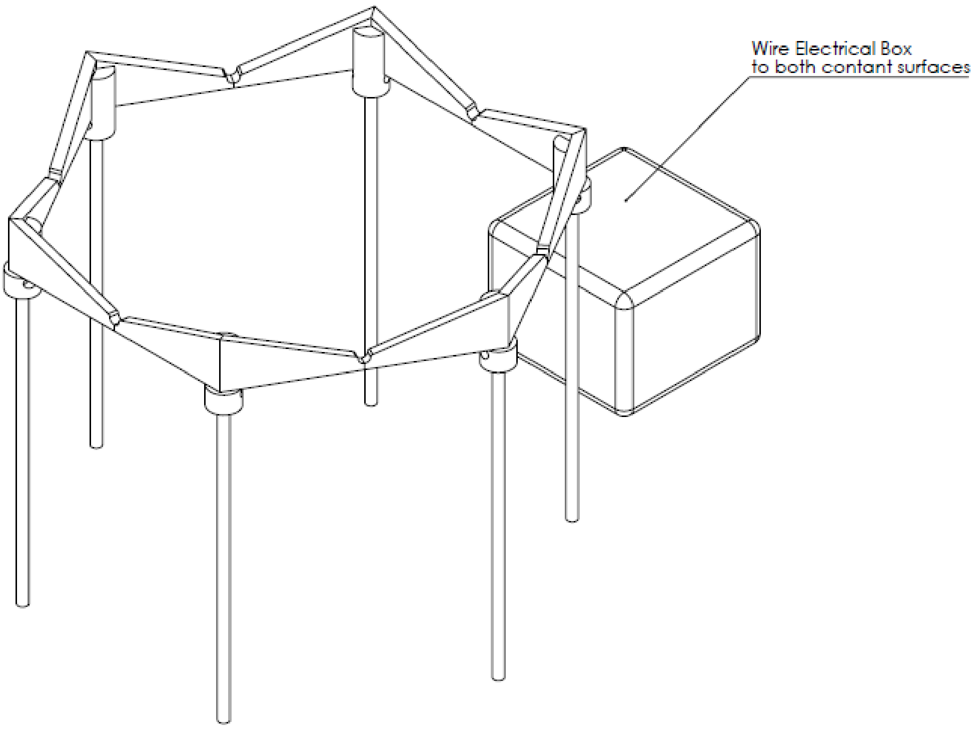
6. Attach the one leg support to each inside corner of the hexagonal hoop



7. Insert one wooden dowel into each leg support



8. Wire charger in electrical box to each contact surface


Wire Electrical Box
to both contant surfaces

Appendix G

Detailed Computations and FEA

Engineering Analysis for Preliminary Design Report

<u>Surface Area Required to Transfer Energy</u>

Copper was determined to be the most feasible conduction material by comparing the difference in price to silver. A solid connection is needed to prevent burning out the contacts from inadequate energy transfer. The amount of surface area required was determined by examining the pin that connects the charging line to the charger.

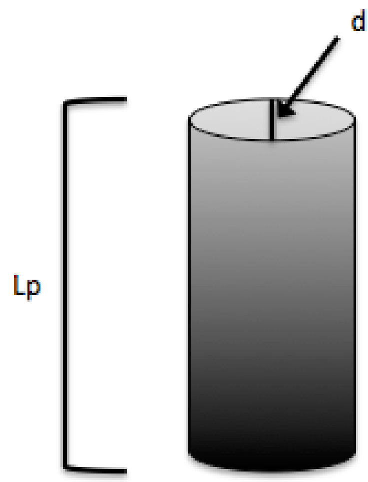


Figure 1: Diagram of Charging Pin

$$SA = Lp(\pi)d = (.5)(\pi)(\tfrac{5}{32}) = .245\ in^2 \qquad (1)$$

SA – Surface Area
Lp – length of pin
d – diameter of pin

$$SA_{bs} = \tfrac{1}{2}(\pi)(da)(w) = (\tfrac{1}{2})(\pi)(\tfrac{1}{2})(\tfrac{1}{2}) = .39\ in^2 \qquad (2)$$

SA_{bs} – Surface Area between contacts on Base station
da - diameter of UAV arm
w – width of base station contact point

From Equation 1, the surface area between the charging line and the charger was found to be .245 in^2. Equation 2 calculated that the surface area between the base station and the UAV is .39 in^2. The surface area will be large enough to successfully transfer energy between the charging station and the UAV.

Wire Thickness

The appropriate wire thickness needed to transfer energy throughout the charging station was initially matched to the wire thickness found on the batter to be, 10 gauge. After further analysis, the team determined that 10 gauge wire would not be needed because that size is only required for discharging the battery (during flight conditions). The charger would only push a maximum of 5A. From research, a table was found that relates wire thickness to the maximum amount of current that can be passed through. The new required conductor to connect the charging station to the battery will be designed to 14 gauge.

Conductor Size for 3% Drop in Voltage

Current (Amps)	Round-Trip Length of Conductor (Feet) / Minimum Wire Size (AWG): 10	20	30	40	60	80	100	120	140
1	16	16	16	16	16	14	14	14	12
2	16	16	16	14	14	12	10	10	8
5	16	14	12	10	10	8	6	6	6
10	14	10	10	8	6	6	4	4	2
15	12	10	8	6	6	4	2	2	1
20	10	8	6	6	4	2	2	1	0
25	10	6	6	4	2	2	1	0	2/0
30	10	6	4	4	2	1	0	2/0	3/0
40	8	6	4	2	1	0	2/0	3/0	4/0
50	6	4	2	2	0	2/0	3/0	4/0	
60	6	4	2	1	2/0	3/0	4/0		
70	6	2	1	0	3/0	4/0			
80	6	2	1	0	3/0	4/0			
90	4	2	0	2/0	4/0				
100	4	2	0	2/0	4/0				

Figure 2: Conductor size from online resource [1]

Power Input Requirement

The charger that will be fitted in the charging station specified the power input requirements. A range of options for power input were examined however, for initial charging stations, power will be run from the grid. This satisfies the charger requirements.

FEA Analysis

Based on the pressure needed to both support the UAV and conduct electricity, a Finite Element Analysis was done on the contact points of the charging station. With a 10 lb load applied to the contact area, the maximum stress is 24 psi. This is well below the 5 ksi yield strength of ABS plastic.

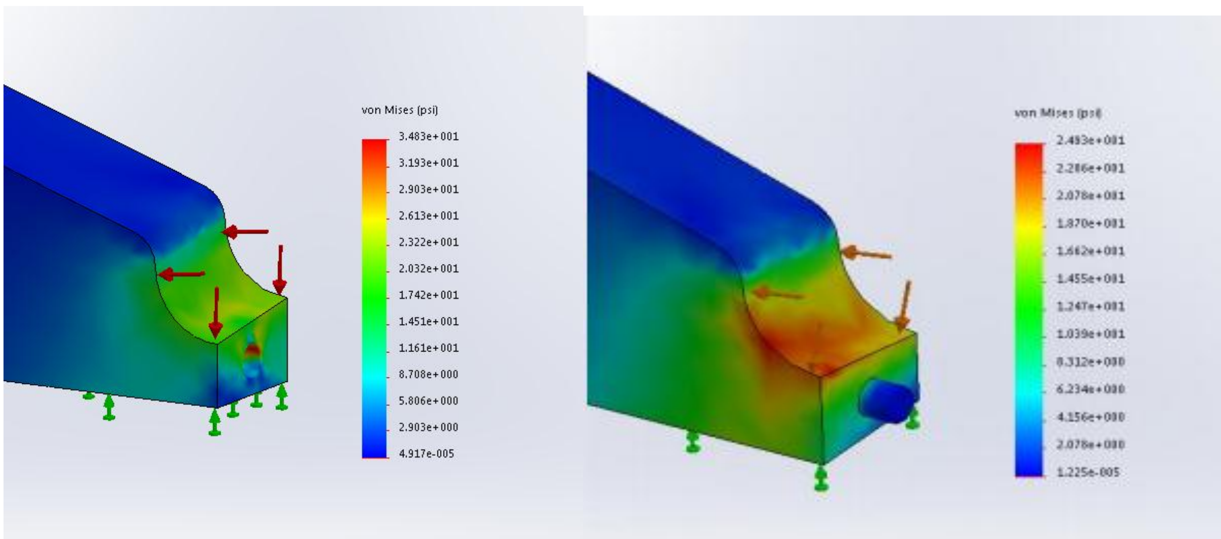


Figure 3: FEA Analysis

Engineering Analysis for Evaluating Previous Designs

Line Tension While Landing

To safely lower and align the UAV onto the charging platform, tether lines will be dropped from the arms containing the battery contacts. The tethers will then be reeled in using motors on the base station. While hovering, the lift force from the propellers is equal to the force from the weight of the UAV. During landing, the UAV will power motors an estimated 10% greater than hovering power. This will allow the UAV to be lowered against the resistance of the lift force, giving more control over the landing procedure. To calculate the tension in tethers, a free body diagram analysis was conducted.

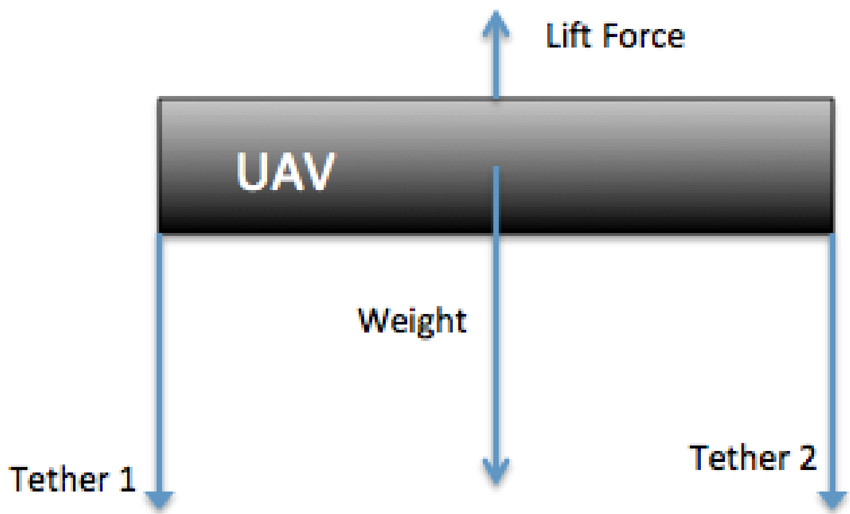


Figure 4: Simple FBD Analysis of UAV and tethers

Using a 10lb UAV for this analysis, the resistive force from the motor is 1lb (10% of total weight). To account for wind gusts, a pure vertical wind was assumed (not likely, but considered for worst case scenario situations). The cross sectional surface area of the UAV was found in equation 1.

$$[illegible] = \pi(r^2) + nLd = \pi(6^2) + (6)(14)(.5) = 1.078\ ft^2 \qquad (1)$$

r - radius of central body on UAV
n - number of arms
L – length of arms
d – diameter of arms

The force from wind was calculated using equation 2 and 3. A wind speed of 30 mph (44 ft/sec) was assumed. The air is assumed to hit the UAV perpendicularly to the surface area and leave parallel.

$□ = □□(□_2 - □_1) = (.0023769)(47.432)(44 - 0) = 4.9606\ □□□$ (2)

Adding equation 1 and 2, the total force in the vertical direction was found.

$□_{□□□□□} \approx 6\ □□□, □□\ 3\ □□□\ □□□\ □□□□$ (3)

Because of an alternative functionality of the tether covered later in this analysis, 30lb rated fishing line will be used. This will easily handle the loading caused from lowering the UAV and has redundancy built in in the event that one tether fails.

<u>Line Tension from Contact Pressure</u>

In order to ensure a solid connection between the contact point on the UAV and the contact point on the charging station, a force will be applied through the anchor tethers to induce a pressure on the points of interest. Copper was determined to be the most feasible conduction material by comparing the difference in price to silver. Based on research [2] of contact points between two flat pieces of metal, pressure as high as 72 psi can be needed to prevent burning out the contacts from inadequate energy transfer. Because of the high force required for this type of connection, the team modified the design to allow for bending in the contact surface to ensure adequate exchange conditions – this is the same technique that the battery charger uses to connect the lead wires.

To determine the new amount of pressure required to successfully conduct energy, the battery connection terminal of the charger was observed. The pin that plugs into the battery is shown in figure 5). To determine the normal force between the pin and the charger pinhole, the force required to pull the pin free was found in an experimental trial. Approximately three (3) pounds pulled the pin free. The surface area was found using equation 4.

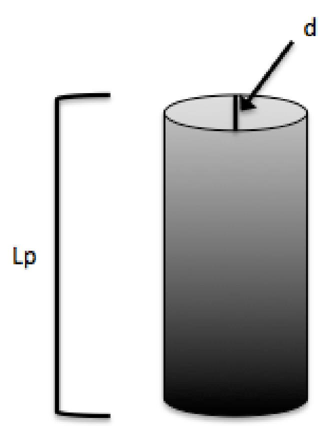


Figure 5: Diagram of Charging Pin

$$SA = Lp(\pi)d = (.5)(\pi)(\frac{5}{32}) = .245\ in^2 \quad (4)$$

SA – Surface Area
Lp – length of pin
d – diameter of pin

Assuming $\mu_s = .6$ because of a dry metal on metal contact, the free body diagram in figure X was examined to find the normal force. Equation 5 shows the derivation of the normal force between the contacts.

$$F_N = \frac{F_F}{\mu_s} = \frac{3}{.6} = 5\ lbs \quad (5)$$

μ_s – static coefficient of friction
F_N – Normal Force
F_F – Friction Force

From the Normal force, the pressure could be found.

$$P = \frac{F_N}{SA} = \frac{5}{.245} = 20.41\ psi \quad (6)$$

Equation 8 applies the pressure over the surface area of the connections between the UAV and the base station found in equation 7, giving the required force on each contact.

$$SA_{bs} = \frac{1}{2}(\pi)(da)(w) = (\frac{1}{2})(\pi)(\frac{1}{2})(\frac{1}{2}) = .39\ in^2 \quad (7)$$

SA_{bs} – Surface Area between contacts on Base station
da - diameter of UAV arm
w – width of base station contact point

$$F_{bs} = P(SA_{bs}) = (20.4)(.39) = 8.2\ lbs \quad (8)$$

F_{bs} – Force on Base Station Contact

Dividing the 10lb weight of UAV over the six contact points gives 1.3 pounds on each. That means that an additional 6.9 pounds must be applied to both contact sections during charging. Because the tether lines are dropped approximately next to the contact points, the force from the tether is applied to the contact points in the model. A 10lb force from each tether will provide the sufficient amount of pressure required and fall safely in the 20lb line rating.

Surface Area Required to Transfer Energy

To determine the amount of surface area contact between the UAV arm and the charging station, the contacts between the charger and the charging line was examined again.

From equation 4 the surface area between the charging line and the charger was found to be .245 in^2. Equation 7 calculated that the surface area between the base station and the UAV was .39 in^2. The surface area will be large enough to successfully transfer energy between the charging station and the UAV.

Wire Thickness

The appropriate wire thickness needed to transfer energy throughout the charging station was matched to the wire thickness found on the battery. 10 gage will be used.

Power Input Requirement

The charger that will be fitted in the charging station specified the power input requirements. A range of options for power input were examined however, for initial charging stations, power will be drawn from the grid. This satisfies the charger requirements.

Motor Specifications on UAV

To reel back in the tether lines after charging has been completed, a small motor must be mounted on the UAV. The motor will be required to reel in two .05lb weights and line, totaling to .1lbs. Equation (9) shows how the relationship between required force and torque was found.

$$\square = \square\ \square\ \square = (.1)(\frac{.25}{12}) = .00208\ \square\square * \square\square\square \quad (9)$$

T – Torque
f – force
r – length to applied force

Many small motors will be able to accommodate this required torque.

Motor Specifications on Charging Station

The motors on the charging station will be required to generate the force necessary to hold the UAV firmly against the charging contacts. As stated in the Line Tension from Contact Pressure section, the additional force required for each contact is 10lbs. Plugging 10 lbs and a 1 in spool into equation 9, a required torque of .8333 ft*lbs was found. Initial research shows that the team will have no problem finding a motor capable of that torque, especially because of the low rpms.

Line Drop Spool

For one of the initial design concepts, a charging line was to drop from the UAV and connect to the base station. Upon investigation of the battery wire, the team determined that rolling up 12 in of 10 gage wire on a UAV would not be a feasible design component because of the in flexibility and weight.

Magnetic Force for Line Connection

One of the possible solutions for aligning and connecting the dropped charge line with the charging station was to use magnets. After further investigation, the team does not find this option a feasible design component. It was discovered that any magnetic field on the UAV would interfere with the compass causing the UAV to fly in undesired directions. Electromagnetics were considered to generate the magnetic field but the relative size and amount of coils required ruled this option out as well.

Force Required to Push Charging Pins in UAC

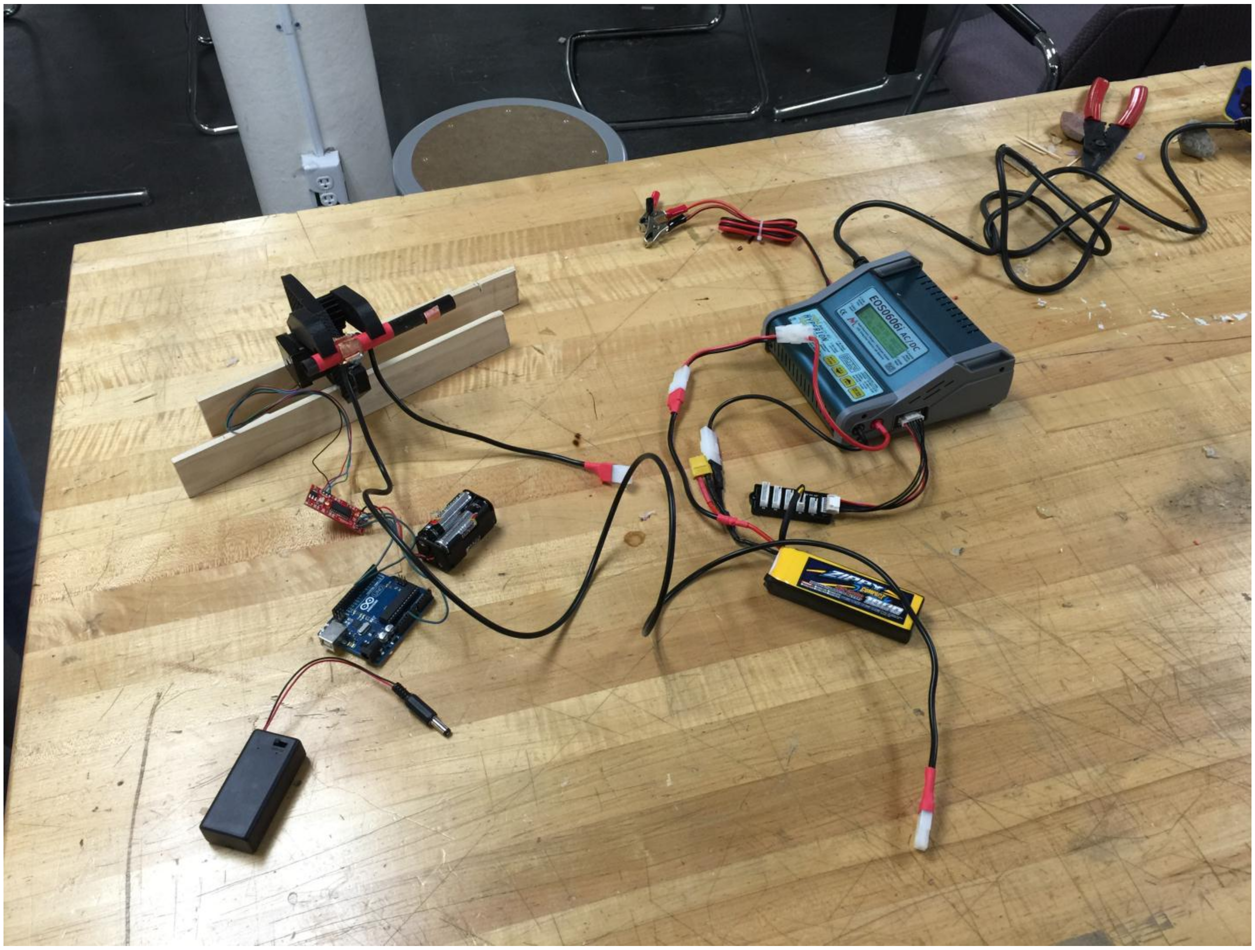
The force required to push charging pins into the UAV charge ports were modeled based on the force required to push the charging lines into the charger. This force was experimentally determined to be 3lbs. A linear actuator would be used for this motion. Tipping and sliding was ignored in this analysis because of the constraints on the UAV legs in the docking station concept.

Reference:

[1] P. Smith. (2014). *Working with Wire* [Online]. Available: https://learn.sparkfun.com/tutorials/working-with-wire

[2] Bureau of Reclamation, "Electrical Connections for Power Circuits," US Department of the Interior, 1991, Vol 3.3.

Appendix H
Original Laboratory Data from All Testing



Nevada Dynamics			
Team 13			
Proof of Concept Test			Test # 1
Description of Test: Test Charge w/ motor			

Issue	Occurrence Yes	Occurrence No	Notes
Motor strength - not enough force	X		motor unusable
Contact pressure to charge	X		successful charge
Total resistance of system	3-4 Ω		very low resistance
Plastic deformation due to heat		X	
Copper contact wear		X	no discoloration
Time to charge from 11.96 V to 12.6 V	~	~	19 min
Proper gear rotation		X	Bad gears
Resistance copper to carbon fiber	X		too high to measure
Current while charging	~	~	1.8 A
Correct motor rotation	X		Arduino code
Time to position arms			2 sec
Lipo battery heat		X	No heat
Lipo bag damage		X	
Stepper shield temp increase	X		Not significant
Arduino uno temperature increase		X	
Stepper motor battery temperature increase		X	
Arduino uno battery temperature increase		X	
Arm and gear pin lacks stability while	rotating	forward/	backward

Nevada Dynamics: Spatial Delivery			
Team 13			
Final Prototype Test			Test: 1
Test Description: *UAV manually set on charging station to ensure safe charging operation of balancer, landing lights, copper contact points, LiPo bag, etc.*			
Issue	Occurrence		Notes
	Yes	No	
Sufficient contact pressure to charge	*X*		*Little contact pressure needed (success)*
Total resistance of system			*684 Ohms, much higher than PoC, still within acceptable limits (success)*
Copper contact wear		*X*	*No visible contact wear after first test (success)*
Starting Voltage			*22.874 V*
Time to charge battery			*64 minutes 48 seconds (success)*
Ending Voltage			*25.124 V (success)*
Current to battery			*2.14 A*
LiPo battery excessive heat		*X*	*No noticable heating of LiPo bag or battery (success)*
LiPo bag damaged		*X*	*Zero damage to LiPo bag or station due to excessive heating (success)*
Station landing lights and switches operational	*X*		*Lights red when not landed, green upon propper landing (success)*

Nevada Dynamics: Spatial Delivery			
Team 13			
Final Prototype Test			Test: *2*
Test Description: *Flight Test in Applied Research Facility, High Bay*			
Issue	Occurrence		Notes
	Yes	No	
Sufficient contact pressure to charge	*X*		*Little contact pressure needed (success)*
Plastic deformation on landing		*X*	*Rough landing, no station deformation (success)*
Total resistance of system			*730 Ohms, much higher than PoC, still very low (success)*
Copper contact wear		*X*	*No visible contact wear after second test (success)*
Starting Voltage			*22.995 V*
Time to charge battery			*69 minutes 59 seconds (success)*
Ending Voltage			*25.200 V (success)*
Current to battery			*2.12 A*
LiPo battery excessive heat		*X*	*No noticable heating of LiPo bag or battery (success)*
LiPo bag damaged		*X*	*Zero damage to LiPo bag or station due to excessive heating (success)*
Station landing lights operational	*X*		*Lights red when not landed, green upon propper landing (success)*
Station circuitry operational	*X*		*Circuitry remained operational and aided in battery charging (success)*
Ample space for landing	*X*		*Error involved with manual flight was negated by large space for landing (success)*
Sawtooth ridge aid in landing procedure	*X*		*Very little force required for hex arms to slide down sawtooth ramps (success)*
Yaw after landing for landing error correction	*X*		*Error during landing corrected by yawing allowed for proper contact for charging (success)*
Hexcopter electical components remain on. Most importantly autopilot	*X*		*UAV autopilot and other electical components all remained on (success)*
Hexcopter take off procedure after charging	*X*		*UAV remained operational after charging sequence had finished (success)*

Appendix I
Manufacturer's Specifications

Solidoodle 4 Specifications

Standard Features:
• Creates plastic parts up to 8" x 8" x 8"
• Uses 1.75mm plastic filament (ABS/PLA)
• Heated Build Platform Heated Build Platform
• Resolution up to .1mm
• 13.5" x 14" x 15" case footprint (L x W x H)
• Internal Steel frame
• Powder coated steel enclosure
• Easy-open lid for quick access
• Internal case fan with air filter to vent build chamber
• Electronics mounted internally and thermally isolated from build chamber
• Thumbwheel calibration of platform height - no wrench required (Z-tab)
• Easy snap-in filament spool holder
• Fully Assembled & Tested

Tech Specs:
• Uses Fused Filament Fabrication (FFF) a.k.a Thermoplastic Extrusion Technology
• Solidoodle Motherboard
• Extruder moves in the horizontal plane (X-Y), Build Platform (moves in the vertical direction (Z)
• Spring-loaded aluminum extruder with stepper motor, .4mm nozzle
• Uses 1.75mm ABS and PLA filaments.
• 100V-240V Universal Power Supply

Precision:
• Able to print at .4mm, .3mm, .2mm, and .1mm resolution

About PowerLab 6

- Simple to operate: just connect PowerLab 6 between a power source and a pack, select a pack-specific preset and start charging, discharging, cycling or monitoring. No jumpers, plugs or dials to set! During Auto Charge, PowerLab 6 automatically determines pack capacity and sets optimal current, then dynamically adjusts charge rate as needed. Alternatively, select manual charge rates from 10mA to 40A.
- Supports both balanced (depending on chemistry) and non-balanced charging (with certain safety limitations) of the following chemistries:
  - LiPo (1s to 6s balanced, 1s to 2s unbalanced; maximum charge rate of 2.0A for unbalanced charging).
  - Li-Ion (1s to 6s balanced, 1s to 2s unbalanced; maximum charge rate of 2.0A for unbalanced charging).
  - A123®/LiFePO4 (1s to 6s balanced, 1s to 8s unbalanced; maximum charge rate of 20A for unbalanced charging).
  - LiMn (1s to 6s balanced, 1s to 2s unbalanced; maximum charge rate of 2.0A for unbalanced charging).
  - NiCd (1s to 19s; maximum charge rate of 20A).
  - NiMH (1s to 19s; maximum charge rate of 20A).
  - 6V, 12V, 24V Lead Acid (Flooded, Gel, AGM, SLA).
- Holds up to 25 user configurable presets (User Presets), optimized for the different chemistries, providing charging strategies for most common RC charging needs. Also holds up to 50 Library Presets. When using the free Charge Control Software, the number of custom presets is virtually unlimited and will grow over time to meet industry needs. Replace and customize presets to match your battery inventory.
- During balanced charging, each cell is balanced independently, providing exceptional charging safety and elevating RC packs to the safety level of cell phones. Typical packs of up to 4Ah capacity charge in 40 minutes or less using charger's 3C Auto Current Mode.
- Latest technology provides the ultimate in safety—even charges packs having hidden physical damage without danger of fire. A pack will not charge if individual cell voltages don't equal total pack voltage.
- Cell balancing to 78µV accuracy with a tolerance of 6mV and automatic over-charge protection assure longest pack life. Automatic temperature monitoring prevents pack over-charging at low ambient temperatures and charger damage at high ambient temperatures. Cold weather settings adjustable per preset.
- Selectable modes: charge only, discharge only, cycle (charge/discharge any number of times) and monitor (no charge or discharge, just measure pack voltage).
- Selectable discharge:
  - Internal discharge 10mA to 8A, 50W max.
  - Regenerative discharge 10mA to 40A, 1000W maximum when powering the PowerLab 6 from a Lead Acid battery. Regenerative discharge takes most of that energy and puts it back into the input battery. For example, when you discharge a LiPo pack for storage, you will be recharging your Lead Acid input battery.
- Multifunction backlit display lets you select presets, replace default presets from a library and shows charging data such as individual cell voltages, charge current, supply voltage, and amount of charge (mAh) put into pack. Plus, the unique Fuel display shows percent capacity remaining in a pack.

Spatial Delivery

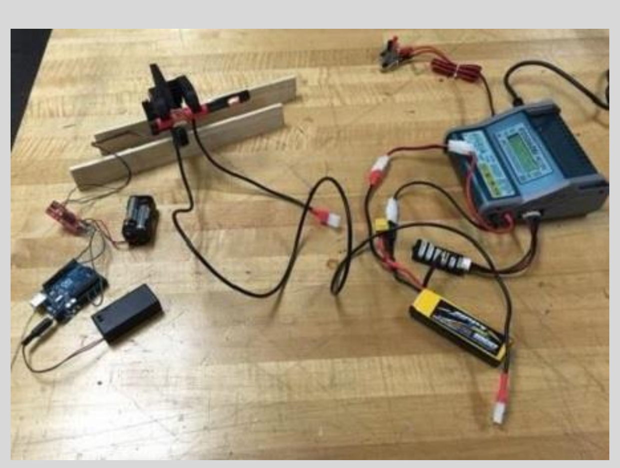
Nevada Dynamics
Evan Autry, Erik Edgington, Daniel Ferguson, Harrison Gray, and Amanda Nelson

Problem Statement

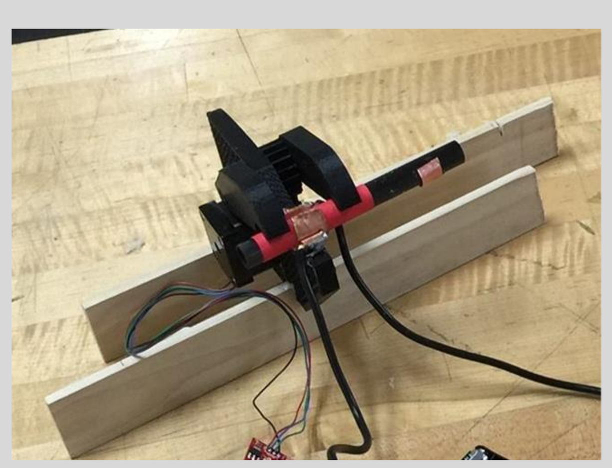
As the Unmanned Aerial Vehicle (UAV) industry expands to include new businesses and clients, there is a need for a charging station to increase the range over which delivery UAV's can travel. Nevada Dynamics has designed a sturdy charging station that is adaptable and allows for a payload to be housed below the UAV during charging. The objective of this station is to recharge a UAV during a mission in order to increase the distance it can travel. A safe, reliable, and durable charging station will be needed to further expand the range of cover for companies integrating UAV's into everyday operations.

Prototype and Testing

Proof of Concept / Prototype
The prototype focused on proving that copper contacts are a viable method of transferring the necessary power to charge a LiPo battery. Copper contacts rely on low resistance created by contact pressure to maintain the flow of electricity, so the second portion of the prototype verified that the weight of the UAV would provide the required pressure.



The prototype allowed the team to test out the proposed circuit on a smaller scale.



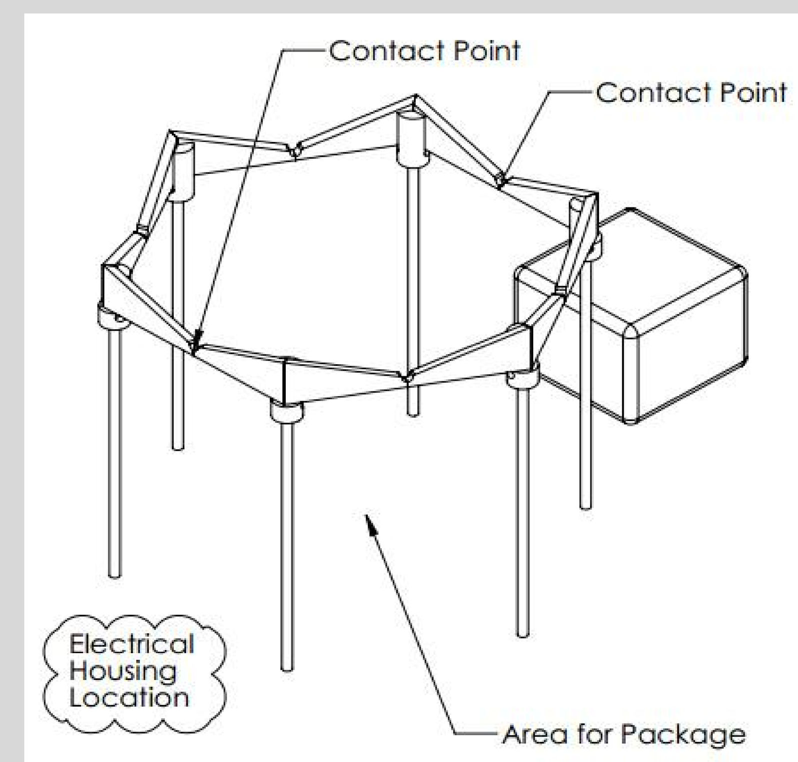
The prototype proved that additional contact pressure was not required.

Final Testing

- Manually connect UAV to the charging station
- Assure the balance charger is functioning
- Assure that the UAV can properly align prior to charging
- Charge the battery using the charging station

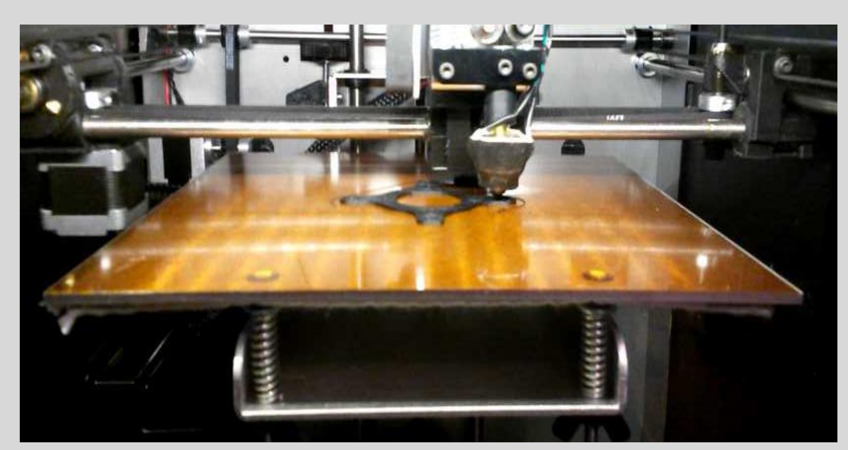
Specifications

- Allow room for a payload to be housed under the UAV during the charging process
  - -16" x 16" x 12"
- Able to align UAV in case of minor errors in GPS reading
- Easy to alter the size of UAV that the charging station can handle
- Able to charge a Lithium Polymer (LiPo) battery in under an hour



Initial design of the hex hoop calling out two key functions.

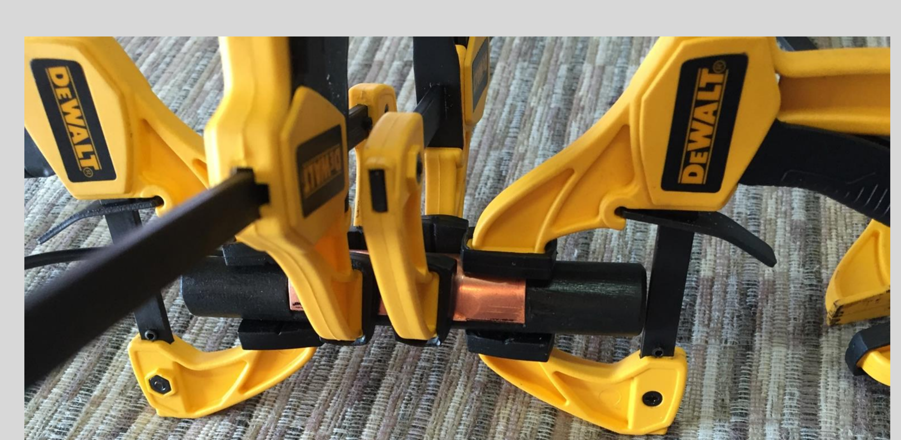
Manufacturing



All parts components of the hex hoop and leg supports were 3D printed.

3D printing was outsourced to complete the hex hoop on time.

Wooden dowels make up the legs and hoop supports.



Gluing the copper contacts to the spacer to be outfitted on the UAV.

Market Analysis

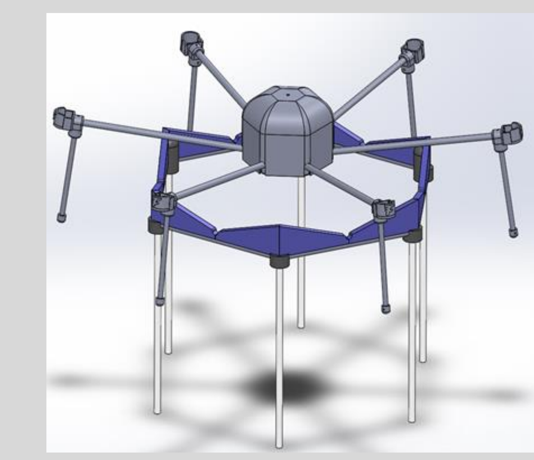
Skysense UAV charging station for commercial drones[1].

Competition Features

- Fast charging of LiPo batteries
- Perfectly suited for one or two UAV designs

Spatial Delivery's Advantages

- Charges a LiPo battery in less than an hour
- Hoop allows for a payload
- Hoop can easily change for different amounts of UAV arms



3D model of the Nevada Dynamics station.

Final Project

Final Features

- Auto pilot can remain on while the battery charges
- Red and green lights indicate proper alignment of the UAV in the station
- Copper contacts on the UAV and station complete the circuit that charges the LiPo battery
- Hoop allows room for a package to be housed below the UAV
- Balance charger functions off of the battery on the UAV
- The hex hoop can be easily changed to adapt to varying amounts of UAV arms

The charger powered by an external power supply is located near the hex hoop.

Final Nevada Dynamics UAV charging station with the test hex copter in place.

Acknowledgements

Special thanks for Andrew Smith and Tony Berendsen for all the help they provided during the course of this project.

References

[1] [2]A. Puiatti, 'Homepage', *Skysense.de*, 2015. [Online]. Available: http://skysense.de/. [Accessed: 11- Feb- 2015].