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EHAWK: UAV - remote launch of Unmanned Aerial Vehicles Kite Based System

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EHAWK: UAV

REMOTE LAUNCH OF UNMANNED AERIAL VEHICLES KITE BASED SYSTEM

by

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A Thesis

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Next, I would like to thank all my amazing professors at Rowan. They have taught me that there is an important balance between technicality and practicality in engineering, a concept that is seemingly forgotten.

Lastly, I would like to thank my family and friends who have supported me thought all these years of college, both graduate and undergraduate.

Abstract

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EHAWK: UAV - REMOTE LAUNCH OF UNMANNED AERIAL VEHICLES KITE BASED SYSTEM
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Unmanned aerial vehicles, also known as UAVs or drones, are becoming favorable assets in multiple fields. Along with this new technology comes new improvements, including the EHAWK: UAV system, a proposed system to increase the range of UAVs by providing an alternate method for launching.

The EHAWK: UAV is a kite based system for launching UAVs. The system uses a kite which acts as a sky anchor or fixed point in the sky. A tether is attached from the kite to the ground. A shuttle device then attached to the tether line. That shuttle carries the UAV up the line and holds it at a predetermined altitude. The shuttle then releases the UAV whenever a command is received and then returns down the line. Releasing the UAV from a shuttle at a higher altitude minimizes onboard energy consumed to bring the UAV to its cruising altitude, effectively increasing its air time and working range.

Multiple kites were investigated to find the ideal one to be use as a sky anchor. It was found that kite stability was a critical factor. The "Flow Form 4.0" kite was chosen and a tether reel system was developed for it.

A shuttle was developed, which was attached to the tether via two vertical pulleys. The tether was wrapped around a horizontal motor driven wheel, which allowed the system to transverse the line. The shuttle had a counter weight setup to keep it stable on the line. It also incorporated a release mechanism which held the UAV during climb.

The whole shuttle system was wirelessly controlled by a remote operated by a ground user.

The system was tested but found to be an unlikely solution. The issue was found in the concept itself. The EHAWK: UAV was strongly affected by the wind, which is an uncontrollable outside factor. Due to lack of control of the wind speed, wind direction, or change in wind speed, the shuttle encountered disturbances that cause it to flail around on the line. This made safely releasing the UAV difficult. Future research is needed to overcome this issue. Even if this issue was resolved, the whole EHAWK: UAV system is less practical than current conventional methods of launching UAVs for most applications.

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Chapter 1

Intro & Background

Problem Statement

Unmanned aerial vehicles, also known as UAVs or drones, are becoming favorable assets in multiple fields including, but not limited to, military defense, ecology research, environmental research, aerial photography, agricultural crop surveillance, search & rescue, and small package delivery [1, 2, 3]. The number of UAVs used in various applications will likely grow in the near future. With this growth comes opportunity for development and improvement. One major issue facing UAVs is flight range. Range is often limited by the available stored energy supply. This available stored energy supply would be the battery charge or amount of fuel carried on the UAV. Some optimization parameters such as weight, motor efficiency, and aerodynamics can be altered, but only to a certain extent. Even with these parameters optimized, there are alternative methods for increasing the range of a UAV. The goal of this project is to explore one of those alternative methods.

A large amount of power is consumed bringing the UAV up to its cruising altitude. Using a separate system to raise the UAV into the sky would allow the UAV to save that stored energy for use later in the flight, effectively increasing the range.

The amount of energy required for a UAV to reach cruising altitude can be estimated from its gravitational potential energy at the height of cruising altitude. Comparing that energy lost to the total energy onboard provides a quantifiable parameter, in the form of percent lost. This can be seen in Equation Set 1. It was found that 20% of its onboard energy was lost to reach a cruising altitude of 500 feet for the Ominus Quadcopter, a UAV used for testing the proposed system.

$$Potential\ Energy = mgh$$

$$Percentage\ Lost = \frac{Potential\ Energy}{Onboard\ Energy\ Stored} * 100\%$$

Equation Set 1: Energy Lost Reaching Cruising Altitude Equation

EHAWK: UAV System

The EHAWK: UAV project uses a kite based system to raise the UAV into the sky. A kite is flown creating tension in the tether line. A wirelessly controlled shuttle system then climbs the taut tether line carrying the UAV. Once at the required altitude, the shuttle releases the UAV, essentially launching it at or close to cruising altitude. The shuttle then returns down the line. The kite and shuttle can then be stored for future use. A diagram of this system is shown in Figure 1.

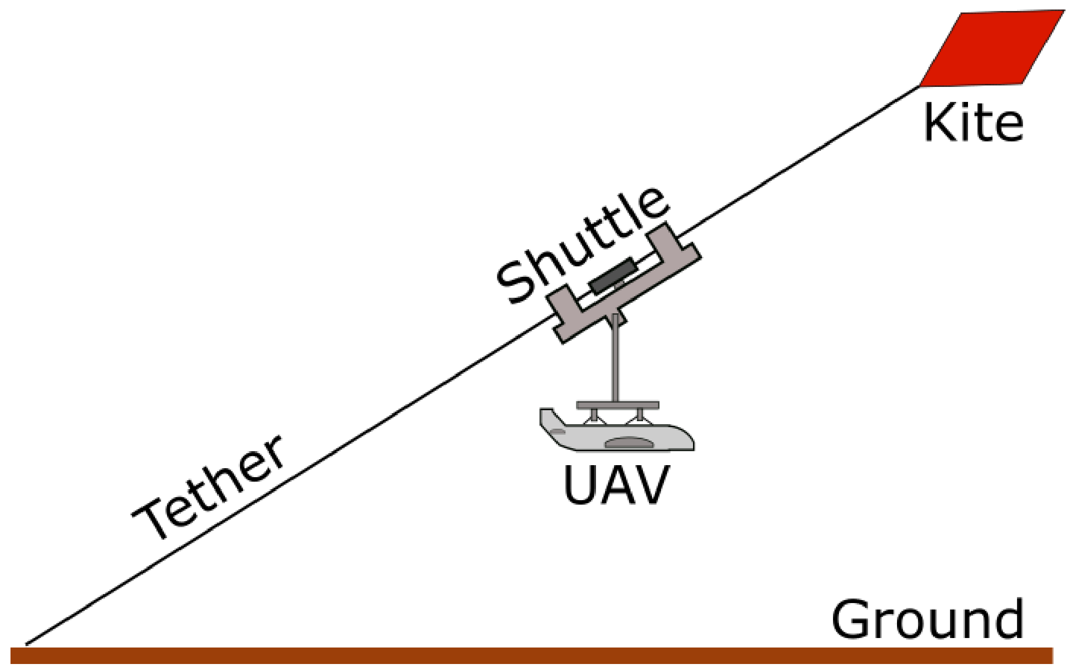

Figure 1. EHAWK System Diagram

This proposed concept also provides an alternative method of launching UAVs. There are two major classifications of UAVs: fixed wing and rotary wing [4]. The EHAWK system could accommodate both styles of UAVs. Helicopter and quad rotor are common rotary wing style UAVs capable of vertical take-off and landing, VTOL. VTOL aircraft have the advantage of being able to launch directly off the ground. Fixed wing style UAVs require forward velocity to create lift for flight. Consequently, these cannot be directly launched off the ground without certain accommodations. For this to be achieved, landing gear needs to be installed adding unnecessary weight. Also, a relatively flat strip of ground is needed to act as a runway for these UAVs. To resolve this issue, many fixed wing style UAVs are launched using a catapult system resembling a crossbow [5, 6]. This is the current system in use for launching most UAVs. The proposed kite based system would also be able to launch the fixed wing style of UAV, since the UAV will be released at an altitude, it will have time to gain forward velocity before nearing the ground.

The EHAWK: UAV has two main components: the kite setup and the shuttle. The shuttle is the system that climbs up the tether to release the UAV. The shuttle, shown in Figure 2, is subdivided into a three subsystems: shuttle carrier, release system, and electronics.

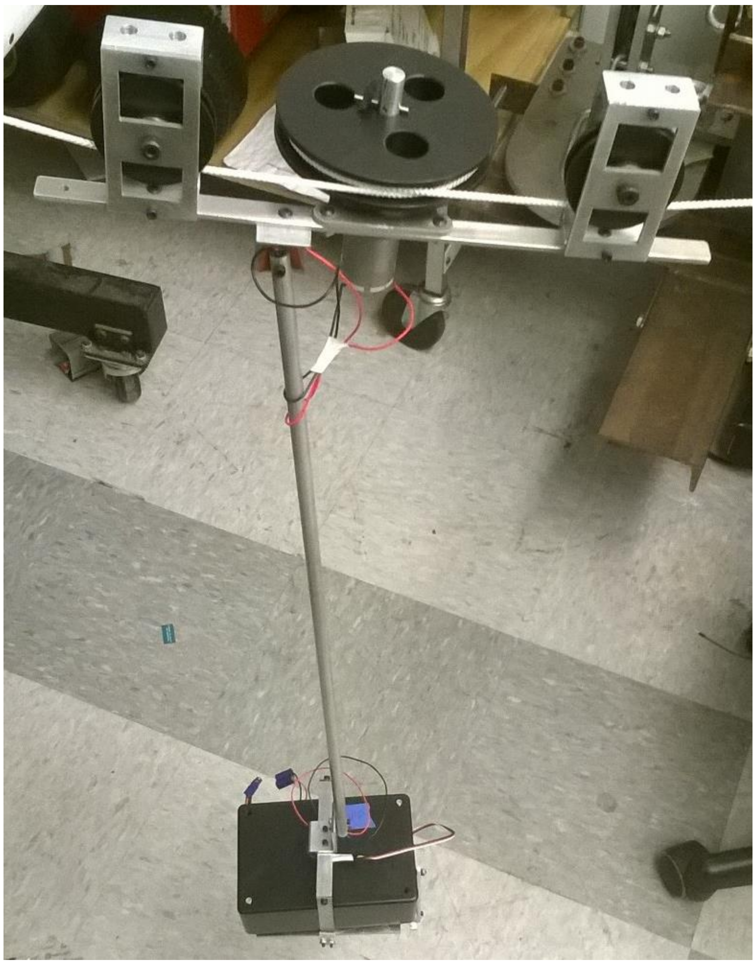

Figure 2. Shuttle

Chapter 2

Drone / UAV

UAV Selection

Three different simple UAVs were used to test the setup. Two were conventional fixed wing style of UAVs. The other was a rotary wing style of UAV capable of vertical take off and landing (VTOL).

The first UAV was a simple styrofoam glider. This was chosen because it was inexpensive and easily replaceable, in case of damage during testing. This is shown in Figure 3. The other fixed wing style used was the “Estes Star Strike RC”, shown in Figure 4. This was chosen to allow testing a UAV capable of flying away from the release on its own power. The final UAV chosen was the “Ominus Quadcopter”, shown in Figure 5. This was chosen to test the EHAWK system with a rotary wing style UAV, particularly a quad rotor style. It was found essential for the EHAWK system to be able to integrate with quad rotor style UAVs due to their rapid increase in popularity [7].

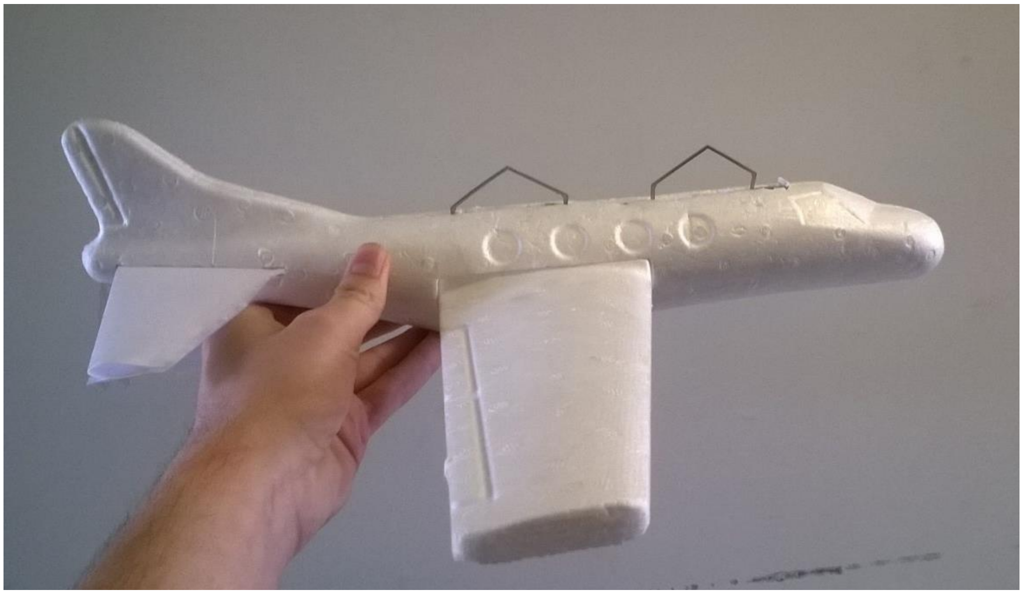

Figure 3. UAV 1 - Styrofoam Glider

Figure 4. UAV 2 - Estes Star Strike

Figure 5. UAV 3 - Ominus Quadcopter

Integration with EHAWK

To connect the UAVs to the release mechanism each were fitted with one or two hooks, depending on the size of the UAV. This hook had to have minimal interference with the flight capabilities of the UAV. A small gauge, less than 3mm, steel wire was used to create the hooks. Figure 6 demonstrates the release mechanism securing a UAV.

Figure 6. Release Securing UAV

Chapter 3

Kite

Kite Requirements

The function of the kite was to act as a sky anchor, creating a fixed point in the sky. This kite was tethered to the ground with a rope. The kite created tension in the rope. This tension allowed the shuttle system, which will be discussed later, to have the ability to climb the rope into the sky in order to release the UAV. The required tension to lift the UAV and shuttle is dependent on the angle of the tether. Once the shuttle was attached onto the tether, two angles in the line were created as shown in Figure 7. The “shuttle angle” is the angle created between the ground and shuttle. The “kite angle” is the angle created between the shuttle and kite. The kite angle is always greater than the shuttle angle.

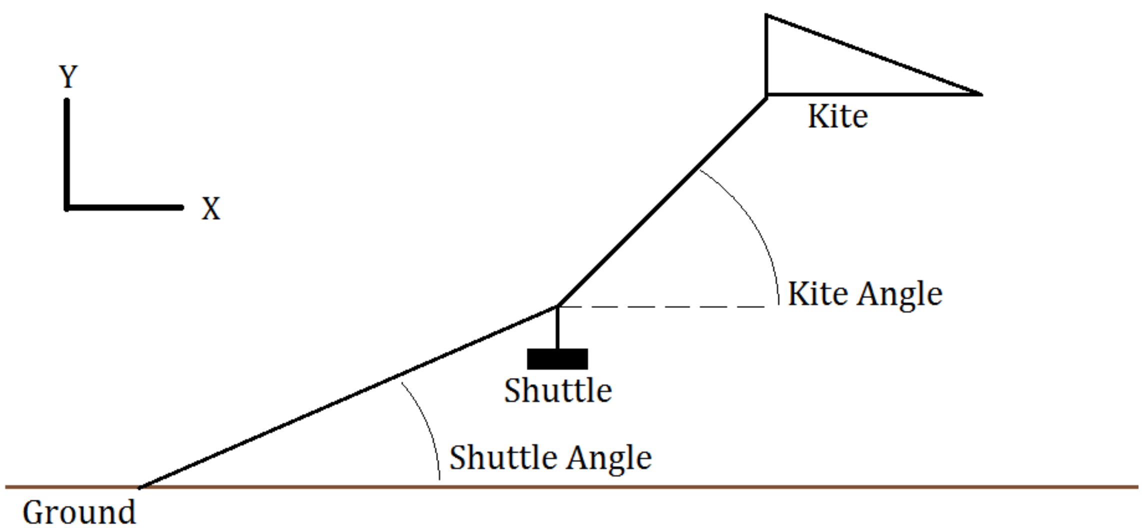

Figure 7. Tether Line Angle Diagram

Since the kite tension is the only controllable design parameter, finding the minimum required kite tension is necessary to select an appropriate kite. The shuttle is acting as a connection point. This creates two separate tensions in the tether: the kite tension and shuttle tension. A free body diagram of the shuttle is shown is Figure 8. The kite tension can be found from a force balance, shown in Equation Set 2. The factors contributing to the kite tension are kite angle, shuttle angle, shuttle weight, and shuttle tension. The shuttle tension is a reacting force that is interdependent with the kite tension. The tether angles themselves are geometrical parameters determined by multiple factors including: length of tether, location of shuttle, and kite tension. With all of these variable codependent factors, creating a practical model for estimation is difficult. There are more variables than governing equations thus creating many possible solutions. To create a design requirement estimation, some reasonable assumptions were made. The weight of the shuttle was estimated to be 6lb, which is heavier than anticipated. The shuttle and kite angles were assumed to be 25 and 40 degrees respectively. The kite angle was assumed lower than anticipated because a steeper kite angle would require less tension to support the shuttle. The kite tension correlating to these requirements is 21 lbf.

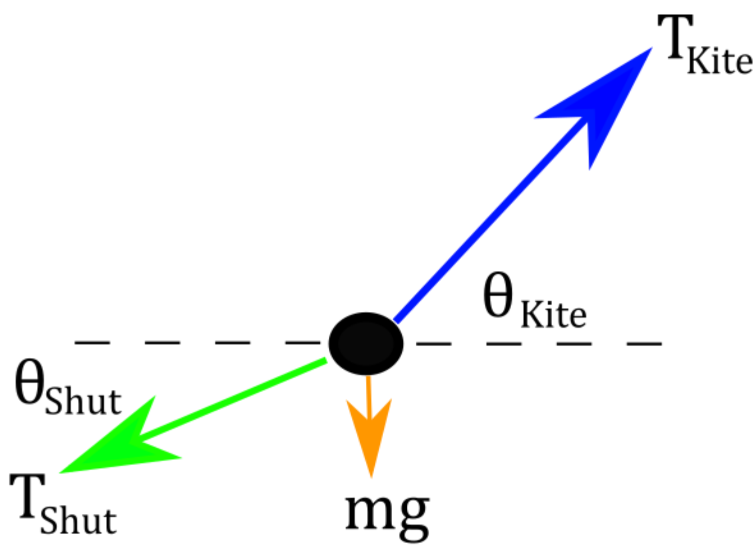

Figure 8. Shuttle on Line Free Body Diagram

$$X: \quad T_{kite} * \cos(\theta_{kite}) = T_{shut} * \cos(\theta_{shut})$$

$$Y: \quad T_{kite} * \sin(\theta_{kite}) = T_{shut} * \sin(\theta_{shut}) + mg$$

$$Combine: \quad T_{kite} = \frac{mg}{\sin(\theta_{kite}) - \cos(\theta_{kite}) * \tan(\theta_{shut})}$$

Equation Set 2: Tether Tension Force Balance Equations

Kite Selection

A series of kite styles were researched and tested. The first kite investigated was the “Liquid Force Spectrum II”, a double lined dynamic kite. This kite is shown in Figure 9. The “Liquid Force Spectrum II” was originally designed for Kitesurfing, a sport in which a kite drags a rider on a board across the water. This kite was explored first because of its use on a previous project by Dr. Zhang. The dynamic kite was used to produce energy in this previous project. It could produce reasonable tension, however, had a major drawback: the nature of the kite itself. The kite, by design, continuously moved in the air. This creates the need for a complicated control system to continuously fly the kite. More importantly, launching the UAV from a moving, non-stable, system would be nearly impossible and lead to many possible issues. Due to this, a static style of kite had to be chosen. After some additional research, the "Flow Form 4.0", shown in Figure 10, was chosen to be the successor to the "Liquid Force Spectrum II". The "Flow Form 4.0" was marketed as a "stable flyer" that is "often used for aerial photography" [8, 9]. This made it an ideal choice. This kite was a single line kite with a compact size of 2.2 meters by 2.6 meters.

Figure 9. Liquid Force Spectrum II

Figure 10. Flow Form 4.0

Field Testing

The kite was field tested three times in open field environments. Each time between 100 and 150 feet of tether was let out. The tether angle relative to the ground, tension in tether, and wind speed were observed. The tension was measured using a digital fish scale attached to the end of the tether, while the angle was measured by taking a digital photograph of the tether. The photo was then uploaded to a computer and the angle was found. The wind speed was obtained from the National Weather Service's website, which provided current weather data for each location [10].

Due to the nature of wind, wind speed is not truly constant. To obtain a constant wind speed in an ideal open field environment, an altitude of at least 274 m or 900 ft would have to be obtained [11]. This is possible but highly impractical. This means the kite cannot be truly static. The average angle of the tether relative to the ground, average tension in the tether, and National Weather Service's wind speeds were recorded to account for these continuous fluctuations. The results of this can be seen in Table 1.

Table 1

Kite Performance Data

Test Date	Wind Speed	Avg Tether Tension (± 2)	Avg Tether Angle (± 5)
Feb 10, 2015	15 MPH	16 lbf	40 Deg
April 2, 2015	19 MPH	20 lbf	45 Deg
April 4, 2015	16 MPH	16 lbf	45 Deg

Simulation

A 3D SolidWorks model of the kite was created, shown in Figure 11. Using SolidWorks Flow Simulation the kite model was evaluated using finite element analysis. The kite was simulated at multiple wind speeds with three different angles of attack. The simulations were run using a mesh setting of 4. The resulting forces in the X and Y direction on the kite were determined. From these forces the resulting tension and angle of the tether could be determined using a simple force balance because it is a static system. The forces in balance are X force on kite (Kx), Y force on kite (Ky), tension in tether (T), and weight of tether. Fifty feet of tether used in our system was weighed at .16 pounds, correlating to .0032 pounds per foot. Three hundred feet of this tether would weigh less than one pound. Since the mass of this tether was minimal, its weight was assumed to be negligible. Therefor we can make the tension in the tether the only reaction force on the kite. This is demonstrated in Figure 12 and Equation Set 3.

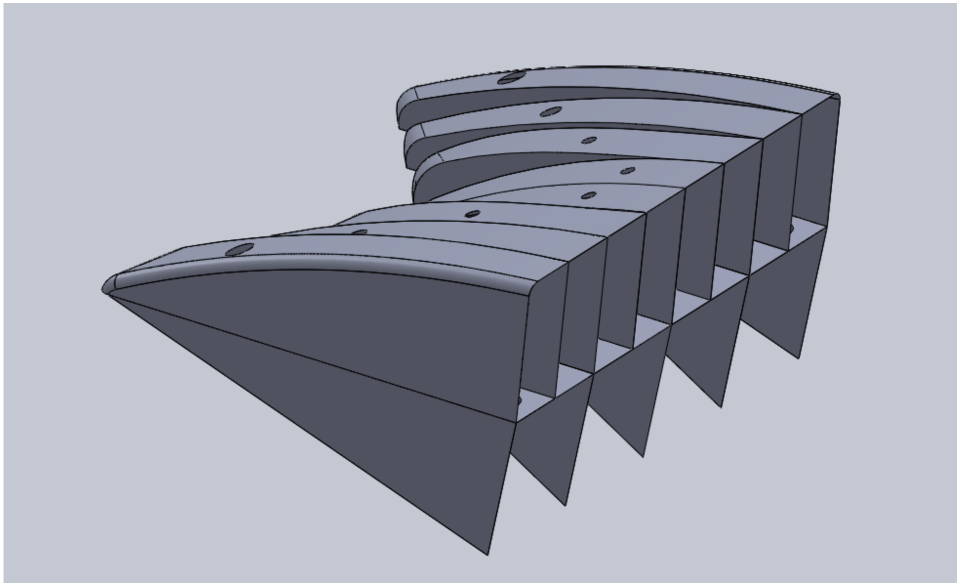

Figure 11. Solidworks Kite Model

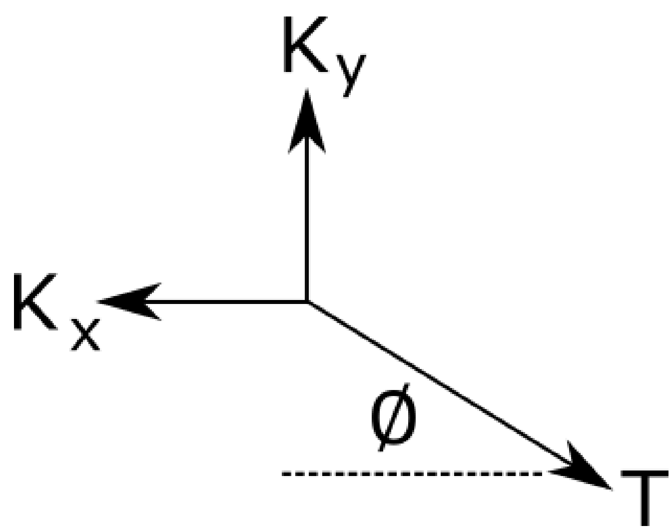

Figure 12. Kite Simulation Force Balance

$$T = \sqrt{K_x^2 + K_y^2}$$

$$\emptyset = \tan^{-1}(\frac{K_y}{K_x})$$

Equation Set 3: Tether Tension Equation

The model's default wind attack angle is shown in Figure 13. This angle needed to be altered to simulate real world conditions. As observed during field testing, the orientation of the kite during flight was approximately 20 degrees (+/- 5 degrees) off of the model's default orientation, shown in Figure 14 & 15. To account for this, the simulation was run at angles of attack of 15, 20, and 25 degrees.

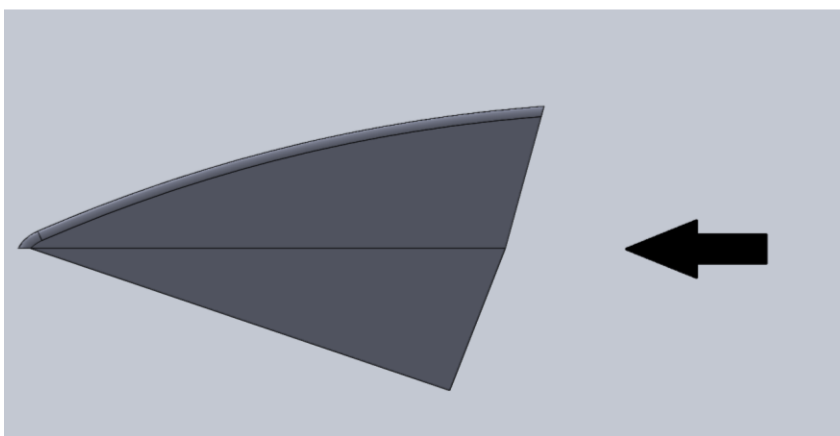

Figure 13. Model Default Angle of Attack Orientation

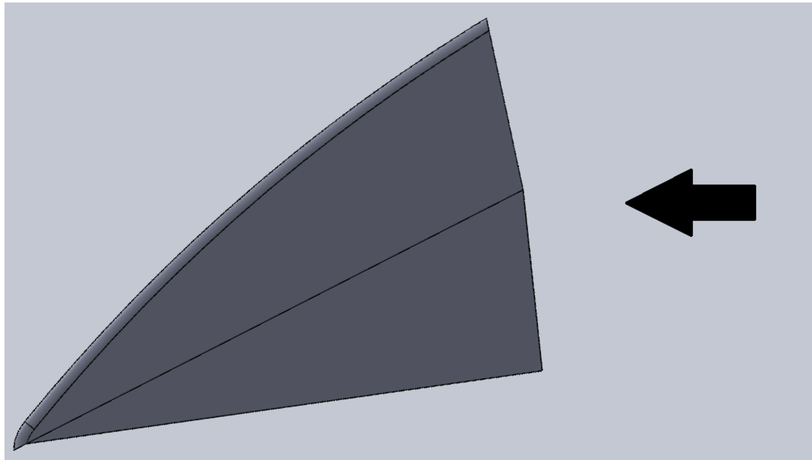

Figure 14. Model Modified Angle of Attack Orientation

Figure 15. Field Test Kite Orientation

The resulting data collected from the simulation can be seen in Table 2. The simulated model data seemed to line up to the field test data at an angle of attack between 15 and 20 degrees. This was close to the orientation angle the kite was observed flying at. An example of this was the Feb 10th, 2015 field test. During that test, a wind speed of 15 MPH resulted in 16 lbf of tension (± 2) at a tether angle of 40 degrees (± 5). According to the simulation, a 15 MPH wind should produce a tension of between 14.14 and 16.02 lbf at a tether angle of between 43.9 and 49.1 degrees. This confirmed that the angle of attack of the kite was between 15 to 20 degrees.

Table 2

Kite Simulation Data

Angle (Deg)	Wind Speed (mph)	X (lbf)	Y (lbf)	Tension (lbf)	Tether Angle (Deg)
15	11	5.5	5.3	7.64	43.94
15	15	10.2	9.8	14.14	43.85
15	19	16.3	15.7	22.63	43.93
15	23	23.9	23.0	33.17	43.90
15	27	33.0	31.6	45.69	43.76
20	11	5.66	6.5	8.62	48.95
20	15	10.5	12.1	16.02	49.05
20	19	16.87	19.44	25.74	49.05
20	23	24.7	28.5	37.71	49.09
20	27	34.1	39.27	52.01	49.03
25	11	5.67	7.33	9.27	52.28
25	15	10.5	14.05	17.54	53.23
25	19	16.9	22.58	28.20	53.19
25	23	24.89	33.3	41.57	53.22
25	27	34.17	45.54	56.93	53.12

The simulated tether angle was consistent at any given angle of attack regardless of wind speed. This is because the lift to drag ratio at any given angle of attack was dependent on shape and not wind speed, making the lift to drag ratio constant. The tension however increased with wind speed. The tension of the tether was plotted against wind speed for each of the three angles of attack. A second order polynomial trend line was then fitted to each data set. The trend line equation and coefficient of determination (R^2) for each was calculated. This data is shown in Figure 16.

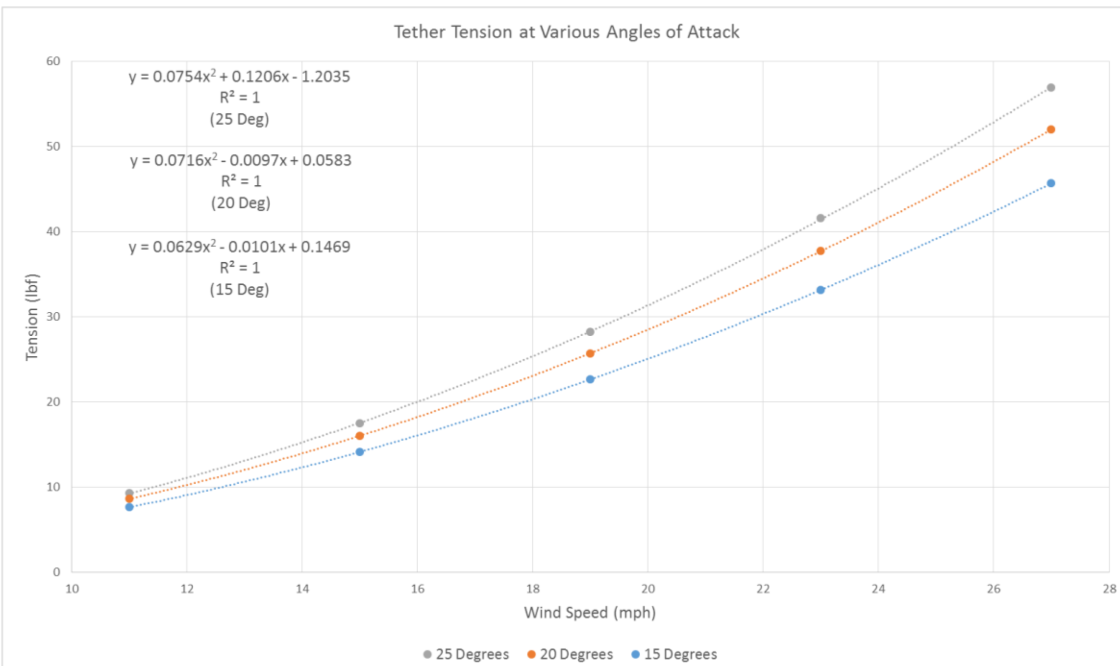

Figure 16. Tether Tension Simulation Data Plotted

The coefficient of determination was found to be “1” for each data set, meaning the trend line followed the data perfectly. Due to this, a trend line equation can be used reliably to estimate tension in the tether at given wind speeds without the use of complicated and time consuming CFD simulations.

Reel Mechanism

The kite operator required a way to launch the kite and reel it back in without using his or her hands the hold the tether directly. A winding reel mechanism was developed as shown in Figure 17. The reel mechanism was created using PVC piping, metal rods, and thin wood. A PVC pipe was cut and used as a core. A larger PVC piece was fitted over the core as a spool. The tether was wrapped around this spool. This section was then pinned to the core with a metal rod. This created a lever for the user to hold preventing the line from unwinding. Circular wood pieces were laser cut and placed on the sides of the spool as hand guards. Another piece of PVC pipe was placed over the core on each end. These pieces rotate free of the core, acting as bearings. This allowed the user to hold the end of the reel while letting line out.

Figure 17. PVC Reel Mechanism

Chapter 4

Shuttle Carrier

Shuttle Carrier Requirements

The purpose of the shuttle carrier was to act as a vehicle to carry the UAV up the tether line. The shuttle carrier needed to have a way to attach to the tether line. The shuttle carrier also needed a way to travel up the line. This requires a source of power and some form of user control. The required power is based on the required force due to gravity and the velocity of the shuttle. The velocity or climb rate of the shuttle is a contributing factor, however it is not as critical as the force. A small climb rate would make the system slow, but the system would still work. A small force, one less than the force of gravity the shuttle has to overcome, would not allow the shuttle to climb at all. For this reason the climb force is more critical than the climb rate. The required climb force can be determined based on the kite angle and weight of the shuttle system, including UAV and release mechanism. To retain a steady state, referring to the shuttle having no acceleration, the climb force exerted in the Y direction must be equal to the weight of the shuttle system acting in the negative Y direction. This would be a minimum requirement, in the real system the shuttle would need to be able to accelerate from stop. This means that the climb force would have to be greater than the minimum requirement. This can be seen in Equation Set 4.

$$F_{climb} \geq \frac{W_{shuttle}}{\sin \theta_{kite}}$$

Equation Set 4: Force Climb Equation

Shuttle Carrier Series 1.0

The original prototype was designed based on a ground mounted power system. Two pulleys were attached vertically to a rigid plastic strip. This is what guided the shuttle along the tether. The tether was fed through one vertical pulley, around a grooved horizontal driving wheel, then back through the other vertical pulley. The driving wheel was connected directly to a fishing wire wheel. The end of the wire was then attached to a ground mounted motor. The concept was for the ground motor to pull in the wire, in turn causing the fishing wire wheel to rotate as the wire was pulled from it. The rotation of the fishing wire wheel would then cause the rotation of the driving wheel. The driving wheel would climb up the tether due to the friction of the tensioned tether wrapped around it. An image of this prototype is shown in Figure 18. When the system was to be brought back down, the ground mounted motor would be rotate in reverse, releasing wire back to the shuttle. As the shuttle climbed back down the rotation of the driving wheel would wind the wire back up around the fishing wire wheel.

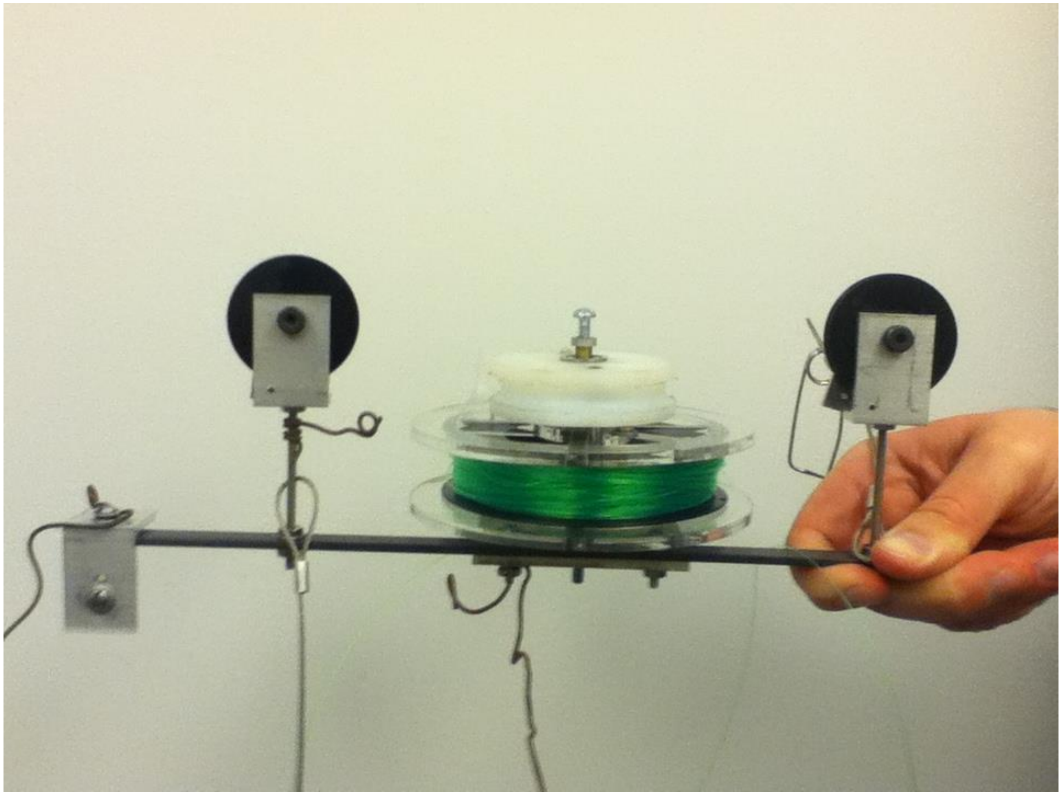

Figure 18. Shuttle Carrier Series 1.0

Attached to the shuttle carrier via a dangling pendulum, was the release system. This pendulum acted as a counterweight to keep the shuttle carrier vertical on the tether. This subsystem is discuss in more detail later.

The first shuttle carrier prototype was tested. The shuttle climbed up a tethered line at approximately a 30 degree angle. Successful and unsuccessful features were observed. The counterweight did an effective job of keeping the system vertical even with disturbance. The largest drawback from the first prototype was the wire based climbing system. The system created entanglement issues during setup and take down. While climbing, the system would tangle on occasion. The largest issue with this system was the retrieval of the system when the shuttle needed to climb back down. The wire did not wind back around the fishing wire wheel as planned. The wire would get tangled causing the shuttle to get stuck, not able to return.

Shuttle Carrier Series 2.0

The Series 2.0 shuttle carrier was based on the original prototype, but completely rebuilt from the ground up. The main alteration of the design was the incorporation of a geared DC motor on the shuttle carrier itself to power the climb up the line. It was determined that the added weight of the motor would be negligible compared to the power it provided. The output of the motor was 60 rpm with stall torque rating of 130 N*cm or 11.5 lbf*in. When attached to the driving wheel, with a radius of 1.75", this could produce around 6.5 lbf. The DC motor fixed the tangling issue of the wire based system and made the shuttle carrier more reliable. The whole framework of the shuttle was refined. The dimension and sub-assemblies, such as the guiding pulley casing, were redesigned and cleaned up as well. The entire frame was constructed of aluminum. A new Delrin driving wheel was fabricated. It was attached to the motor with a simple custom coupling. The Series 2.0 shuttle carrier is shown in Figure 19.

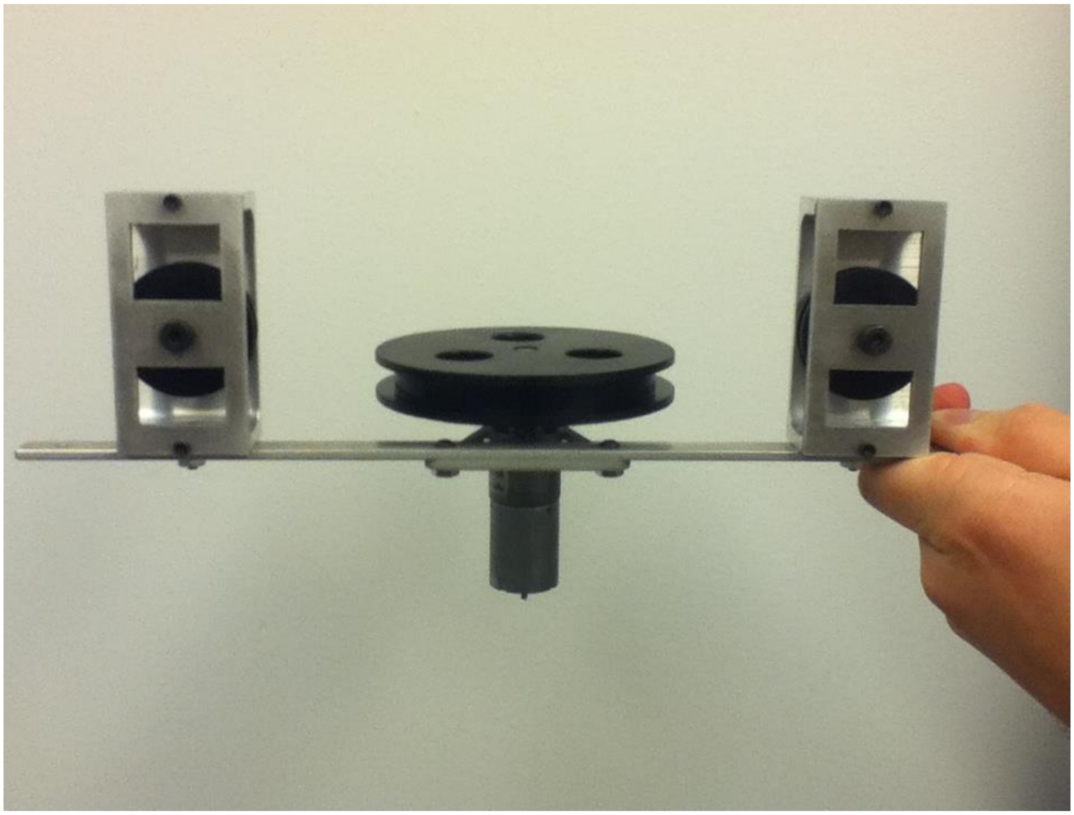

Figure 19. Shuttle Carrier Series 2.0

The Series 2.0 shuttle carrier was tested by being made to climb a tether at approximately 30 degrees, 40 degrees, and 65 degrees. This was done by anchoring a tether at two fixed points of different heights. The shuttle had no issues climbing at 30 and 40 degrees although it climbed slower than desired. At 65 degrees the shuttle seemed to be struggle slightly. It was also observed that all the weight of the device was on one guide pulley, leaving the other floating above the tether. This issue is shown in Figure 20. The counterweight was attached at the far left of the shuttle. Since the counterweight was left of both guide pulleys, it caused a moment, creating a lever of which the left guide pulley was the focal point. This took the weight off of the right pulley, as demonstrated in Figure 21. This made the tether sit only on the left guide pulley.

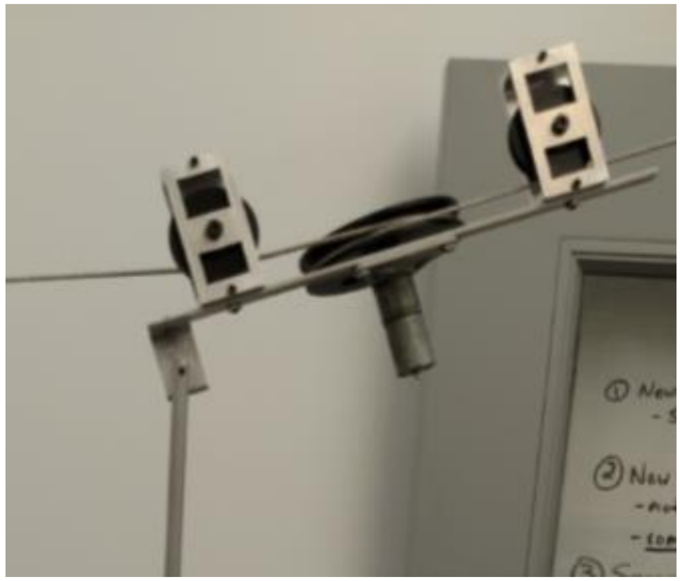

Figure 20. Guide Pulley Leverage Issue

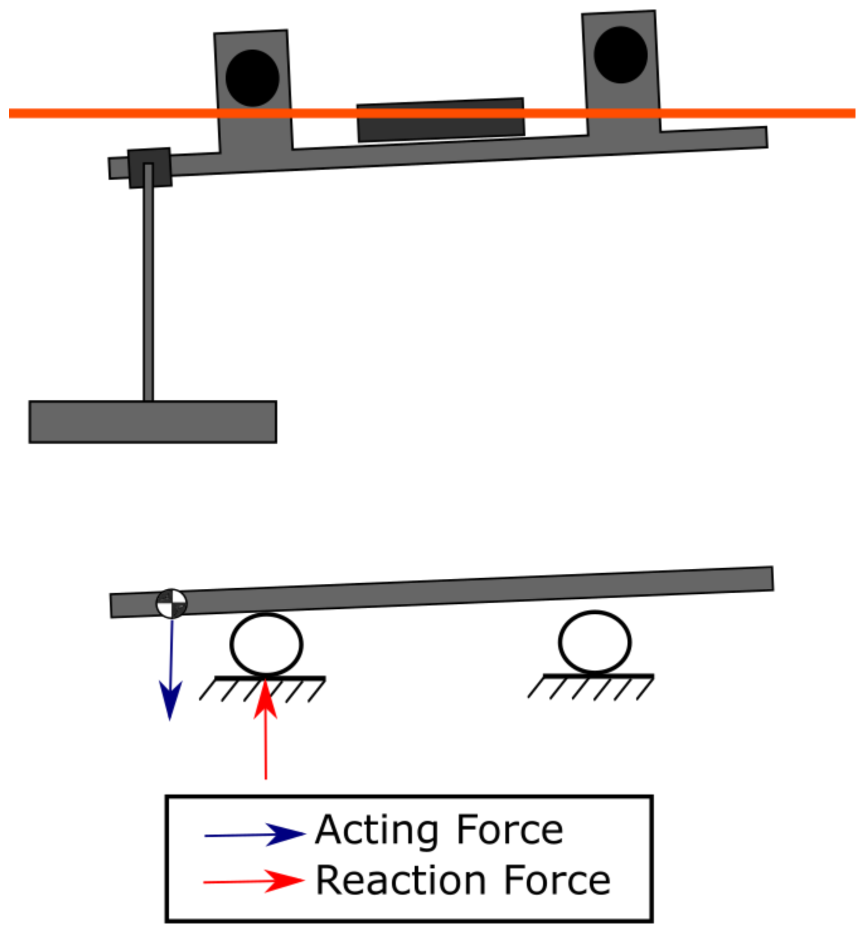

Figure 21. Guide Pulley Leverage Issue – Model

Shuttle Carriers Series 2.1

The Series 2.1 shuttle carrier was a modification of the original Series 2.0 shuttle carrier. A new, more powerful motor was found. The motor had a higher rpm rating of 200 rpm with a stall torque rating of 17.5 kg*cm or 15.2 lbf*in. A new motor mount and coupling were fabricated for use with this motor. The driving wheel itself was not altered. The counterweight was relocated between the two guide pulleys. It was positioned slightly off center to avoid difficulties when mounted directly below the driving wheel. This relocation made the tether sit on both guide pulleys instead of just one, resolving the previous issue. More square holes were milled out of the guide pulley mounts to further reduce weight. The 3D model of the shuttle carrier is shown in Figure 22.

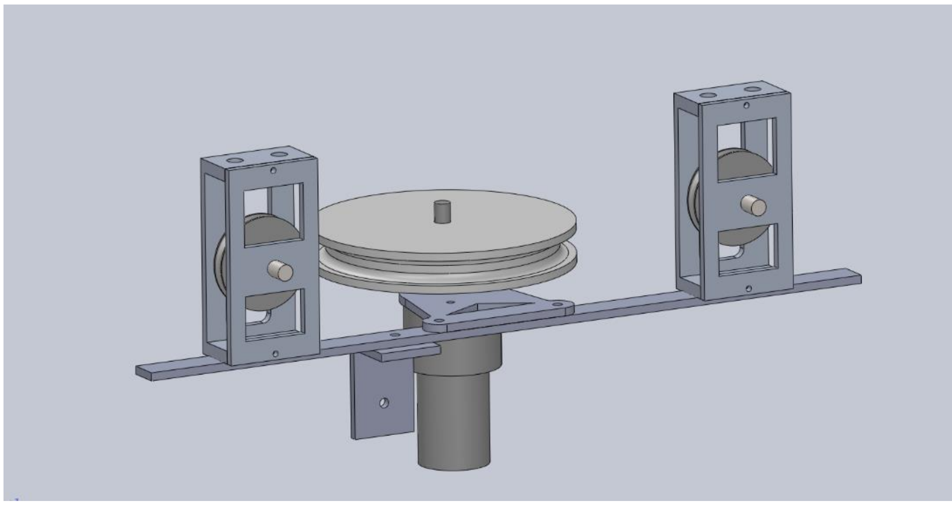

Figure 22. Shuttle Carrier Series 2.1 Model

The Series 2.1 shuttle carrier was tested climbing up a tether at angles of approximately 40 degrees and 65 degrees. The shuttle was tested with and without a 2.5lb weight added for each angle tested. It was found that the shuttle could climb at both angles with and without the added weight. This become the shuttle design for the final product, as shown in Figure 23.

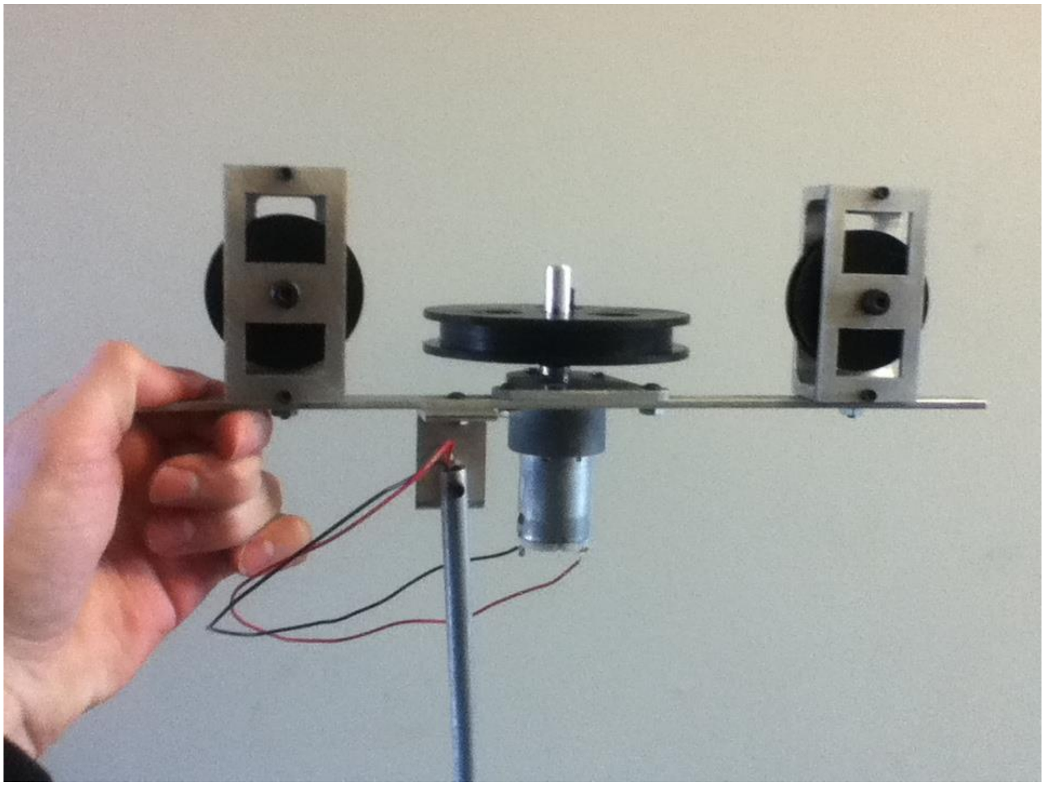

Figure 23. Shuttle Carrier Series 2.1

Chapter 5

Release System

Release System Requirements

Attached to the shuttle via pendulum was the release system. This subsystem served multiple functions. This subsystem: acted as a counterweight, supplied a platform to hold the electronics, and held/released the UAV.

Release System Counterweight Stabilization

The release mechanism and accompanying electronics were attached to the shuttle via a dangling pendulum-type structure. This served both purposes of keeping the UAV away from the tether wire for launch and acting as a stability system counter weight to keep the shuttle vertical on the line. If the shuttle were to pitch left or right on the tether line, the moment arm of the counter weight would cause a correcting moment bringing the shuttle back to vertical. This is shown in Figure 24. When the system was disturbed, a moment was created below the tether from the mass of the counter weight (M) at the distance (D) created by the pendulum arm. This moment was attempting to correct the system. A smaller moment is also created above the tether from the mass above of tether (m) at the shorter distance (d). This moment attempted to further disturb the system. Since the correcting moment was larger, this counter weight made the system stable.

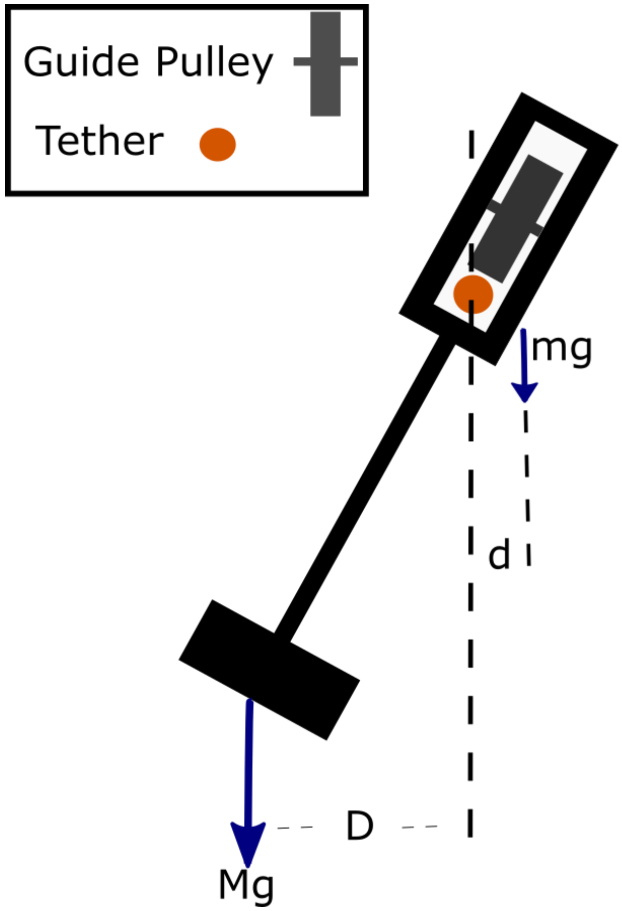

Figure 24. Counter Weight Stabilizing System

Release System Series 1.0

The Series 1.0 release system consisted of a baseplate with the electronics mounted to it along with a DC motor to operate the release mechanism. The release mechanism consisted of a claw and small motor-driven system. The motor drove a worm gear. This was fed through a threaded hole on a small platform. As the worm rotated, the platform moved up or down. This platform was attached to a claw linkage which reacted to the linear motion by clamping and releasing the claw. The system could release the UAV, however, an alternate approach was pursued. The motor used could not be driven directly off of the microcontroller. The motor needed an external battery along with a motor controller module. This added unnecessary weight and complexity to the system. An alternate setup using a servo for the release was investigated. A servo would be able to be controlled and powered by the microcontroller itself. This would save weight and complexity. A servo also allowed for more precise movements and control of the release mechanism.

Release System Series 2.0

The Series 2.0 release system incorporated a servo release mechanism. Series 2.0 still had the electronics directly mounted to the baseplate. The servo was mounted on the bottom of the baseplate. The servo was attached as part of a four bar linkage. One of the links contained an upward angled slot. The wire hook(s) of the UAV rested in this slot, held in place by gravity. When locked, the servo would be at a vertical position of 0 degree. Having this link vertical minimized the torque on the link, created by the weight of the UAV, trying to force the mechanism open. The rotation of the servo from the 0 degree position to the 103 degree position caused that link to rotate downward, releasing the UAV. This setup is shown in Figures 25 & 26.

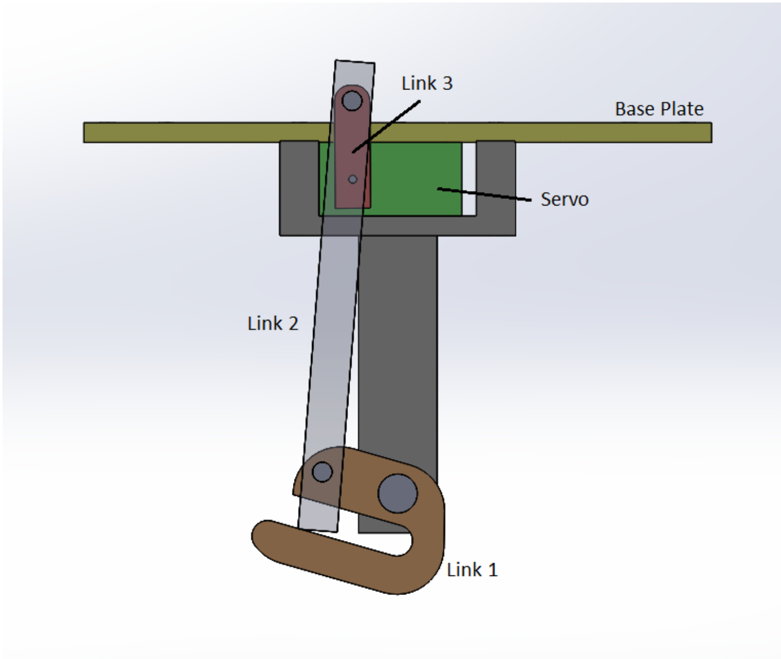

Figure 25. Release System Series 2.0 Closed

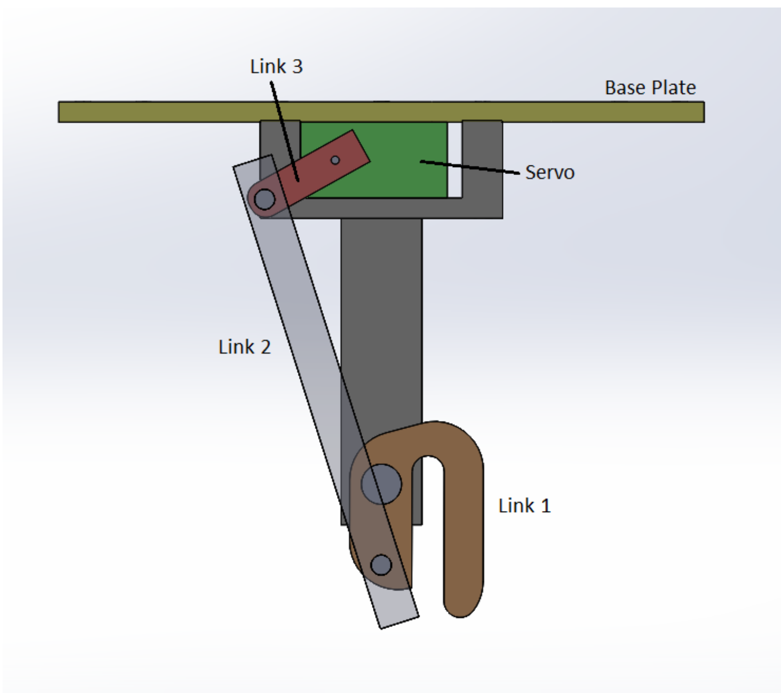

Figure 26. Release System Series 2.0 Open

The Series 2.0 release system was individually tested and found to operate successfully. The subsystem was then combined with the Series 2.1 shuttle carrier. This full setup was tested on a tether anchored to two fixed points at different heights. The release mechanism was found to work successfully during this test as well.

Release System Series 2.1

The Series 2.1 release system retained the same releasing mechanism, but altered the placement of the electronics. All of the on board electronics were mounted into a 6"x 4" x 2" project enclosure. The enclosure was mounted to the baseplate using Velcro. This improvement organized and contained the wiring while adding protection to the on board electronic equipment. This became the final version of the subsystem. An image of this is shown in Figure 27.

Figure 27. Release System Series 2.1 with Electronics Black Boxed

Chapter 6

Electronics

Electronic Requirements

The shuttle system had to be able to reliably climb and descend the kite tether along with releasing the UAV. Since this system would be a minimum of 50 feet in the air, the system had to be wirelessly controlled. Having long tethered wires mounted to a ground unit would become a tangle risk, increase complexity, and add weight.

Micro-Control and Wireless Components

The electronic system was controlled using two Arduino Uno microcontrollers. It was made wireless by utilizing an Xbee system. Xbee is a radio module capable of wirelessly transmitting and receiving information. Mounted to each microcontroller was an Xbee Pro attached via an Xbee shield. The shield allowed the Xbee Pros to mount directly to the microcontroller without messy wiring. The Xbee Pros are rated at a wireless range of one mile. The Xbees create a Zigbee mesh network. Zigbee is a specification standard for personal area networks based on IEEE standard 802.15.4 [12, 13]. This is similar to a Bluetooth network. The first Xbee was considered the router. This acted as a transmitter and was used in the remote control. The other Xbee was considered the coordinator. This acted as a receiver and was mounted in the shuttle. This wireless system was chosen because it is able to handle long distances with lower power consumption and easily compatible with Arduino.

Remote

The remote consisted of a 6” x 4” x 2” projects box with three push buttons and a power switch, shown in Figure 28. The push buttons corresponded to: shuttle climb, shuttle descend, and release open. With this setup the release was closed by default unless the signal was sent to open it. The internal electronics consisted of a 9V battery, Arduino Uno with Xbee router, and a pull up resistor circuit.

Figure 28. Remote Control Box

Pull up resistor circuit. The pull up resistor circuit was used to eliminate button bouncing error. Button bouncing, or contact bouncing, is the momentary noise seen by a logic unit when a button is pressed or released [14, 15]. For this circuit, shown in Figure 29, a 5 volt supply from the Arduino goes to pins 4, 5, and 6. This makes all of the pins receive a default “high” value. When a button is pressed, the signal is grounded for that button, changing the value seen by the corresponding pin to “low”.

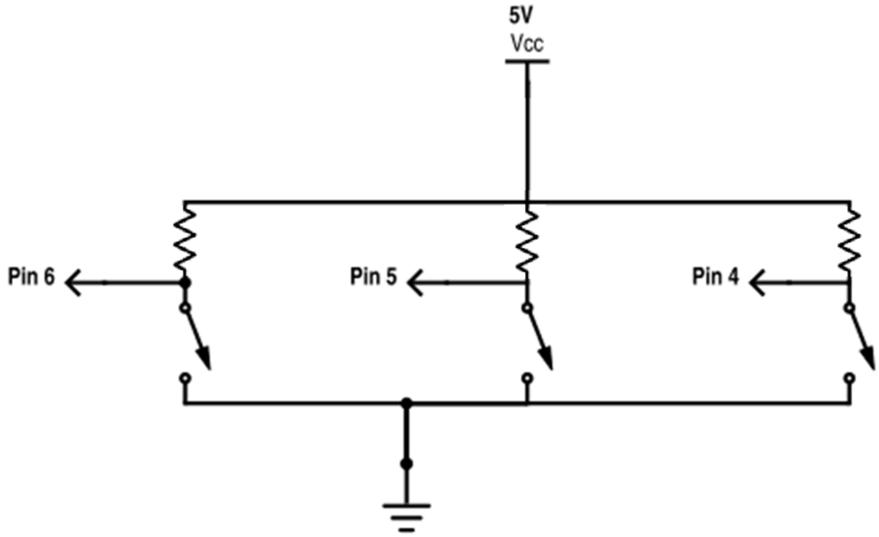

Figure 29. Pull Up Resistor Circuit

Programming. When the remote is activated and no buttons are pressed, it continually sends out a default signal of “S”, referring to “Stop”. If a single button is pressed, the remote will send out a “U”, “D”, or “R’ corresponding to the button activated. “U” corresponds to “Up” to have the shuttle climb up, “D” corresponds to “Down” to have the shuttle descend down, and “R” corresponds to “Release” to have the shuttle release the UAV. The Ardrino code for this can be found in Appendix A.

Onboard Electronics

Except for moving parts, the electronics on the shuttle are protected in a 6” x 3” x 2” project box. This box was attached to the release baseplate via Velcro. Velcro was used instead of glue or other adhesive because it was strong enough to hold the black box on while still retaining the possibility to remove the box in order to change batteries or access electronics inside. The onboard electronics consist of: a 9V battery, a 11.1V LiPo battery, an Arduino Uno with Xbee coordinator, a motor controller module, a shuttle carrier motor, and a servo.

Motor control. The Arduino has a max voltage output of 5 V [16]. It was capable of powering the servo directly, however, it was not capable of supplying the voltage required by the shuttle carrier motor. The motor controller module was used to combat this issue. This module acts as an intermediary between the LiPo battery which powered the motor and the Arduino. The microcontroller sent one digital and one PWM analog signal to the module. The digital signal determined the direction of the motor either forward or backwards. The PWM analog signal determined the motor's speed from complete stop to full speed. This is shown in Figure 30.

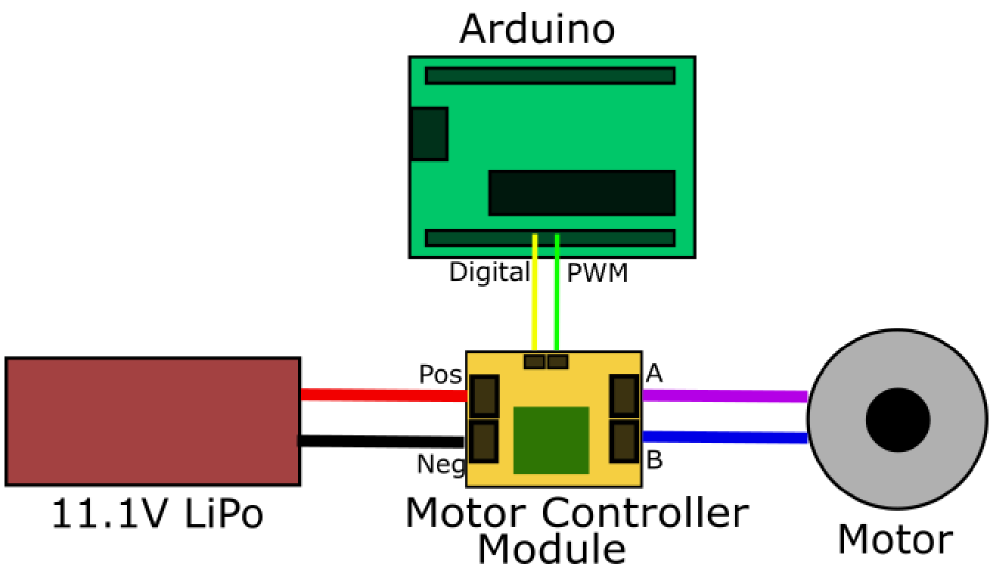

Figure 30. Motor Controller Module Setup

Programming. The Arduino with the Xbee coordinator onboard the shuttle continuously received the data signals sent by the remote transmitter. When a signal of "S" was detected, the Arduino retained or went to its default status. The default status was to supply no power to the motor and have the release in the closed position with the servo at 0 degrees. If a signal of “U” or “D” was detected, the release would remain in the closed position, but a PWM signal of max speed would be sent to the motor controller module along with a digital signal for direction. This would make the shuttle climb or descend the tether while keeping the release closed. If a signal of “O” was received the motor controller would get a signal to supply no power to the motor while the servo was directed to go to position 103 degrees. This would open the release allowing the UAV to fly off or allow a UAV to be loaded onto the shuttle. An organized layout of these signals and responses is shown in Table 3. The Ardrino code for this can be found in Appendix A.

Table 3

Control Table

Signal	**Direction**	**Speed**	**Servo Angle [deg]**
‘S’	Fwd	0	0
‘U’	Fwd	Full	0
‘D’	Back	Full	0
‘O’	Fwd	0	103

Chapter 7

Final Product & Testing

Final Product

For the final product the Flow Form 4.0 kite was used. The finalized shuttle used the Series 2.1 shuttle carrier, Figure 31, and the Series 2.1 release system, Figure 32, attached by a hollow aluminum rod. The wire running from the electronics to the shuttle carrier motor was fed through this rod. The final shuttle is shown in Figure 33. It weighed a total of approximately 3 pounds without a UAV attached.

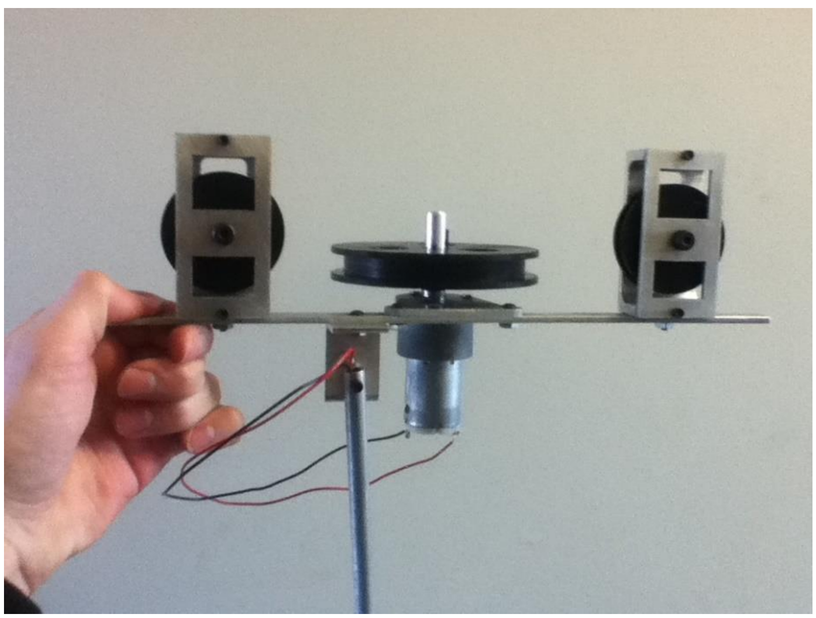

Figure 31. Final Shuttle Carrier - Series 2.1

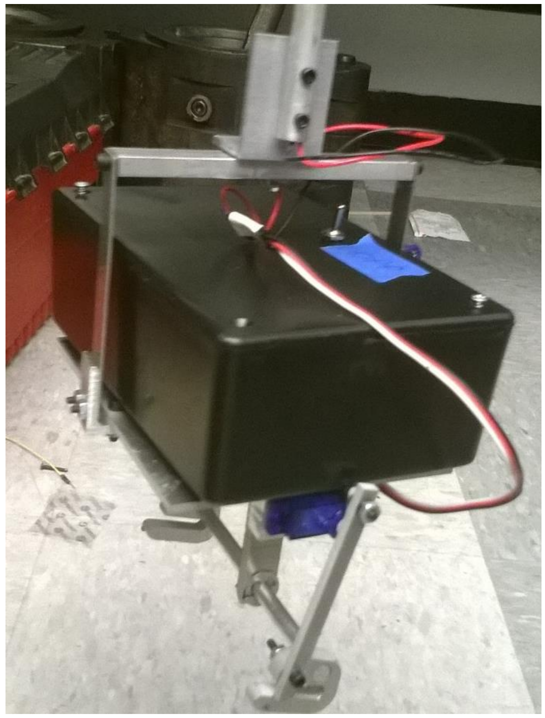

Figure 32. Final Release System - Series 2.1

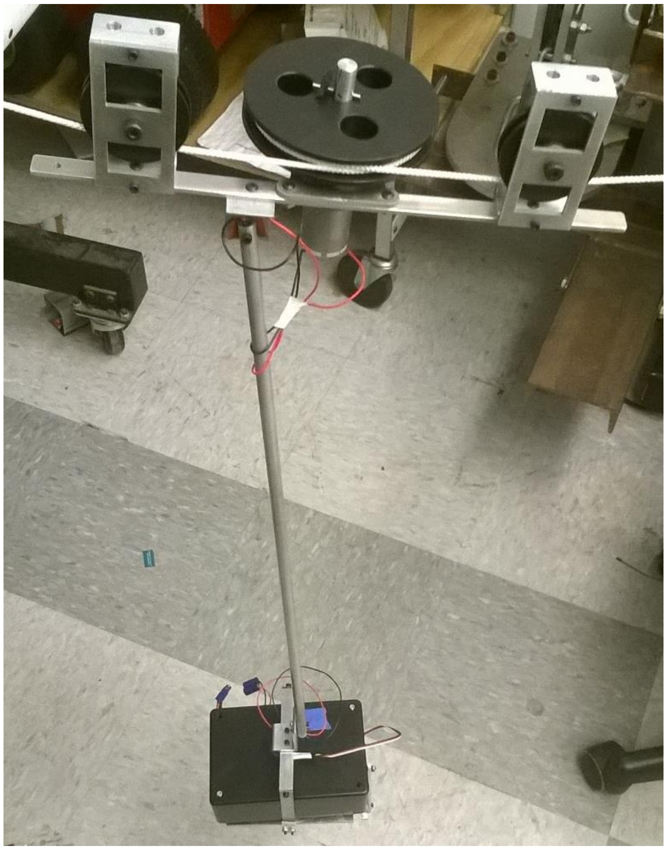

Figure 33. Final Product – Shuttle

Testing

Initially, this product was tested by having the shuttle travel up a fixed tether to then release a UAV. The tether was anchored to two fixed points at different heights creating an angle. This was done at 40 degrees and 65 degrees. The shuttle was able to climb both and release the UAV. This test was repeated with a 2.5lb weight added. This shuttle was successful again at both angles.

The field test would confirm that this product would work in a real life application. For this the Flow Form 4.0 kite was flown with 100-150 feet of tether let out. One of the three UAVs was locked into the release mechanism. The shuttle was then attached to the tether to climb the line. The most successful test, however reached only 20 feet before it had to release the UAV and return down. Other tests climbed higher, but could not safely release the UAV. The issue was in the nature of the design.

The kite itself produced enough tension in the tether to support the shuttle. The variation in tension is the factor causing the failure. The tension in the line would increase or decrease by a few pounds, due to slight changes in the wind. This caused the tether to become either taut or relaxed. These slight decreases in tension caused the shuttle on the tether to drop downwards, while slight increases in tension caused the shuttle to be pulled vertically upwards. This is shown in Figure 34. As the tension increased, the difference between the "kite angle" and "shuttle angle" decreased. This pulled the shuttle vertically up. The same effect occurred in the opposite direction when the tension decreased. This oscillating disturbance caused the shuttle to bounce around on the line. This made it impossible to safely release the UAV with the shuttle flailing around. During one test, the buildup of this disturbance even caused the flailing shuttle to pull the kite down from the sky.

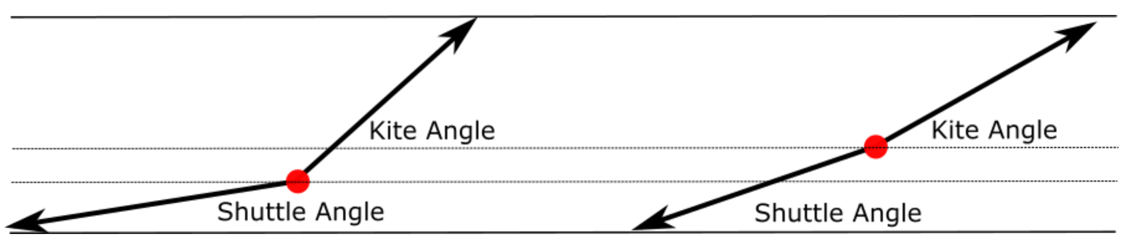

Figure 34. Shuttle Vertical Position with Alternating Tension

The disturbance can be quantified by the change in height of the shuttle. The height of the shuttle can be determined from the shuttle angle and length of tether from the ground to the shuttle. The largest deflection occurs when the shuttle is located in the center of the tether. To account for the worse case, the length of tether to shuttle can be considered half the total tether length. This is shown in Equation Set 5.

$$h = \frac{L_{total}}{2} * \sin(\theta_{shut})$$

$$\Delta h = h_{t+1} - h_t$$

Equation Set 5: Disturbance Shuttle Height

The shuttle angle can be found either by field test; or calculated from a known kite tension, shuttle weight, and kite angle. This equation was found by rearranging the previous equation for kite tension and solving for the shuttle angle. This is shown in Equation Set 6.

$$\theta_{shut} = \tan^{-1}(\tan\theta_{kite} - \frac{mg}{T} * \frac{1}{\cos\theta_{kite}})$$

Equation Set 6: Shuttle Angle

Chapter 8

Conclusion

After research, development, and testing of this system, it was found that the EHAWK: UAV system would not be a viable solution at this time.

The disturbance in the line caused by the changing wind speed made it impossible to keep the shuttle stable enough to safely release a UAV. To minimize disturbance, the tension in the kite tether would have to be increased. The same amount of change in tension would create a lesser disturbance with a higher kite tension. This means a tension drop from 25 lbf to 20 lbf in the line would create more of a disturbance than a tension drop from 40 lbf to 35 lbf. To obtain this higher tension, the kite would have to be flown higher. This would require adding an anchoring system and possibly upgrading to a higher tension rope to account for the stronger winds.

This brings up the question of how this system is stable enough for aerial photography. During kite aerial photography, the camera is attached to a stabilizing rig with pan and tilt. This rig is then attached to the tether close to the kite itself [17]. Since the rig is always close to the kite, which is acting as an anchor point, it sees minimal deflection as the tension varies. This is unlike the EHAWK system which climbs up the entire tether experiencing the worst deflection in the middle of the line between the kite and ground. This can be thought of as a beam supported by a fixed point at both ends. The most deflection would be caused by adding a weight in the center of the beam while the minimal amount of deflection would be caused by adding that same weight on the end of the beam directly above the anchor point.

If the disturbance issue can be overcome, there are still many practicality concerns. The kite needs to be launched and brought to its desired altitude, which is a burdensome task in itself. If that altitude is high with strong winds, then an anchoring system needs to be implemented with it. High altitudes also bring up FAA regulation concerns. A large kite hundreds of feet in the air voids the possibility of any stealth uses as well. The proposed system requires a small team to operate. At minimum one person is required to operate the kite while in the air and another is needed to: attach the shuttle to the tether, load the UAV to the shuttle, and operate the shuttle controls.

Some of these concerns are able to be overcome however, if used in specific applications, most likely military. Implementing this system onboard ships at sea would eliminate FAA concerns. Stealth is less of a concern in this environment as well. There is also current research into autonomous flight control of kites, which would simplify the use of this system [18, 19].

Overall though, the slight increase in range of the UAV would be negligible compared to the practicality concerns. A catapult launching system would be a far much more practical and is an already implemented solution. With a catapult system there would be no need for launching a kite to a high altitude, along with no FAA regulation concerns regardless of environment. It can be simply loaded up with a UAV and operated by a single individual. It also can work for stealth uses. For practicality reasons alone, the proposed system is not a valid solution when compared to modern solutions already implemented. If future research and development can overcome current issues, this system may be a viable option.

Chapter 9

Future Work

Most importantly, future research would focus on overcoming the disturbance issue. Flying the kite at higher altitudes should be the first option to test. Another possibility is to modify the project to incorporate a blimp or balloon style of sky anchor instead of a kite. These, while still affected by wind, would be less sensitive to wind changes. This could assist in minimizing the disturbance. This style of system would be simpler overall and easier to launch compared to the kite system. Similar technology is already being used to gather weather data using weather balloons [20]. If the kite aspect is retained instead of investigating a balloon style sky anchor, the system could be integrated with an autonomous flight control system to fly the kite. Research into damping the motion of the tether or adding damping to the counterweight stability system are other possible areas of future development. A possibly solution is developing an active tether tension control system. This additional mechanism would pull or release tether to maintain constant tension in the tether line to minimize disturbance.

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Appendix A

Code

Remote Code

```
const int buttonUp = 4;// the number of the pushbutton pin
const int buttonDown = 5;
const int buttonOpen = 6;

int vec = 'S';

// variables will change:
int buttonUp1 = 0;         // variable for reading the pushbutton status
int buttonDown1=0;
int buttonOpen1=0;

void setup() {
 Serial.begin(9600);
  pinMode(buttonUp, INPUT);
  pinMode(buttonDown, INPUT);
pinMode(buttonOpen, INPUT);
}

void loop(){
  // read the state of the pushbutton value:
  buttonUp1 = digitalRead(buttonUp);
 buttonDown1 = digitalRead(buttonDown);
 buttonOpen1 = digitalRead(buttonOpen);
  // check if the pushbutton is pressed.
  // if it is, the buttonState is HIGH:
  if (buttonUp1 == LOW && buttonDown1 == HIGH) {
// vec = 'U';
      Serial.println('U');

  }
   else if(buttonDown1 == LOW && buttonUp1 == HIGH) {

  //vec = 'D';
  Serial.println('D');

  }
   else if(buttonOpen1 == LOW ) {
    //Open servo release
    //vec =O
  Serial.println('O');
```

```
   }
  else{

//   vec = 'S';
   Serial.println('S');
  }
  delay(150);


}
```

Onboard Receiver Code

```
int incomingByte;      // a variable to read incoming serial data into
int fs=0;
#include <Servo.h>
Servo myservo;

void setup() {
  // initialize serial communication:
  Serial.begin(9600);

  pinMode(12, OUTPUT); //Initiates Motor Channel Direction
  pinMode(11, OUTPUT); // Speed
  myservo.attach(9);

}

void loop() {
  // see if there's incoming serial data:
  if (Serial.available() > 0) {
    // read the oldest byte in the serial buffer:

    fs=0;
    incomingByte = Serial.read();




    if (incomingByte == 'U') {
      Serial.print("Up ");
       digitalWrite(12, HIGH); //Establishes forward direction of Channel A

  analogWrite(11, 255);   //Spins the motor on Channel A at Full speed



    }
    if (incomingByte == 'D') {

      Serial.print("Down ");
        digitalWrite(12, LOW); //Establishes backward direction of Channel A

  analogWrite(11, 255);   //Spins the motor on Channel A at Full speed
```

```
    }

     if (incomingByte == 'S') {
     Serial.print("stop ");
       digitalWrite(12, HIGH); //Establishes FWD direction of Channel A
  analogWrite(11, 0);
     myservo.write(0);
    }
// Clamp

if(incomingByte == 'O'){

   myservo.write(103);

   }

  }

  }
```

Appendix B

SolidWorks Models and Drawings

Models

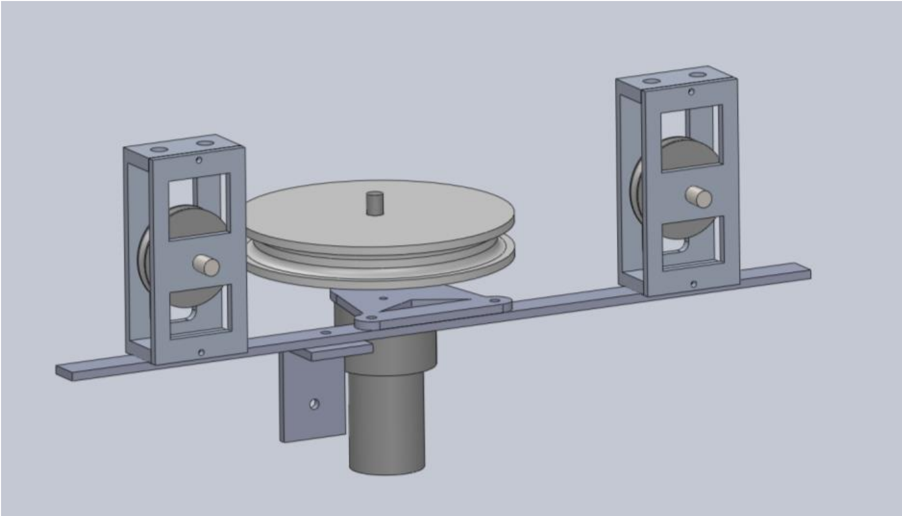

Figure B-1-1: Shuttle Carrier Model

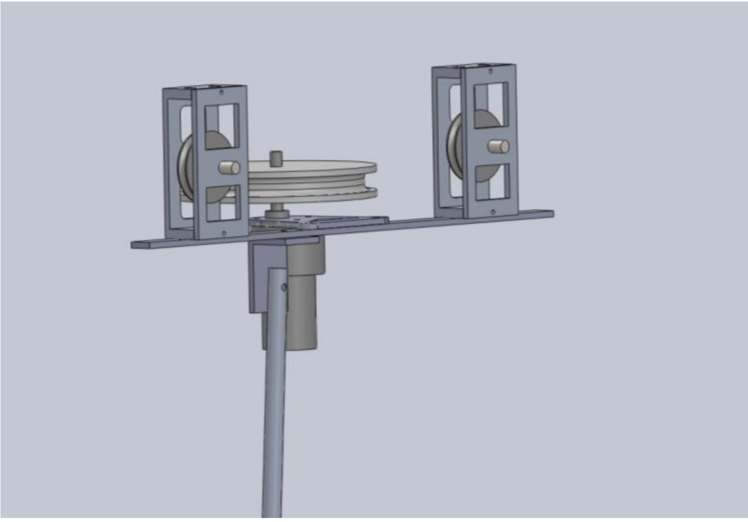

Figure B-1-2: Shuttle Carrier Model

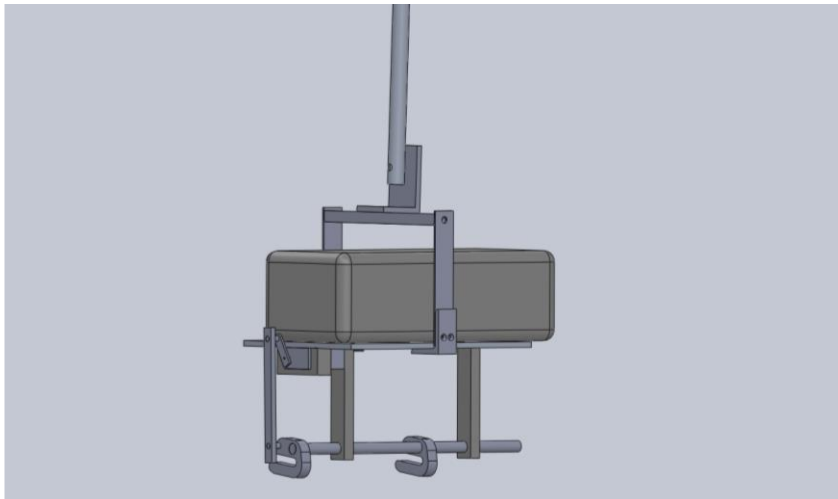

Figure B-1-3: Release System Model

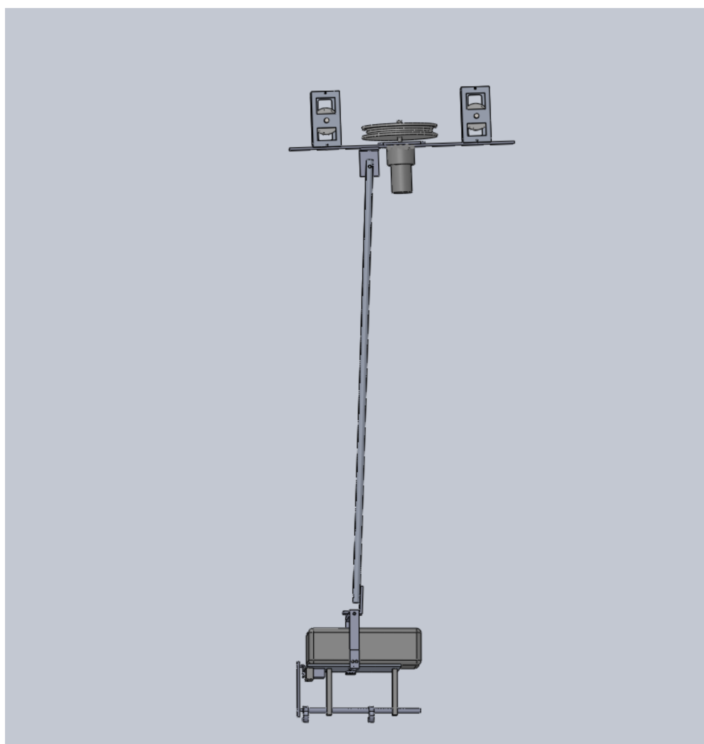

Figure B-1-4: Complete Shuttle Model

Drawings

ALL OF THE FOLLOWING FIGURES ARE IN UNITS OF INCHES

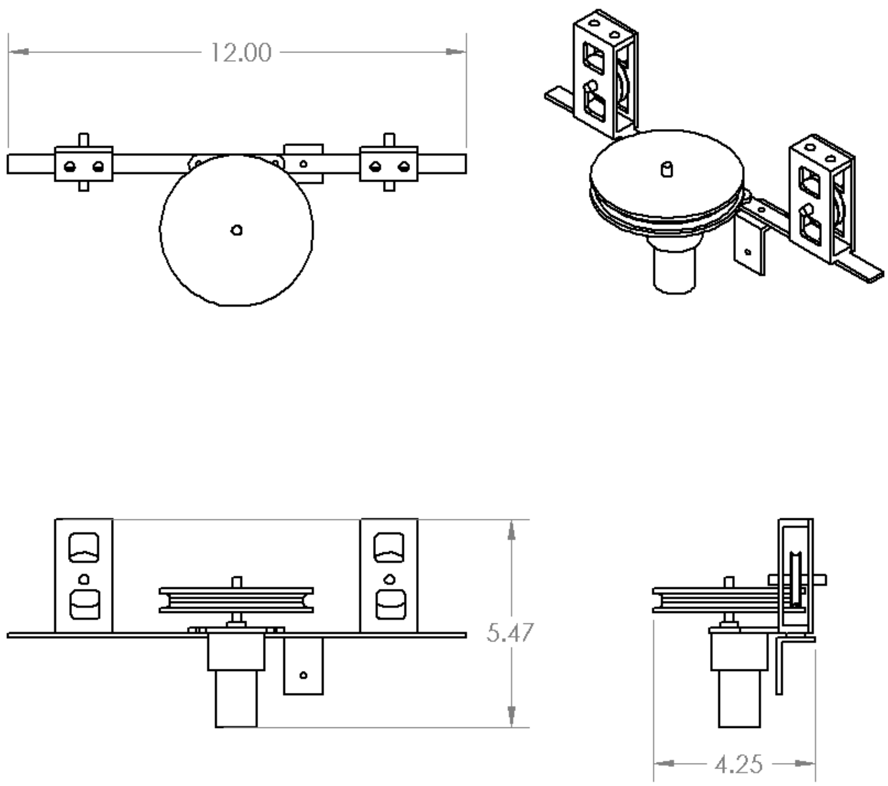

Figure B-2-1: Complete Shuttle Carrier Drawing

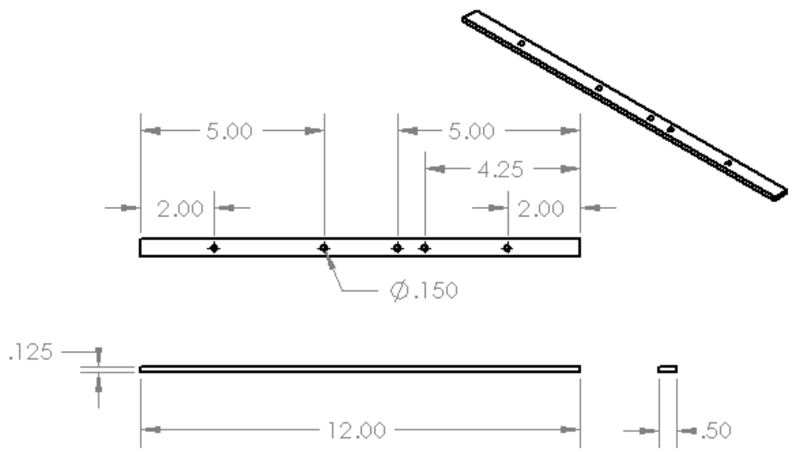

Figure B-2-2: Shuttle Carrier Main Rail Drawing

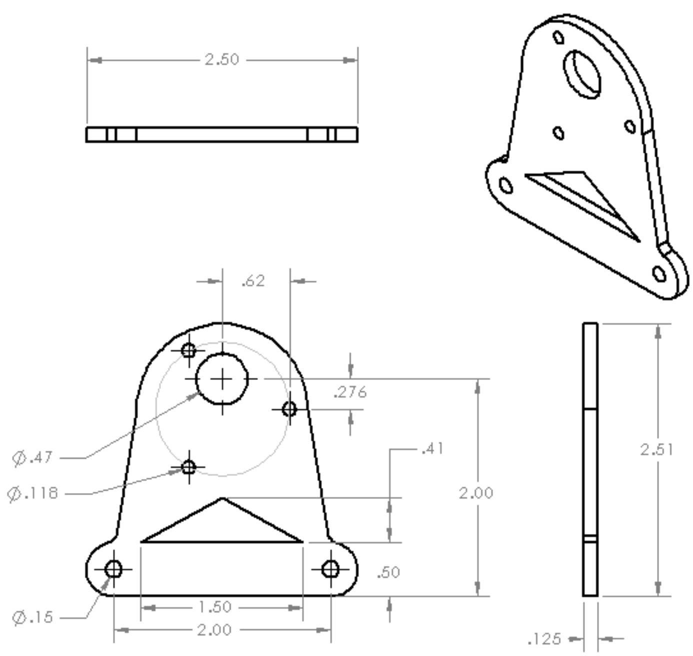

Figure B-2-3: Shuttle Carrier Motor Mount Drawing

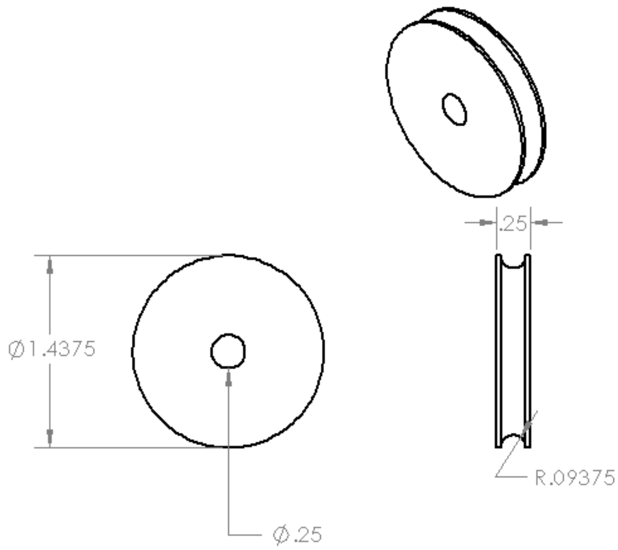

Figure B-2-4: Shuttle Carrier Vertical Pulley Drawing

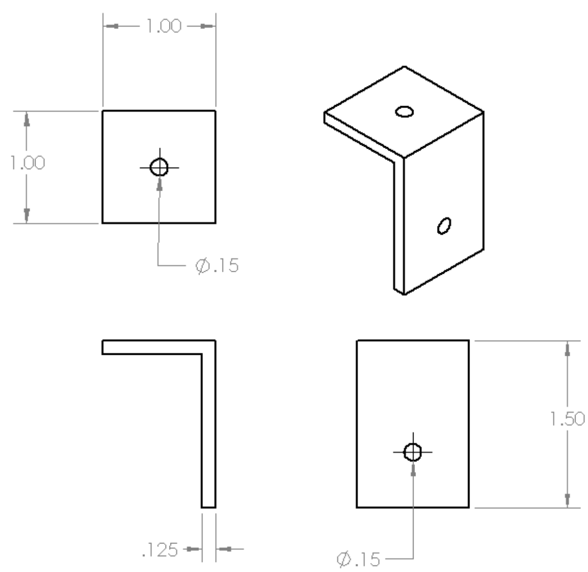

Figure B-2-5: Shuttle Carrier Angle Bracket Drawing

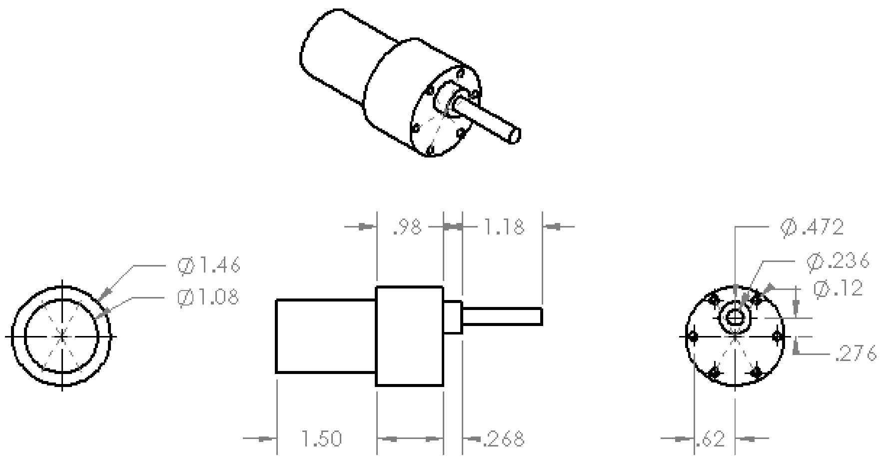

Figure B-2-6: Shuttle Carrier Motor Drawing

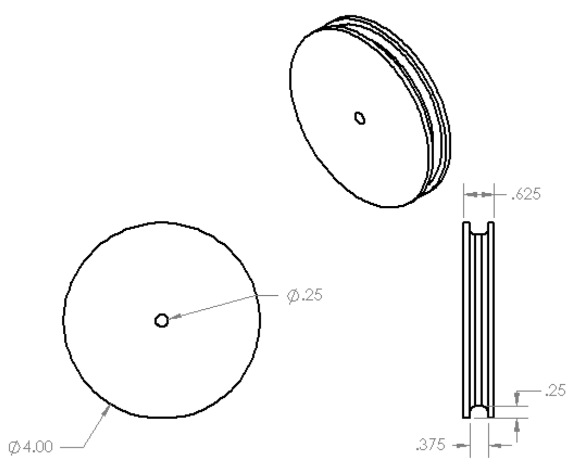

Figure B-2-7: Shuttle Carrier Driving Pulley Drawing

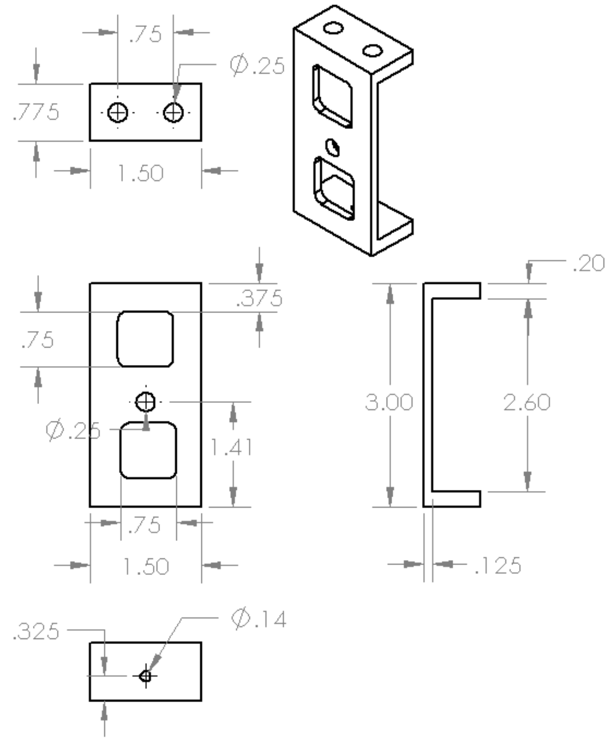

Figure B-2-8: Shuttle Carrier Main Pulley Housing Drawing

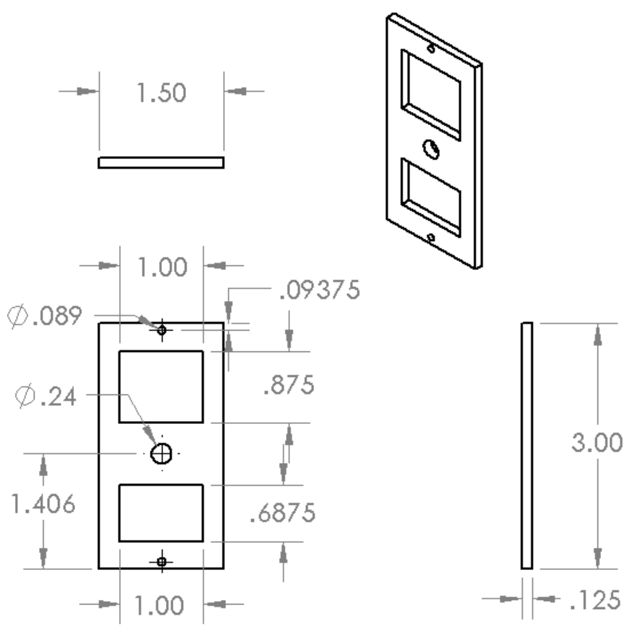

Figure B-2-9: Shuttle Carrier Pulley Housing Side Drawing

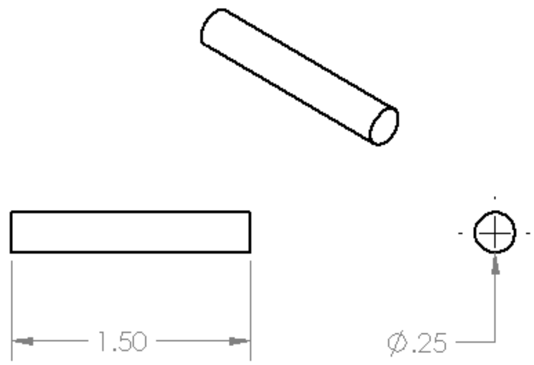

Figure B-2-10: Shuttle Carrier Pulley Pin Drawing

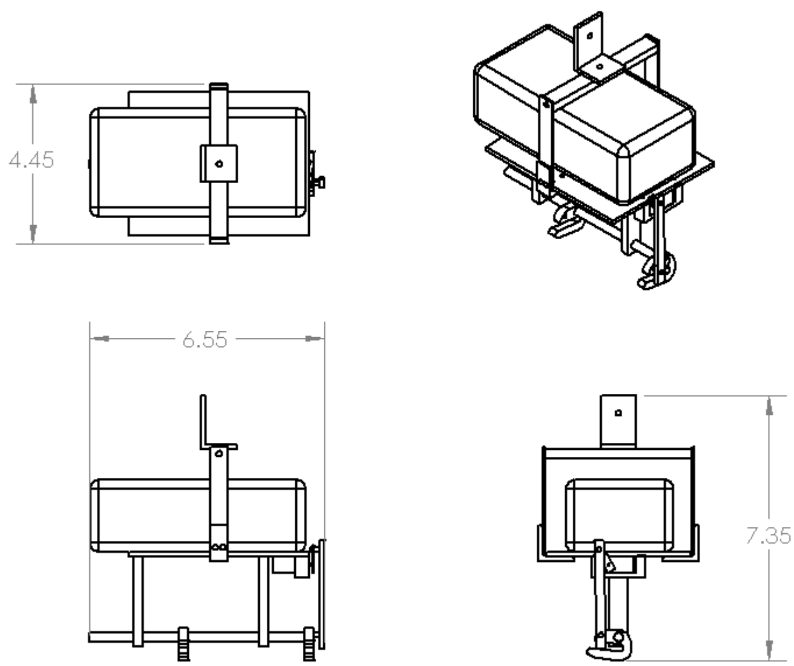

Figure B-2-11: Complete Release System Drawing

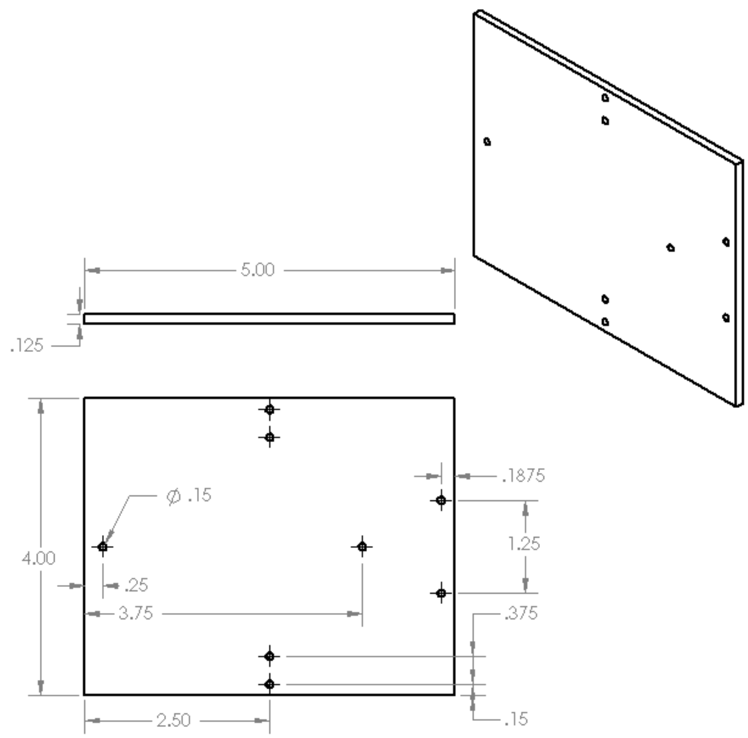

Figure B-2-12: Release System Baseplate Drawing

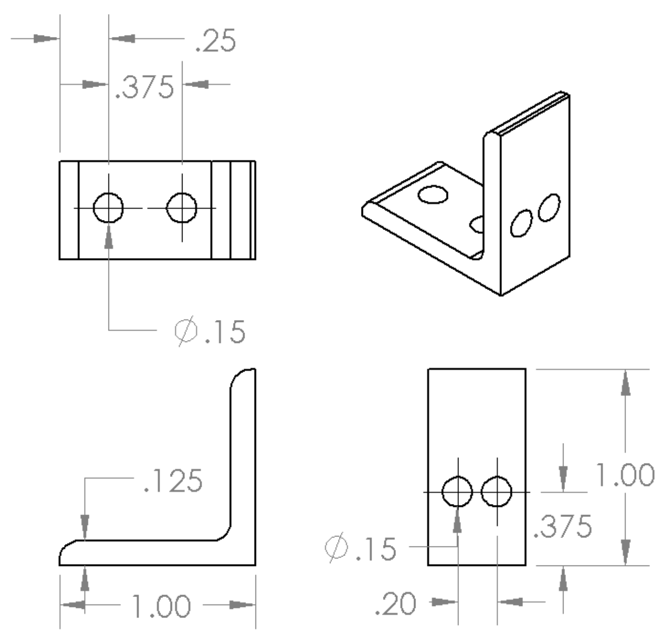

Figure B-2-13: Release System Elbow Connector Drawing

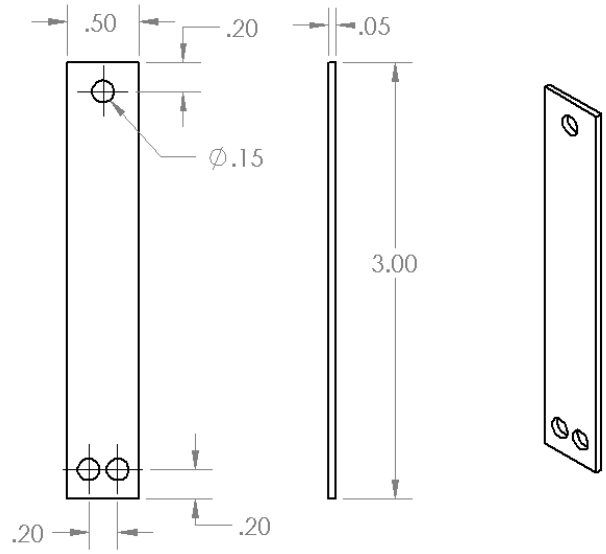

Figure B-2-14: Release System Side Support Drawing

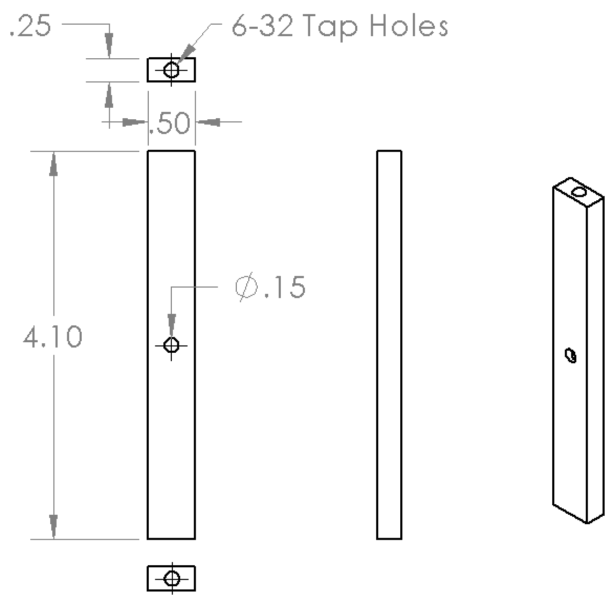

Figure B-2-15: Release System Top Cross Member Drawing

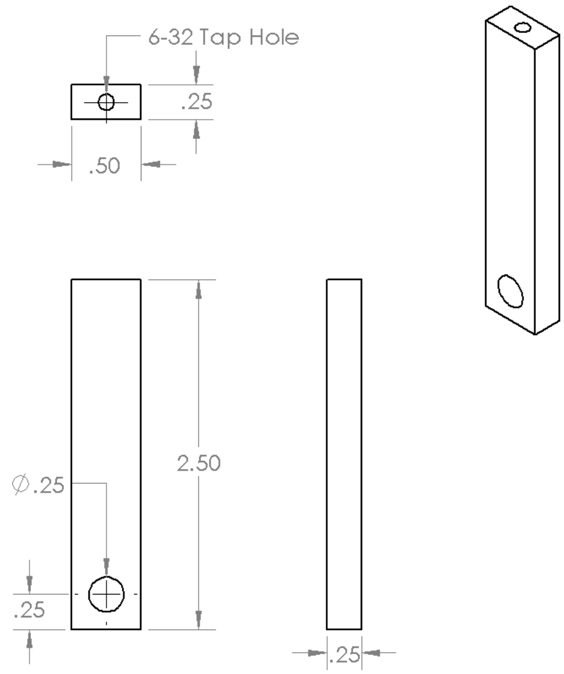

Figure B-2-16: Release System Release Mechanism Support Drawing

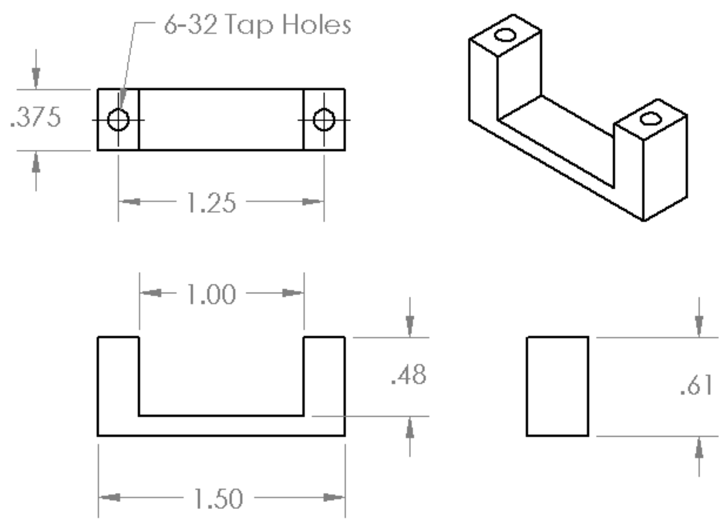

Figure B-2-17: Release System Servo Mount Drawing

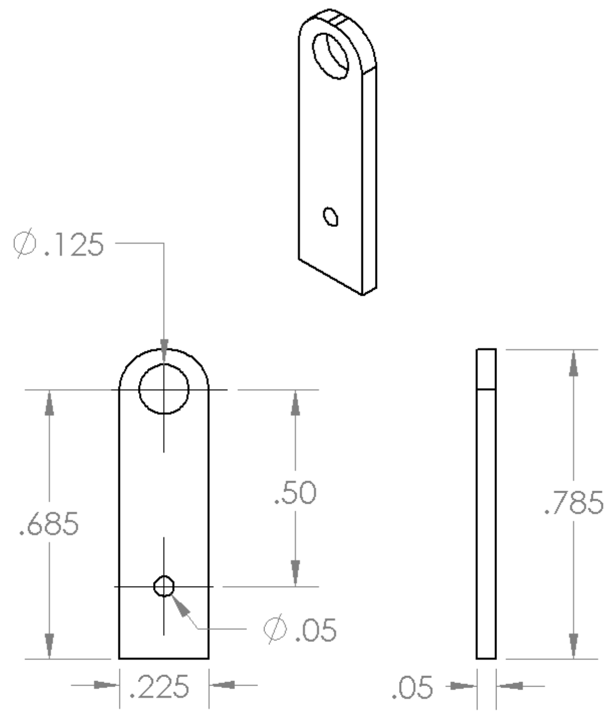

Figure B-2-18: Release System Servo Crank Link Drawing

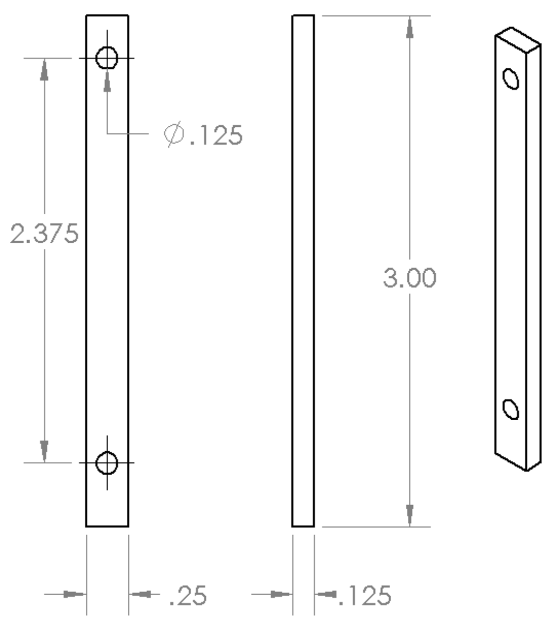

Figure B-2-19: Release System Long Link Drawing

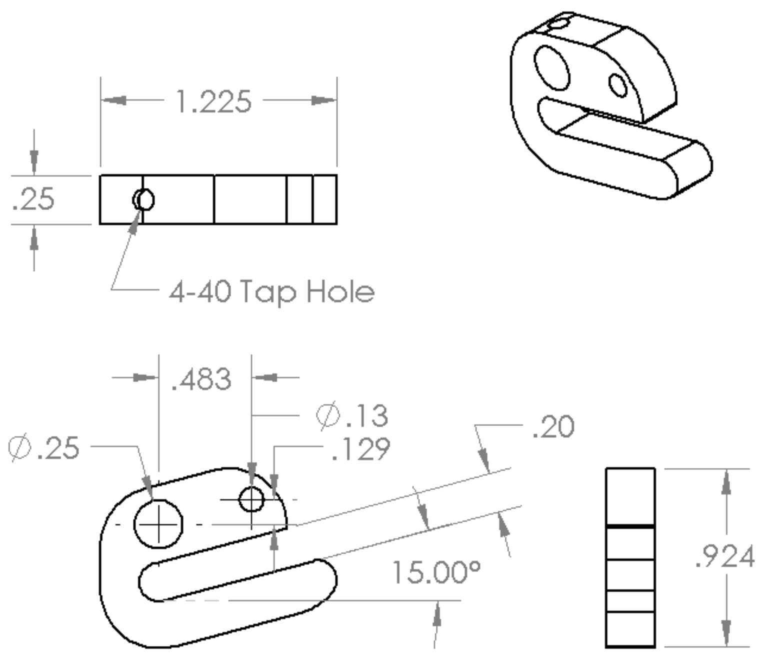

Figure B-2-20: Release System Release Link Drawing

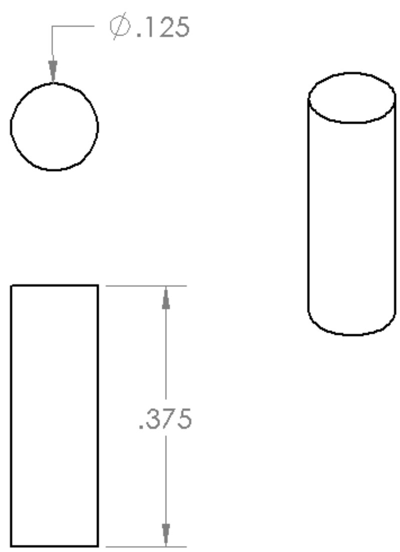

Figure B-2-21: Release System Link Pin Drawing

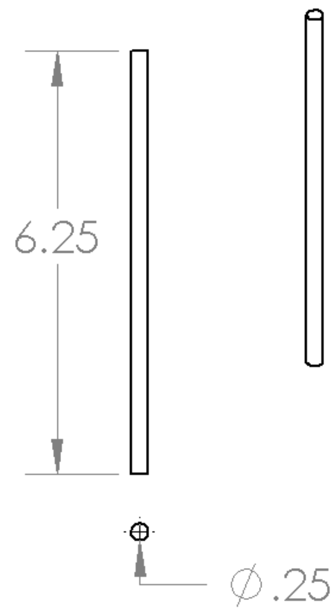

Figure B-2-22: Release System Shaft Drawing

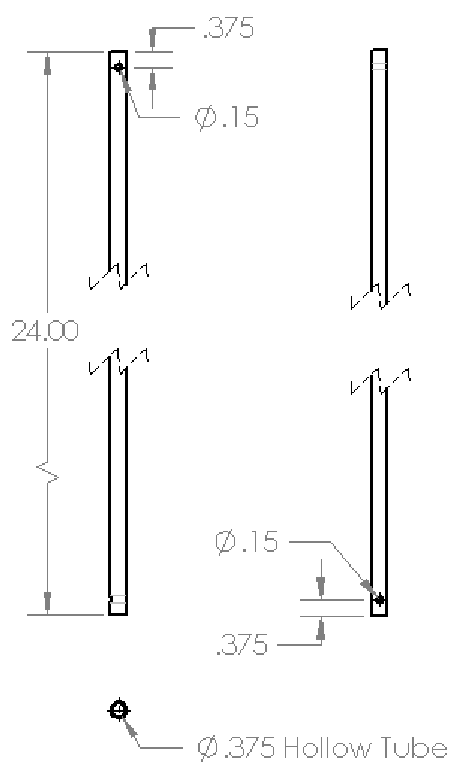

Figure B-2-23: Pendulum Connecting Rod Drawing