ECE 445

Senior Design Laboratory

Design Document

Electromagnetic Launch System with Switchblade Drone : Design Document for ECE 445

Team #4

Shuyang Qian (sq8@illinois.edu)
Zheng Fang (zhengf4@illinois.edu)
Xinyu Xia (xinyux4@illinois.edu)
Ruike Yan (ruikey2@illinois.edu)

TA: Adeel Ahmed

March 22, 2022

Contents

1 Introduction

1.1 Problem

In modern society, the widespread adoption of Unmanned Aerial Vehicles (UAVs)[1] has introduced a plethora of benefits and opportunities. However, with these advancements come new challenges and concerns that need to be addressed. The rapid proliferation of UAVs in various sectors, such as agriculture, disaster management, surveillance, delivery services, and environmental monitoring, highlights the need for a comprehensive understanding of the implications of this technology on society.

Switchblade UAVs are small but highly effective drones that have gained popularity in commercial applications due to their maneuverability, versatility, and ability to be launched quickly and quietly. However, the current technology used to power these drones, pneumatics, has limitations in terms of launching speed, cost, and portability. Additionally, the existing Switchblade UAVs require computer chips to control the UAV to spread the wings of the drone. This process can be time-consuming and may lead to delays in operations. To overcome these challenges and improve the design of Switchblade UAVs, there is a need to explore alternative power sources. To successfully develop this technology, it is essential to draw upon expertise from both commercial and engineering sectors. Commercial experts can provide valuable insights into the specific requirements of UAVs in various industries, while engineering experts can help ensure that the technology is scalable, cost-effective, and technically viable. By bringing together expertise from multiple fields, it may be possible to develop an electromagnetic launch system that revolutionizes the field of drone technology.

In recent years, there has been a growing interest in electromagnetic technology as a means of powering drones. This technology offers several advantages over traditional power sources, including faster launching speeds, greater portability, and reduced costs. By harnessing the power of electromagnetism, it may be possible to improve the design of Switchblade UAVs and make them more effective in commercial applications, such as aerial photography, inspections, agriculture, and delivery services.

1.2 Solution

The project aims to develop an electromagnetic launch system that can effectively launch Switchblade drones for various commercial applications. This innovative solution for high-speed unmanned aerial vehicles will incorporate the latest advances in electromagnetic technology, including high-powered magnets and electromagnetic coils, to provide a powerful and efficient launch mechanism. The resulting system will be lightweight, portable, and easy to deploy.

There are four critical steps to achieve a functioning system: design and construction of the launch system, development of the foldable wing mechanism, integration of subsystems, and testing and validation.

One advantage of electromagnetic-launched drones over pneumatic-launched drones is that they do not require heavy air pumps, which can be cumbersome and impractical. Instead, electromagnetic-launched drones can utilize convenient batteries or capacitors, reducing the overall weight and making the system more portable and user-friendly.

Additionally, existing drones are often made of metal, which can be heavy and expensive. Switchblade drones made from lightweight PLA materials offer a lower cost and lighter mass. This design aligns with the disposable nature of the spring blade drone, making them more cost-effective and versatile for commercial usage.

Through careful planning, design, and testing, this project has the potential to revolutionize the field of unmanned aerial vehicles, enabling high-speed, long-distance flights with a switchable drone that is lightweight, cost-effective, and more suitable for various commercial applications.

1.3 Visual Aid

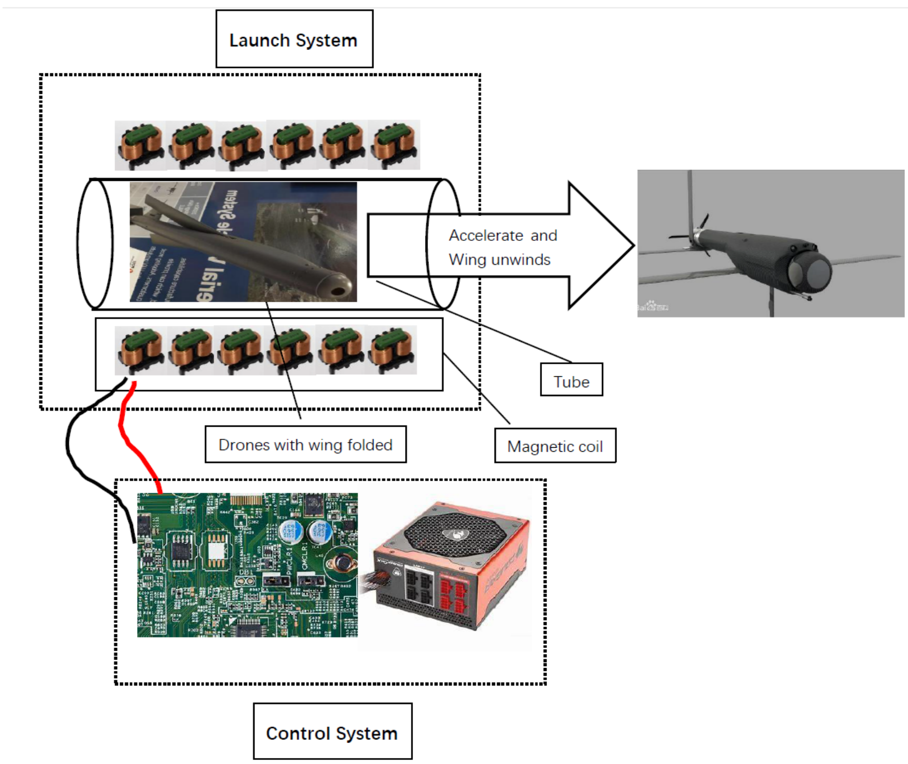


Figure 1: The Visual Aid of Electromagnetic Launch System with Switchblade Drone

1.4 High-level Requirements List

1. The drone should accelerate continuously and finally gets a speed of 3-6 m/s to take off.The launch system can work when the dip angle is 0-30 degree.The launch system can work outside normally when the wind speed is 0-3 m/s.

2. The switchblade drone should fold its wings on the launch rail and should complete the deployment of all four wings within 1 second after launch.

3. Drone should be able to fly a distance of 10 meters after launch.

2 Design

2.1 Block Diagram

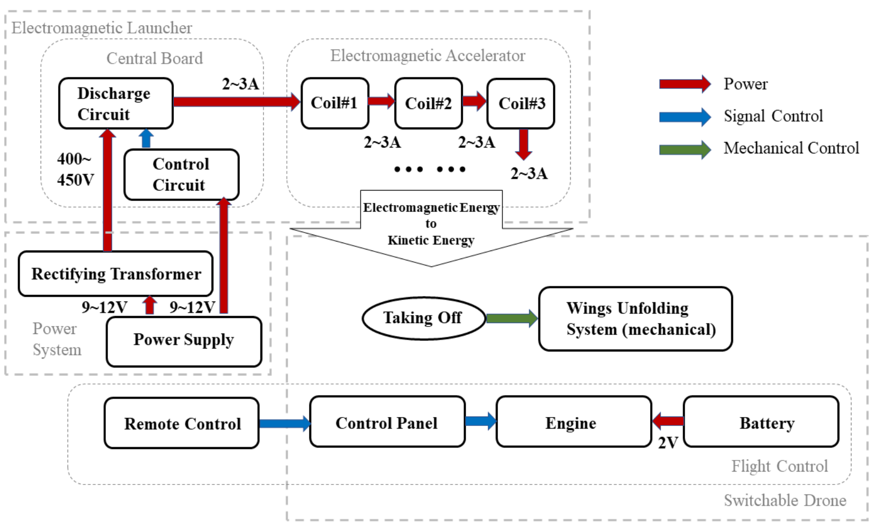


Figure 2: Block Diagram

2.2 Physical Diagram

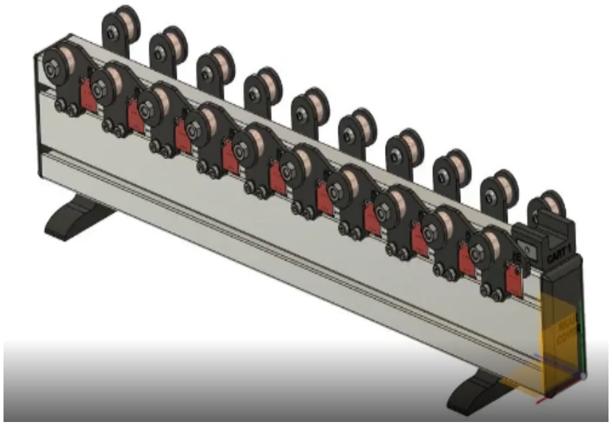


Figure 3: Physical Diagram of Rail

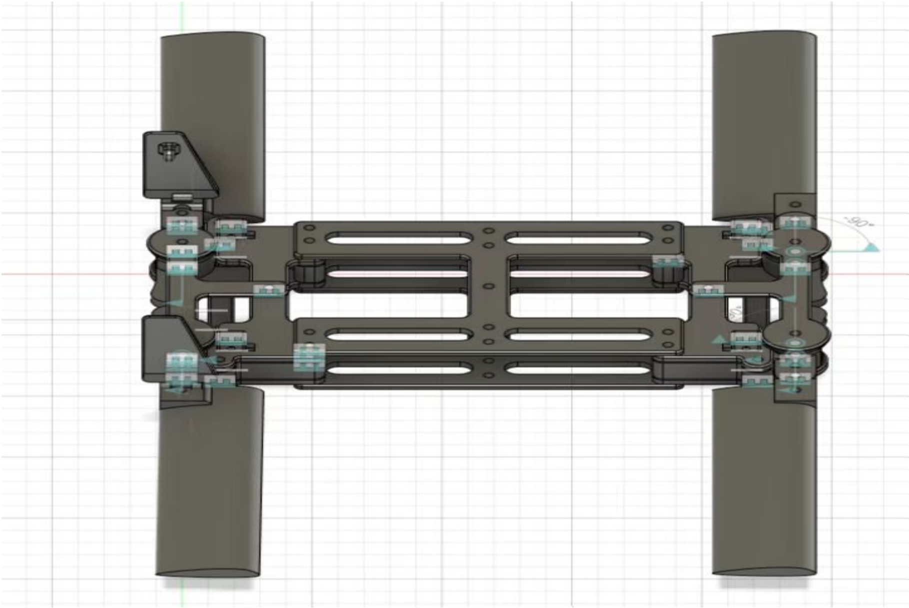


Figure 4: Physical Diagram of Drone

2.3 Subsystem Description

2.3.1 Power Supply Subsystem

The power supply subsystem is an integral part of an Electromagnetic Launch System for drones. The main function of this subsystem is to provide a stable and regulated 450V DC output voltage from an input voltage range of 9V to 12V. After incresing the output voltage, the subsystem will store its energy to 400 capacitors with 450V 1500uF. If we open the switch of the capacitors, the coils will be generated at 400-450V. The system utilizes a Zero Voltage Switching (ZVS) resonant converter, which is known for its high efficiency and reduced switching losses. The circuit design diagram and physical photo are shown in Figure 5 and Figure 6.

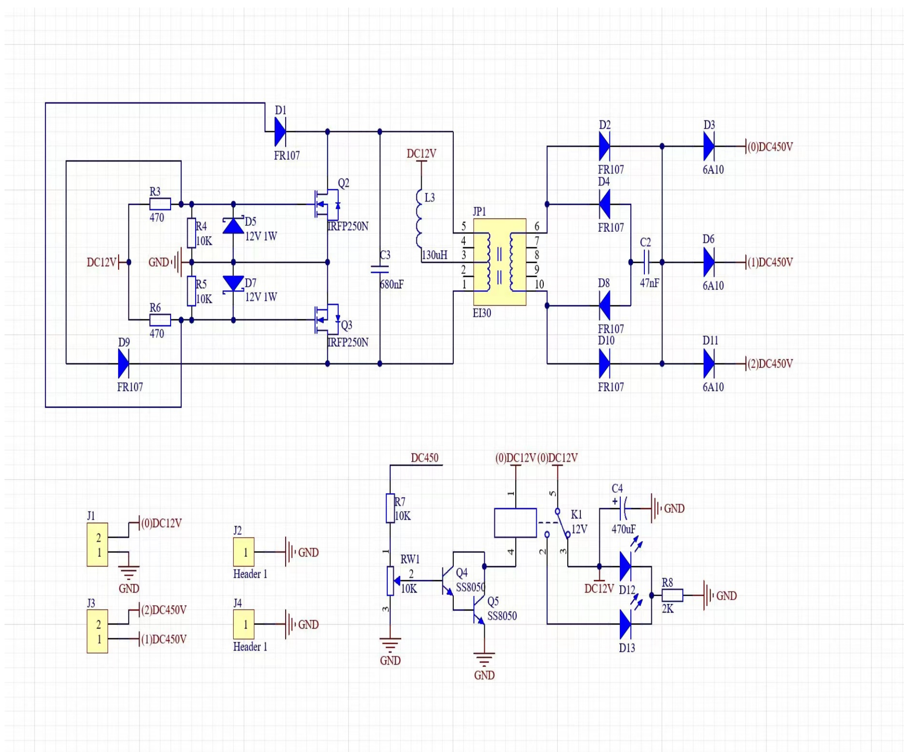


Figure 5: Circuit Design Diagram

This power supply subsystem is designed to handle a wide input voltage range while maintaining a stable output voltage, ensuring that the drone's launch system can function reliably under varying input conditions. The subsystem incorporates various stages to ensure the desired output is achieved and to provide adequate protection to the system.

An EMI filter is used at the input stage to minimize noise and interference from the input voltage, improving the power quality of the system. The input voltage is then rectified and filtered to provide a constant DC voltage for the ZVS resonant converter. The full-bridge rectifier and capacitor filter combination helps in achieving this goal.

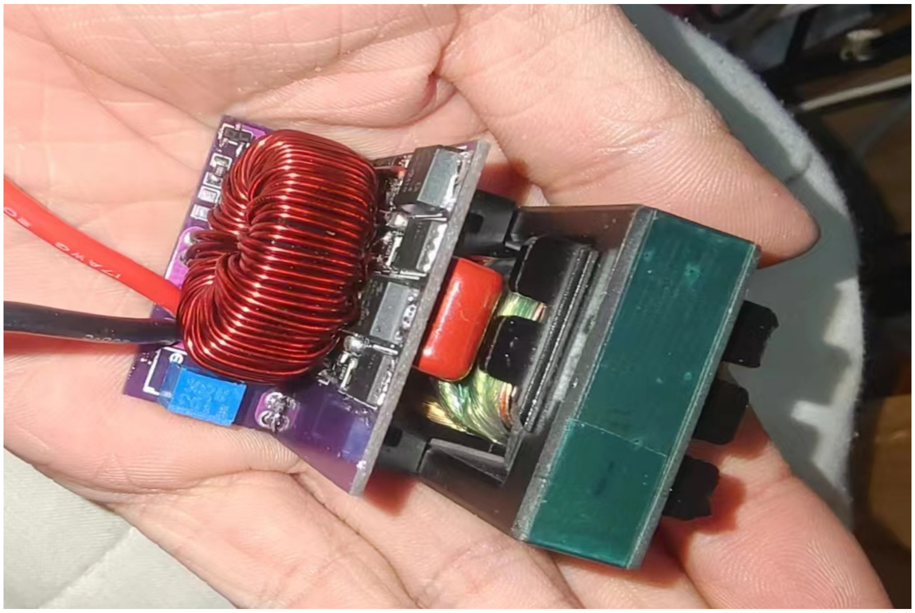


Figure 6: Physical Photo

The core of the power supply subsystem is the ZVS resonant converter. It steps up the rectified DC voltage to the required 450V output voltage. The ZVS converter takes advantage of a high-frequency transformer, resonant inductor, resonant capacitor, and switching devices (MOSFETs) to achieve zero-voltage switching, resulting in improved efficiency.

The output of the ZVS converter is then rectified and filtered to produce a smooth, stable 450V DC output. Schottky diodes can be used in the output rectifier stage for lower voltage drop and faster switching, while a capacitor filter ensures a stable output voltage.

To maintain a consistent output voltage, a feedback loop is implemented for voltage regulation. The feedback loop utilizes an optocoupler to isolate the high-voltage side from the low-voltage control side. A voltage reference, such as a Zener diode or voltage regulator, provides a reference voltage for comparison, ensuring that the output voltage remains stable at 450V, regardless of load changes.

Circuit protection measures are incorporated in the subsystem to safeguard it from potential hazards. Fuses protect the circuit from overcurrents and shorts, while overvoltage protection, such as a crowbar circuit or transient voltage suppressor diode, shields the output stage from voltage spikes and surges. Reverse polarity protection, using a series diode or MOSFET-based circuit, prevents damage in case a battery or plug is inserted backward.

Safety considerations, such as proper grounding, isolation between AC and DC sides, and thermal management through adequate heat sinking and ventilation, are also addressed in the design to ensure reliable operation and user safety. We use capacitors to store energy. On the one hand, it can prevent the burning of the whole circuit when it is in the circuit, and at the same time, the instantaneous burst energy of the capacitor is stronger than that of the normal battery, so it can have more energy when accelerating the UAV. Not only that, the materials we use to fix the coils and components are resistant to high voltage and high temperature.

We also did some mathematical calculation to ensure the safety and feasibility. We assume the efficiency of power supply module is $\phi = 60\%$and the power we need is 100W.

- Minimum Input Voltage: $V_{inMin} = 9$V: $P_{inMin} = \frac{P_{out}}{\phi} = \frac{100W}{0.6} = 166.667$W
$I_{in_min} = \frac{P_{inMin}}{V_{inMin}} = \frac{1666.67W}{9V} = 18.519$A
- Minimum Input Voltage: $V_{inMax} = 12$V: $P_{inMax} = \frac{P_{out}}{\phi} = \frac{100W}{0.6} = 166.667$W
$I_{in_max} = \frac{P_{inMax}}{V_{inMax}} = \frac{1666.67W}{12V} = 13.889$A

In summary, the power supply subsystem is a crucial component in the Electromagnetic Launch System for drones, converting a wide range of input voltage to a regulated 450V DC output using a ZVS resonant converter. The subsystem incorporates filtering, voltage regulation, circuit protection, and safety measures to ensure reliable operation and user safety.

Requirements	Verifications
1. The output voltage should be a stable 450V DC and should be maintained for one minute.	1. Use a voltmeter to check the output voltage on both sides of the output to check if it is 450V and if it is stable DC.
2. The power supply subsystem should be able to store the energy in a 450V 1500uF capacitor.	2. Connect the energy depleted capacitor to the output of the Power supply subsystem and check if the capacitor has stored energy after 1 minute of charging.
3. The temperature of the components in the subsystem, especially the coils, should not be higher than 200 degrees Celsius to prevent fire, short circuit, breakage and other hazards.	3. Use the subsystem to run for 50s and detect the change of temperature of the components in it, especially the coil, with time. Determine if the maximum temperature exceeds 200 degrees Celsius.

Table 1: RV Table for Power Supply Subsystem

2.3.2 Electromagnetic Accelerator Subsystem

There are two modules in this subsystem: a central board module and a mechanical structure module. The electromagnetic launch subsystem is designed to accelerate a magnet, which is attached to a drone, using electromagnetic forces. This subsystem leverages the principles of electromagnetic induction and interaction between magnetic fields to propel the drone along a launch track.

The core concept of electromagnetic launch relies on the interaction between the magnetic fields generated by the coils in the launch system and the magnet attached to the drone. When electric current passes through the coils, it creates a magnetic field. The controlled and sequential energizing and de-energizing of these coils create a moving magnetic field along the launch track.

The magnet attached to the drone experiences a force due to the changing magnetic fields, causing it to accelerate along the launch track. This force results from the fundamental principle that a moving charge in a magnetic field experiences a force perpendicular to both the velocity of the charge and the magnetic field direction. In the case of the electromagnetic launch system, the moving magnetic field effectively "pulls" the magnet and the attached drone along the track, increasing its speed until it reaches the desired launch velocity.

2.3.2.1 Central Board Module

We need power supply subsystem to give VCC to our central board module in this subsystem. The control and switching circuitry in the system is responsible for energizing and de-energizing the coils in a precise sequence, ensuring smooth and controlled acceleration. The position sensing system provides essential information about the magnet's position and velocity along the launch track, allowing the control system to adapt the switching sequence and timing of the coils accordingly.

We need following key components for central board module:

1. **Microcontroller or Programmable Logic Controller (PLC)**: To manage the switching sequence and timing of the electromagnets.
2. **Power Electronic Switches (e.g., IGBTs, MOSFETs)**: These are used to control the current flow through the electromagnets, allowing for rapid and precise control of the magnetic forces.
3. **Gate Driver Circuits**: These provide the necessary voltage and current to drive the power electronic switches.
4. **Protection Circuits (e.g., overcurrent, overvoltage protection)**: To protect the system from electrical faults and ensure safe operation.
5. **Position Sensors (e.g., Hall effect sensors, optical encoders, or inductive sensors)**: These are placed along the launch track to detect the magnet's position and velocity accurately.
6. **Signal Conditioning and Processing Circuits**: These circuits convert the raw sensor data into useful information for the control system.
7. **Glass Fiber Board**: The glass fiber board is resistant to high pressure and high temperature and prevents direct contact between human body and electronic components.

The circuit diagram and PCB design diagram are shown in Figure 7 and Figure 8.

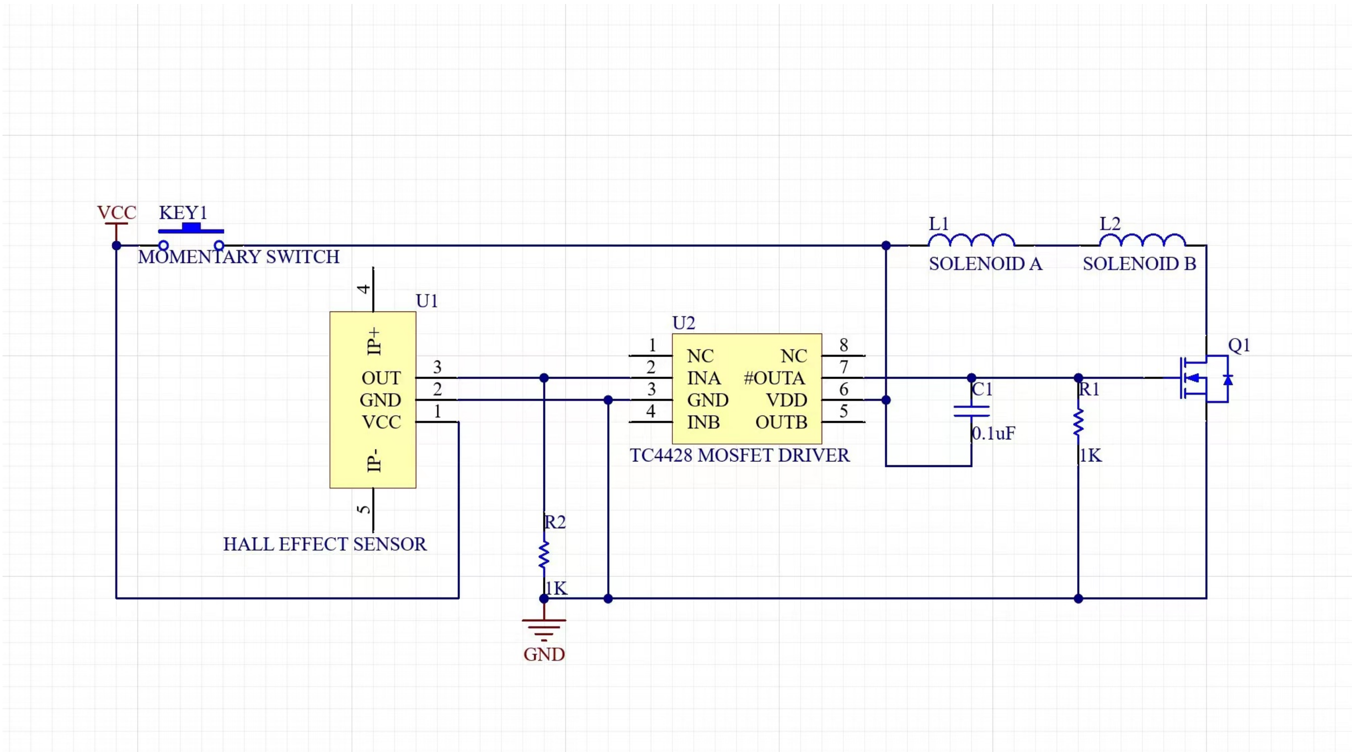


Figure 7: Single Coil Circuit Design Diagram

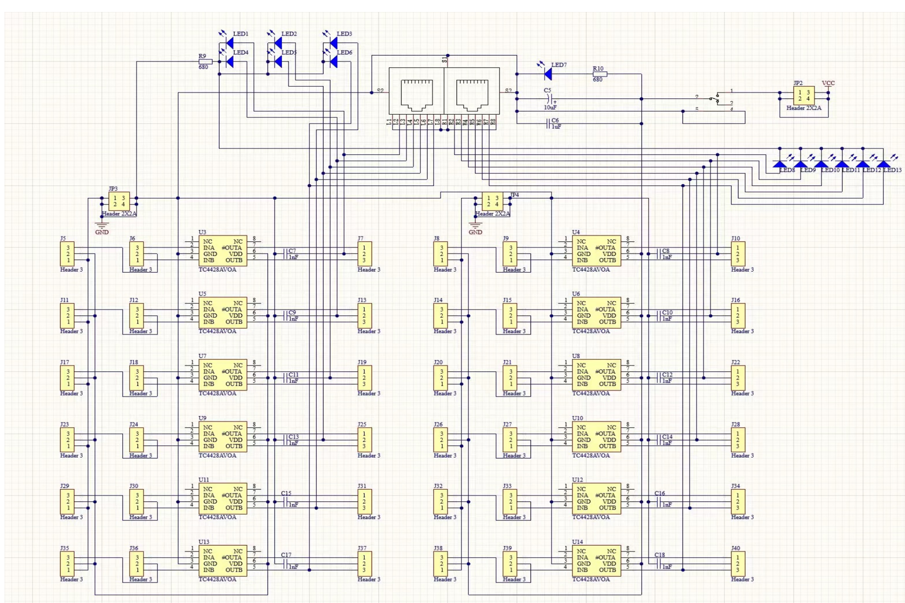
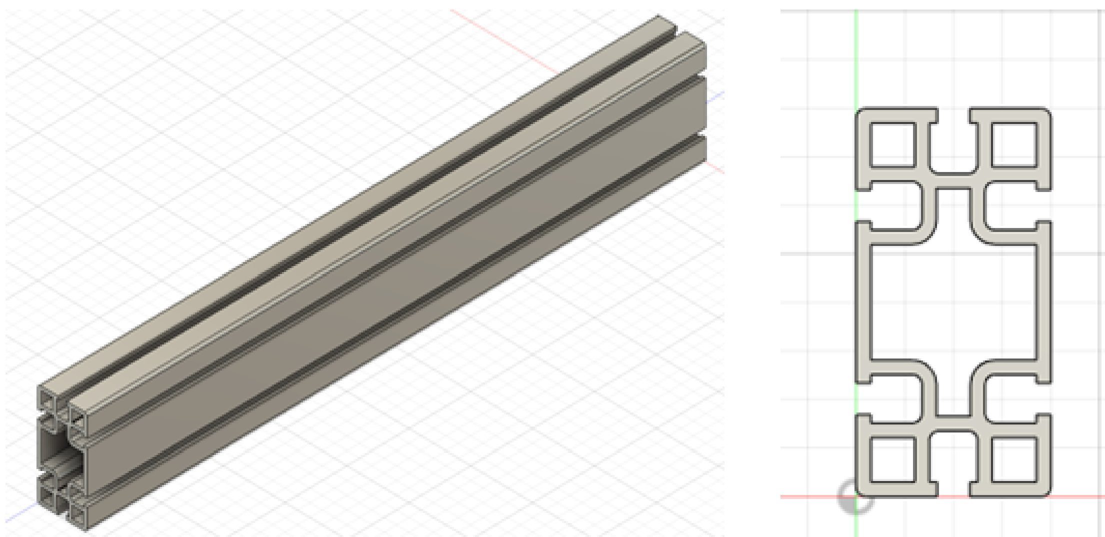


Figure 8: Central Board PCB Design Diagram

2.3.2.2 Mechanical Structure Module

The mechanical structure module is needed to let the cart which connects with magnetic and drone accelerate continuously in a fixed direction. The mechanical design is based on the function of central board module. And we need following key components:

1. **4080 Aluminum Profile**: 4080 aluminum profile is a standard aluminum profile which has fixed cross-sectional dimensions. It fits perfectly as the rail of the launch system for the reason that it is easy to design related non-standard parts such as coil holder and cart. Additionally, it has a relatively low friction coefficient, which is conducive to improving the launch speed. The CAD diagrams are shown in Figure 9(a) and Figure 9(b).

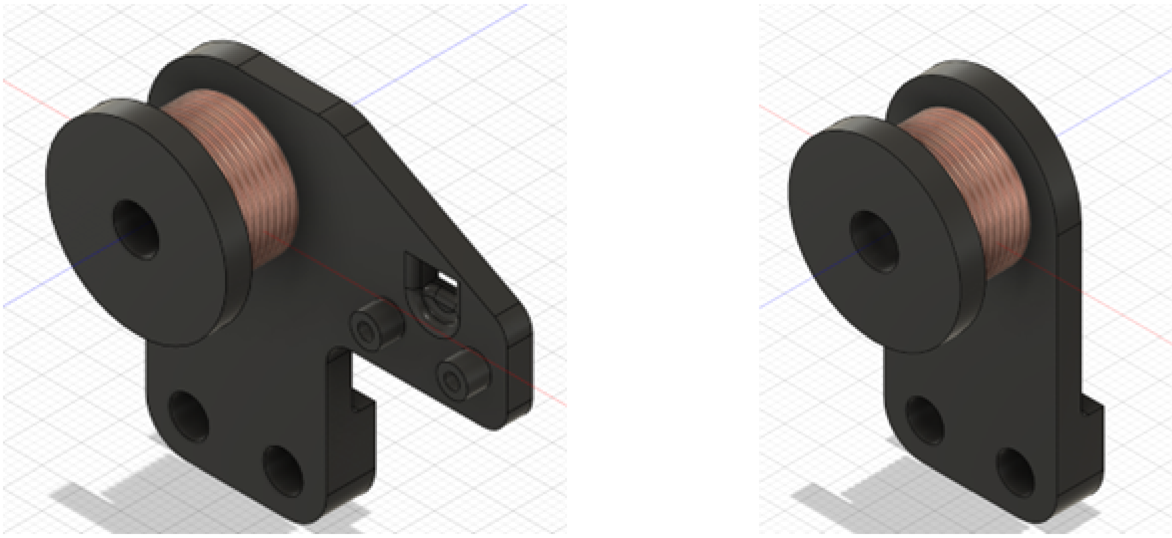


(a) Overview (b) Cross Section View

Figure 9: 4080 Aluminum Profile Rail

2. **Coil Holders**: Coil holders should be fixed on the rail and hold the coils. There are two different kinds because one side of coil holders should also hold the hall effect sensor. The dimensions of coil holders fit the rail which let them can be fixed by M4 screws. Too many coils will lead to an increase in resistance and a longer distance for the friction to do its work. After calculation in tolerance analysis, we decide to use 10 sets of coils on each side to accelerate our drone. The CAD diagrams are shown in Figure 10(a) and Figure 10(b).

3. **Cart**: The cart should be fixed with magnetic and drone. The magnetic should be parallel with coil so that it can be accelerated by electromagnetic force. The drone should be fixed with the drone but separates after the cart arrives at the end of the rail. Additionally, the cart should slide in the gap of the rail. The CAD diagram is shown in Figure 11.



(a) With Hall Effect Sensor (b) Coil Only

Figure 10: Coil Holders

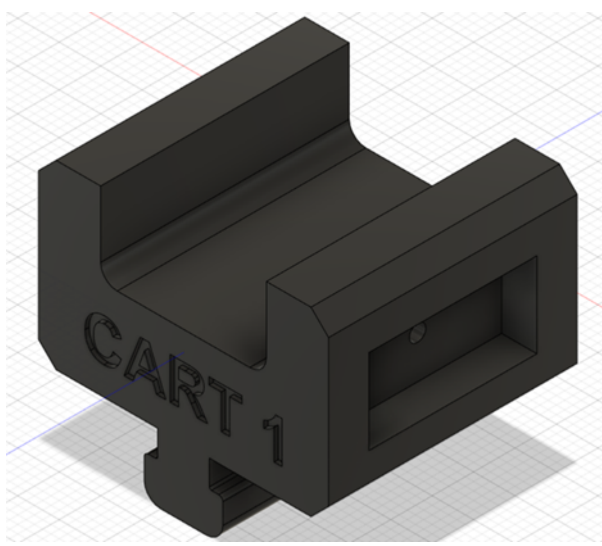


Figure 11: Cart

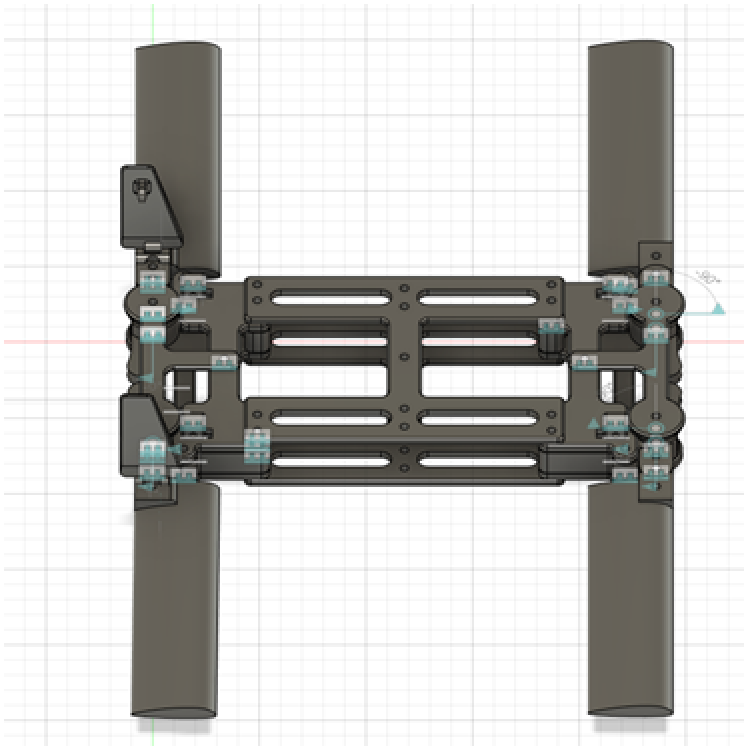
Overall, the electromagnetic launch subsystem provides a rapid and controlled means of accelerating a drone by exploiting the interactions between magnetic fields and moving charges. This technology can offer significant advantages in terms of efficiency, scalability, and the potential for non-contact propulsion, making it a promising option for various applications, including drone launching systems.

Requirements	Verifications
1. The drone should accelerate continuously and finally gets a speed of 3-6 m/s to take off.	1. Use high-speed camera to record the whole process when testing. Calculate the average speed when the cart is at different positions.
2. The launch system can work when the dip angle is 0-30 degree.	2. Do the speed test same as the above under different dip angles.
3. The launch system can work outside normally when the wind speed is 0-3 m/s.	3. Use wind tunnel to create working situations with different wind speeds. Do the speed test same as the above and observe if the system is stable.
4. During the acceleration process, the current in the coil should continuously change direction with the movement of the drone to achieve the effect of non-stop acceleration.	4. Using an ammeter in series with a coil, the movement of a small magnet is used to simulate the movement of a drone to detect the current steering. A voltmeter is used to detect if the MOSFET is operating properly.

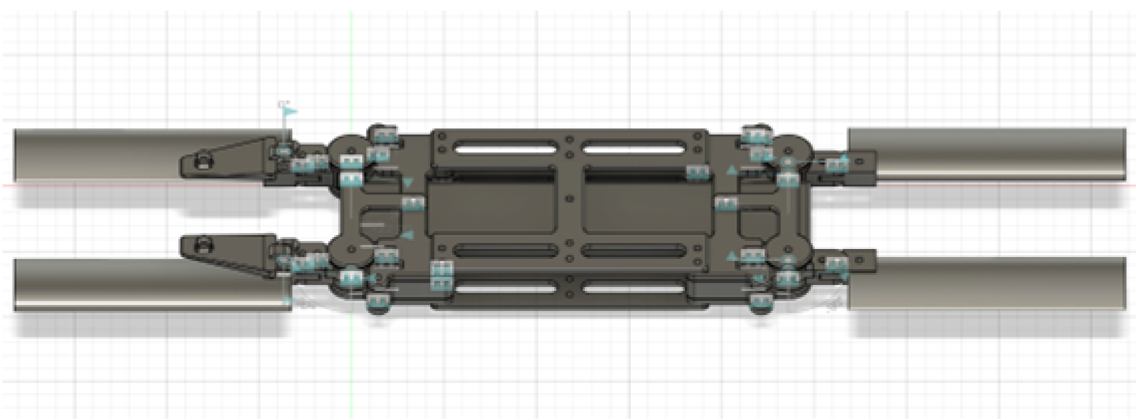
Table 2: RV Table for Electromagnetic Accelerator Subsystem

2.3.3 Switchable Drone Subsystem

The switchable drone subsystem consists of the main body and two sets of flexible wings. The main body provides a stable platform for the flexible wings and the fly control subsystem. The main body is 3D printed using light PLA material. The flexible wings mechanism is achieved through mechanical structure. It opens the wings after the drone leave the electronic launcher. After the wing is open the structure is fixed and ensure the wing doesn't move during the flying process. The subsystem can also fold the wing inside the main body when the drone is inside the launcher. This function is achieved by a spring system. When the slider is connected to the drone (the drone is inside the launcher) the slider will press the spring and fold the wing inside the body. After the pressure is removed, the spring recover to its initial position to open the wing. After the wing is open the fix structure will fix the wing. The total length of the drone is 248mm, and the width is 108mm. The length of the wings is 150mm, and the width is 40mm. The total weight of the drone is about 400g. Figure 12(a) and Figure 12(b) show the overview of the switchblade drone.



(a) Switchblade Drone in Open Mode



(b) Switchblade Drone in Fold Mode

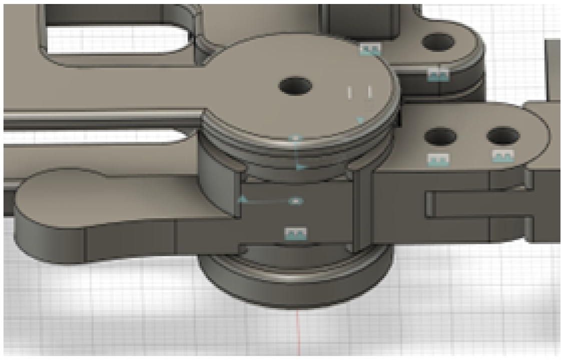
Figure 12: Overview of the switchblade drone

The switchblade drone mainly consists of the following parts:

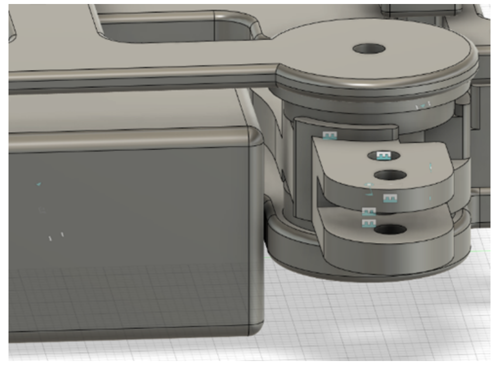
1. **Switchblade Structure**: This structure is mainly achieved through a torsion spring with an outer diameter of 10mm, a wire diameter of 1.4mm, and 6 coils. The torsion spring keeps the wings unfolded in its natural state, and the locking structure ensures that the wings are locked in place when unfolded (see Figure 13(a)). When a slider is inserted, the spring is compressed, causing the wings to fold parallel to the body (see Figure 13(b)). When the slider is removed, the wings will return to the unfolded state under the action of the spring. In addition to the spring, the switchblade structure also consists of a trigger and a fixing structure. The trigger (see Figure 13(c) and Figure 13(d)) is mainly composed of three main parts, with the longer end in contact with the slider. Folding function is achieved by inserting and removing the slider. The middle circular part is connected to the spring to achieve the rebound effect, and the feet of the spring are embedded in the groove of the trigger to achieve the connection. At the same time, the upper and lower sides of this part are connected to the body through flat thrust bearings (outer diameter 21mm, inner diameter 12mm, thickness 5mm). In addition, the middle part also has a 10mm wide groove connected to the locking structure. The shorter end is connected to the wing through two M4 screws. The fixing structure is mainly composed of two upper and lower plates (see Figure 13(e) and Figure 13(f)). The upper plate is connected to the trigger through M4 screws and flat bearings. The lower plate is connected to the trigger through M4 screws and flat bearings, and also has a groove for fixing the spring. The fixing structure and trigger are both made by 3D printing using PLA material.

2. **Locking Mechanism**: The locking mechanism is mainly composed of a fixed structure, a spring (wire diameter of 0.4mm, outer diameter of 8mm, and length of 25mm), and a small slider. The small slider and spring are located inside the fixed structure. When the wing is in the deployed state, the small slider will be inserted into the groove of the trigger structure under the action of the spring, thus locking the wing (see Figure 15(a)). When folding the wing, first manually pull the slider backwards, and then fold the wing (see Figure 15(b)). The fixed structure is mainly composed of two parts, upper and lower (see Figure 15(c) and Figure 15(d)). The spring is fixed in a cylindrical groove and can be horizontally compressed and stretched along the groove. The slider follows the spring to move forward. The cylindrical protrusion at the upper end of the slider (see Figure 14(e)) can be inserted into the square groove on the bottom plate of the fixed structure. The handle (see Figure 14(f)) can be connected to the slider to make manual pulling more comfortable and also serves as a certain limiting function. Structure in this part are 3D printing using PLA.

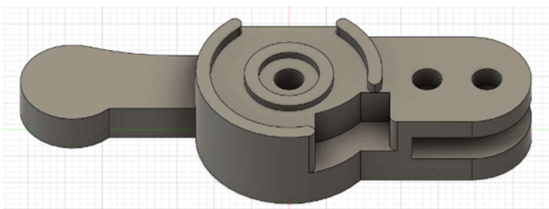
3. **Wings**: There are three sets of wings in this subsystem: the front wing, tail wing, and vertical tail fin (see Figure 15(a) 15(b) 15(c)). The front wing and tail wing have the same shape, width, and length, with a cross-sectional view of the wing shown in Figure 15(d). The width of the front wing and tail wing is 40mm, the length is 150mm, and the thickest part is 7mm. The front wing and tail wing mainly provide lift for the drone. They are connected to the trigger of the switchblade structure through an M4 screw. When the drone is on the electromagnetic launcher, the wings are folded parallel



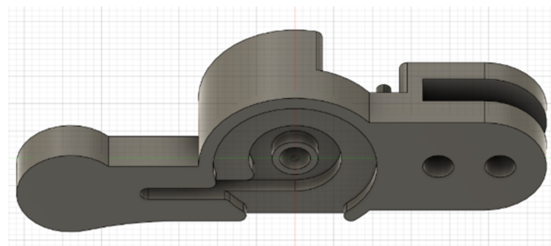
(a) Switchblade Structure in Open Mode



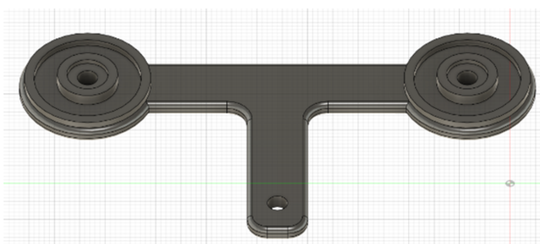
(b) Switchblade Structure in Fold Mode



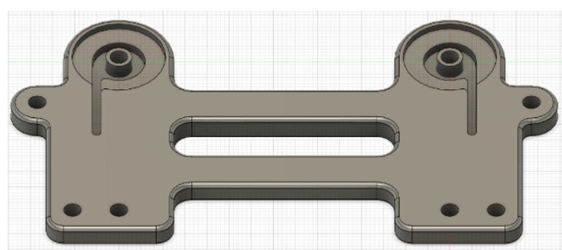
(c) Trigger in Switchblade Structure



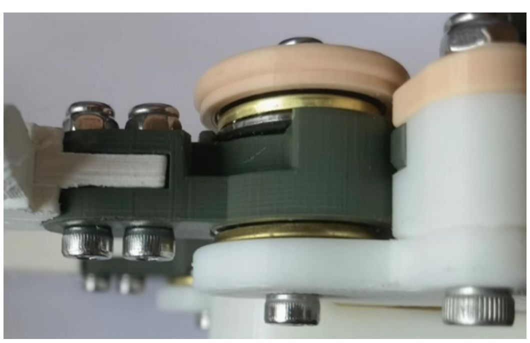
(d) Trigger in Switchblade Structure



(e) Upper Plate in Switchblade Structure



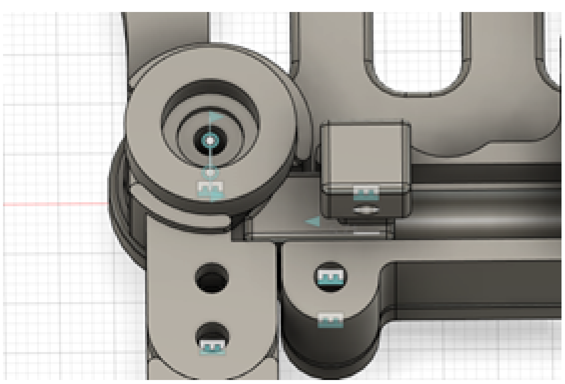
(f) Lower Plate in Switchblade Structure



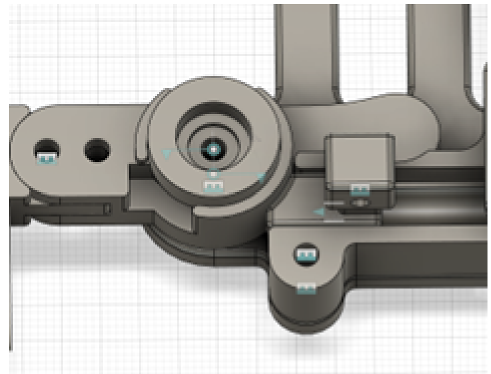
(g) Physical Diagram of Switchblade Structure

(h) Physical Diagram of Switchblade Structure

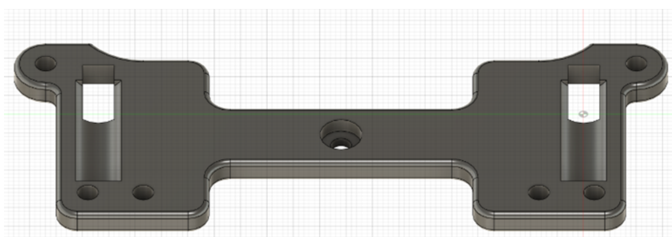
Figure 13: Switchblade Structure



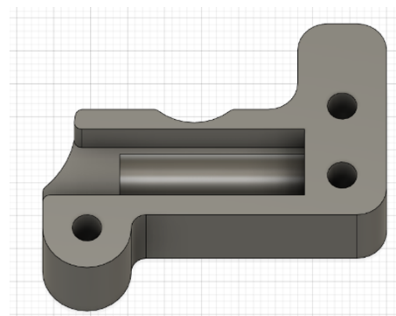
(a) Locking Mechanism in Lock Mode



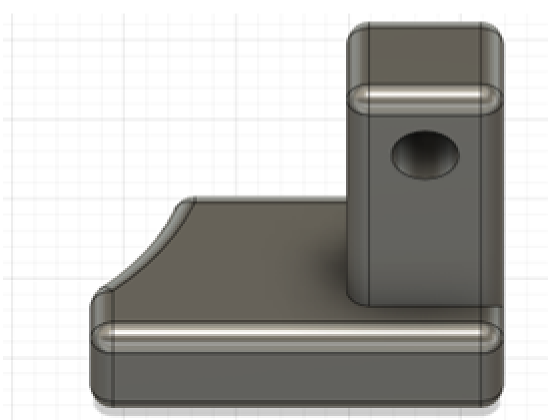
(b) Locking Mechanism in Unlock Mode



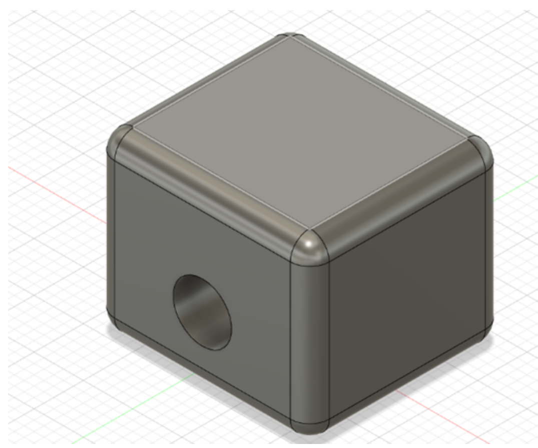
(c) Upper Plate in Locking Mechanism



(d) Lower Plate in Locking Mechanism



(e) Slider in Locking Mechanism



(f) Handle in Locking Mechanism

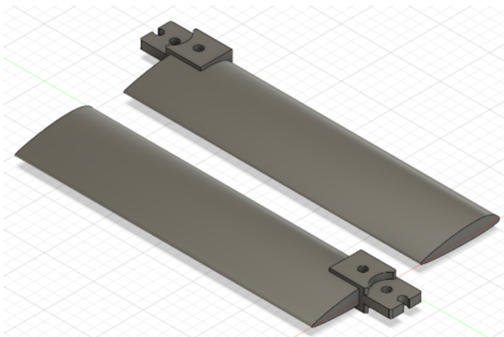
Figure 14: Locking Mechanism

to the fuselage. When the trigger is released after the drone leaves the launcher, the wings rotate 90 degrees to become perpendicular to the fuselage and are locked in place by a locking structure to ensure flight stability. The vertical tail fin is connected to the trigger of the switchblade structure through an M4 screw. The vertical tail fins are connected by a 140mm-long thin wire, which is fixed to a protruding ring on the vertical tail fin. When the wings transition from the folded state to the expanded state, the thin wire gradually tightens and pulls the vertical tail fin to keep it vertical. The vertical tail fin is a vertical wing surface installed at the tail of an aircraft, and its function is to help the aircraft rotate about the vertical axis in the air, thereby controlling the aircraft's heading stability and turning attitude. By changing the aircraft's lateral stability, it enables the aircraft to better maintain straight flight or change direction during flight, while also compensating for the lateral force generated by crosswinds to ensure flight safety. The length of the vertical tail fin is 52mm, the widest part is 30mm, and the narrowest part is 15mm. All three pairs of wings are made of PLA material using 3D printing.

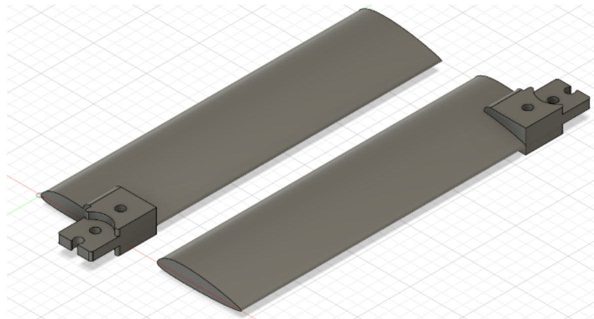
4. **Main Structure**: This part is mainly composed of two identical bottom plates, one on top of the other (see Figure 16), which are connected to the front and rear switchblade structures through M4 screws. The middle section is a hollow structure, which leaves space for future installation of power and flight control devices.

Requirements	Verifications
1. Drone can fold the wing when in the launcher and open the wing when leave the launcher.	1. Test the torsion spring with different wire radius to ensure the spring can provide enough torsion. Build the prototype of drone and test the function without launcher.
2. Drone can fix its wing after the wing is open.	2. Test the compress spring with different wire radius to ensure the spring can provide enough force. Build the prototype of drone and test the function without launcher.
3. The launch system can work outside normally when the wind speed is 0-3 m/s.	3. Calculate the lift of the wing and compare to the weight of the drone. And make sure the lift is greater than 5N.

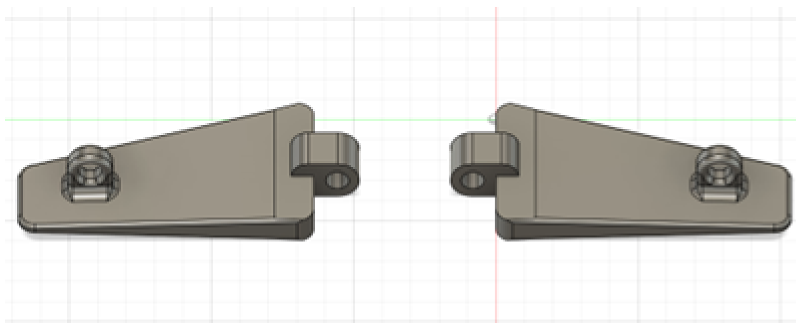
Table 3: RV Table for Switchable Drone Subsystem



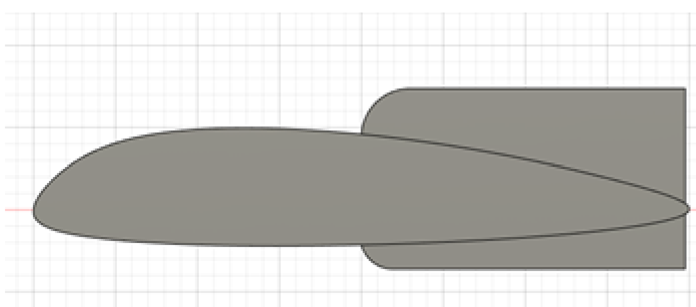
(a) Front Wing



(b) Tail Wing



(c) Vertical Tail Fin



(d) Cross Section of Front Wing and Tail Wing

Figure 15: Locking Mechanism

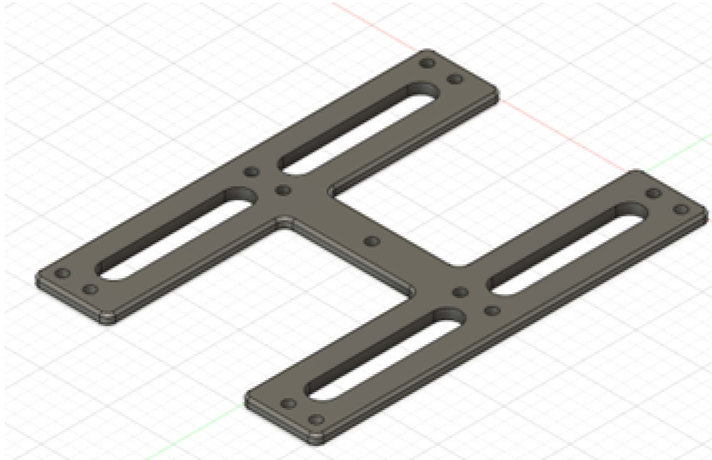


Figure 16: Main structure

2.3.4 Flight Control Subsystem

The flight control subsystem consists of a remote-control unit, a control circuit, an on-board battery, and an engine. The diagram of this subsystem is shown in Figure 17. The remote-control unit will use an antenna to send our instructions of turning, the remote signal will then be receive and interpret by the control circuit which is also equipped with an antenna. The control circuit with produce signal to control the action of the engine, including the action of propeller and rudder. An on-board battery will be implemented to provide power for the engine. The aim of this subsystem is helping the drone to fly a desired distance and control its direction in real time.

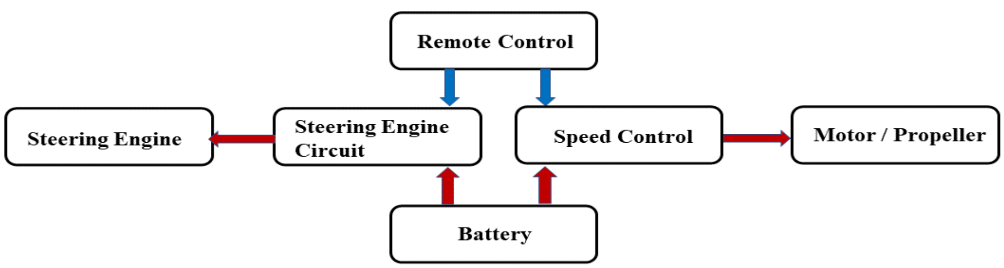


Figure 17: Subsystem Diagram of Flight Control Subsystem

We need following key components:

1. **Steering Engine Circuit**: We designed this circuit in order to translate the signals received by the receiver and control the two steering engines according to the translated signals. As a result, we can use our remote control to navigate the drone after taking off. The circuit's parameter are all align with the criterion of the power supply and the steering engine. After credible number of tests, we will find some one to help finish the building of the circuit.

2. **Speed Controller**: Inside our control panel there is also an electronic speed controller. It is implemented between the power supply and the motor, used to control the speed of the moto. According to our desired motor, the speed controller we select is a brush electronic speed controller, and it can be attached straightly to a lithium battery. Our choice is Hobbywing V2 Speed Controller, it has 40A working current, 55A instant current, 5V working voltage and weight of 39g.

3. **Remote Control**: Our choice for the remote control and its corresponding receiver is Microzone MC6C Control MC7RB Receive. They have frequency band of 2.400GHz 2.483GHz.

4. **Steering Engine**: Our choice for steering engine is Micro servo MG90S, it is 90 degrees movable, 12g in weight, 4.8V working voltage and 2kg/cm torque.

5. **Motor Propeller**: Our choice for motor and propeller is DXW KV2450 and HQProp 1060. The motor has 804W power, 36.6A working current and 31.3g weight.

6. **Battery**: Our choice for battery is JFLY 3S Lithium Battery. It has capacity of 1500mAH.

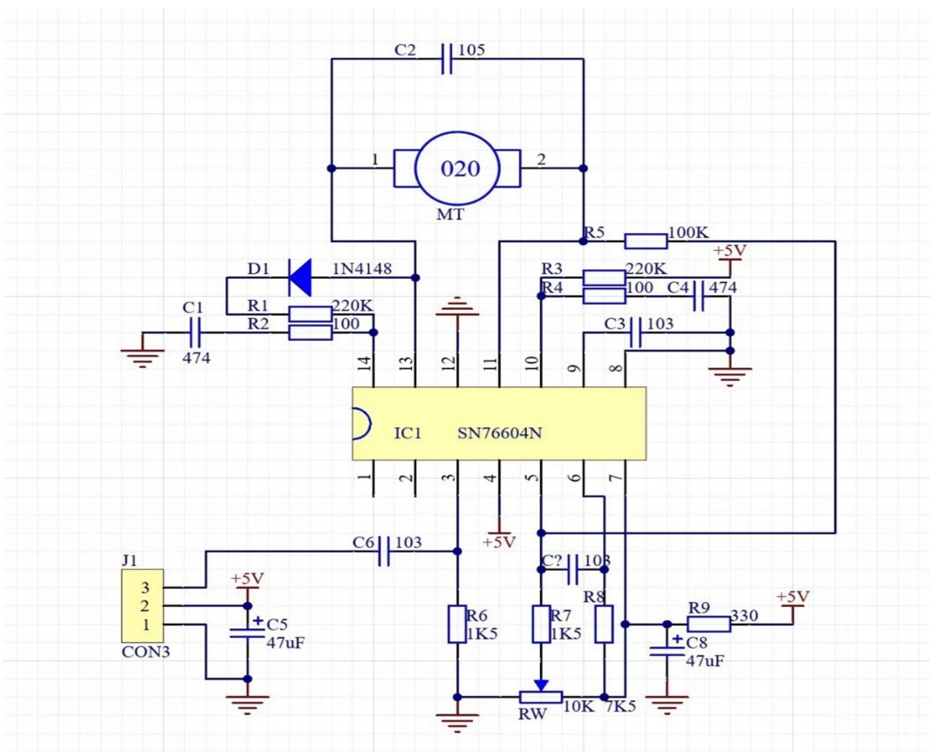


Figure 18: Circuit Diagram of Steering Engine Circuit

Figure 19: Physical Diagram of Speed Controller, Remote Control, Steering Engine, Motor Propeller and Battery

Requirements	Verifications
1. On-board components should be light enough, no more than 500g.	1. Sum up the total weight, if more than limit, find better components.
2. The design of the steering engine system allow drone to turn its direction efficiently.	2. Use prototype drone (similar shape and weight but no detailed mechanism) to test navigate function.
3. Each component should work within its voltage and current limit. For example: $V(steeringengine) \leq 4.8V$, $V(speedcontroller) \leq 5V$	3.Simulate the system on computer to check the circuit work properly. Integrate the system step by step , use a multimeter to measure the parameters before connecting a new component.

Table 4: RV Table for Flight Control Subsystem

2.4 Tolerance Analysis

The most important function for the project is to let the drone accelerate to a proper launch speed which is 3-6m/s. However, we cannot calculate the force between the magnetic and the magnetic field generated by coils. Instead, we decide to do a test for the acceleration effect of one coil and do some calculation to estimate the launch speed for 10 coils.

According to energy conservation equations:

$$W_{electromagnetic} - W_{fiction} = \frac{1}{2}Mv^2 \tag{1}$$

$$W_{electromagnetic} - \mu mgl = \frac{1}{2}Mv^2 \tag{2}$$

We first build one pair of coils and tried to accelerate a PLA block with a magnet on its bottom (the total weight is 0.5kg, as the desired weight of the drone is 0.4kg to 0.6kg) on a 0.1m aluminum rail. The friction coefficient is very close to 0.5 according to our tests using spring-loaded thrust meter. We denote M as the weight of the drone.

$$M = 0.4 \sim 0.6 \text{ kg} \tag{3}$$

Then we use high-speed camera to estimate a resulting velocity v_1.

$$v_1 = 1.5 \text{ m/s} \tag{4}$$

Put parameters in the equation, we can find the kinetic energy increment caused by one pair of coils. As we plan to have 10 pairs of coils along the rail, the total resulting kinetic energy increment will be ten times bigger.

$$l = 0.1 \text{ m} \tag{5}$$

$$\mu = 0.5 \tag{6}$$

$$g = 9.81 \text{ m/s}^2 \tag{7}$$

$$\frac{W_{electromagnetic}}{10} - 0.5M \times 9.81 \times 0.1 = \frac{1}{2}M \times 1.5^2 \tag{8}$$

$$W_{electromagnetic} = 16.155 \times M \tag{9}$$

For the ten coil situation, the rail is 1m long. Use this approximate final kinetic energy, we can estimate the final velocity of the drone.

$$16.155M - 0.5M \times 9.81 = \frac{1}{2}M \times v_{final} \tag{10}$$

$$v_{fnnal} = 4.74 \text{ m/s} \tag{11}$$

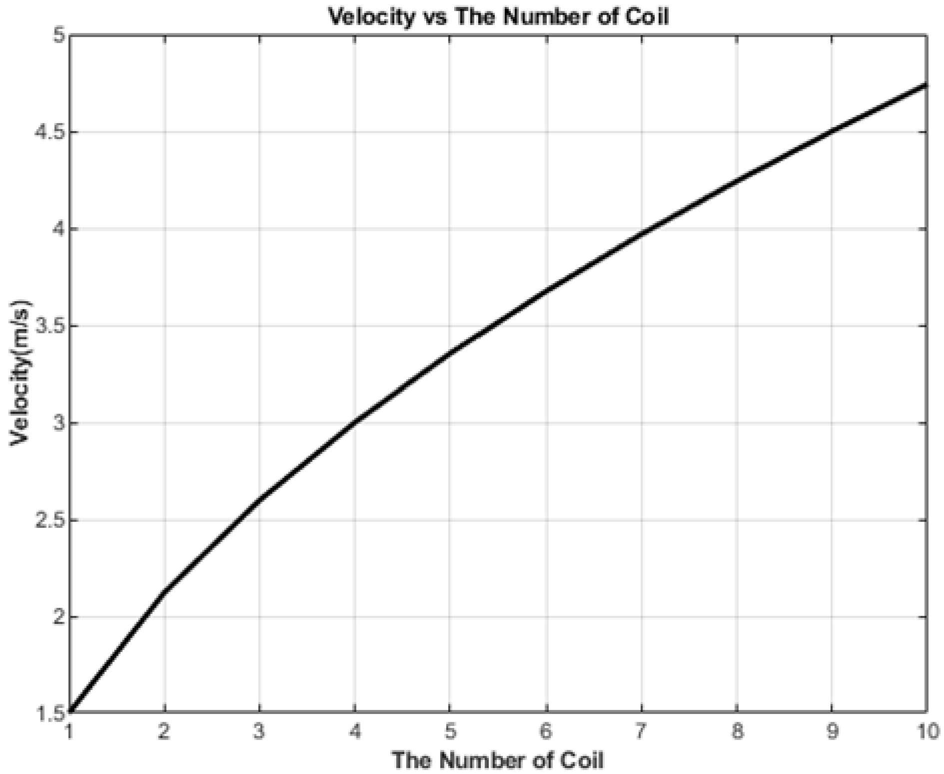


Figure 20: Velocity vs The Number of Coil

According to calculation result, the goal of 3-6m/s can be achieved. We will continue to improve our design to increase the launch speed such as increases the current in the coil or design extra components to decrease the friction effect. Figure 20 shows the acceleration process from the drone passes through 1 coil to 10 coils according to calculation.

3 Ethics and Safety

3.1 Ethics

According to the IEEE Code of Ethics [4], as professionals, we hold paramount the safety, health, and welfare of the public and are responsible for promptly disclosing factors that may endanger the public or the environment. Therefore, when testing our electromagnetic launch system and switchable drone, we will take precautions to ensure public safety. Warning signs will be placed around the test sites to prevent unauthorized entry to potentially dangerous areas.

Furthermore, in accordance with the IEEE Code of Ethics [4], we will avoid any unlawful conduct in our professional activities, specifically relating to laws and regulations regarding unmanned aerial vehicles. Compliance with all regulations and laws is essential to ensure the safety of the public and the environment. According to the Chinese agency responsible for drone safety[5], CAAC, drone use is allowed without a permit or a license in China, subject to UAS Laws, the general rules for flying drones in China. The restrictions include maximum height (120 meters), maximum distance (must keep the drone in sight). We will obey the rules strictly and apply for permission if necessary.

Lastly, we will seek, accept, and offer honest criticism of technical work, acknowledging and correcting errors, in line with the IEEE Code of Ethics [4]. We will actively seek guidance and constructive criticism from peers and experts to optimize our project and ensure the highest level of technical excellence.

3.2 Safety

When utilizing our electromagnetic launch system, the power supply system generates high voltage and an extremely high current flows through the coil, both of which can be lethal to the human body. Therefore, we decide to design a voltage boost module to ensure that we can use a relatively low voltage power supply to improve its safety. Additionally, the large current flow may generate significant heat at both the power supply and the coil, potentially damaging the circuit or causing a fire. Hence, we decide to install some cooling devices to make sure the temperature doesn't get too high.

According to the Occupational Safety and Health Administration (OSHA) standards[6], employers should provide a safe and healthy workplace, free from recognized hazards that could cause harm to employees. So we should ensure that appropriate safety measures, such as warning signs, are in place to alert people of potential hazards. OSHA standards also require that employers conduct regular inspections. So we should ensure that the whole system is in good working condition and that all safety measures are functioning properly.

According to Electromagnetic Compatibility (EMC) regulation[7], an electrical and electronic equipment should permit it to operate as intended in the presence of other electrical and electronic equipment, and not to adversely interfere with that other equipment. So we will check and make sure that the launch system does not have a negative influence on surrounding electrical and electronic equipment. Therefore, we will exercise caution and implement appropriate safety measures during testing to ensure the safety of all individuals involved.

4 Cost and Schedule

4.1 Cost

We take the average salary of UIUC graduates as our hourly wage, and our average working hours is 20 hours per week. For this project, we approximately work 13 full weeks. Then we can get following labor cost table, the resulting total labor cost would be around 52000$.

Name	$/Hour	Hours/Week	Weeks	Multiplier	Cost ($)
Shuayang	20	20	13	2.5	13000
Zheng	20	20	13	2.5	13000
Xinyu	20	20	13	2.5	13000
Ruike	20	20	13	2.5	13000
Total	20	80	13	2.5	52000

For the components and materials, see the following bill of materials (BOM). The resulting expected cost of the parts is 223.1$.

Name	Mfr	DESC	Cost ($)	Qty	Total($)
KV2450 Motor	DXW	804W, 36.6A, 31.3g	15	1	15
MG90S Steering Engine	Micro servo	90degrees, 12g, 4.8V, 2kg/cm	2.5	2	5
3S Lithium Battery	JFLY	1500mAH, 11.1V	10.5	1	10.5
V2 Speed Controller	Hobbywing	40A, 55A(instant), 5V, 39g	12	1	12
B3 Charger	imaxRC	10W, 800mA	3	1	3
1060 Propeller	HQProp	27.66g, 25.4cm	0.8	6	4.8
MC6C Control	Microzone	70MW, 6V, 550g	18	1	18
MC7RB Receive	Microzone	6V, 9.6g	4	1	4
Launcher PCB Board	Self-Designed	Details in subsystem part	100	1	100
Flight Control PCB Board	Self-Designed	Details in subsystem part	20	1	20
Aluminum Rail	Oulihua	50*150*1000mm	17.4	1	17.4
PLA	ELEGOO	1000g	9.3	2	18.6
Spring		304	0.8	6	4.8
Total					223.1

4.2 Schedule

Week	Shuyang	Zheng	Xinyu	Ruike	Overall
2/20	Search information, preparation	Search information, preparation	Search information, preparation	Search information, preparation	Background research, preparation
2/27	Pre-design of launcher mechanism	Pre-design of launcher circuit	Pre-design of drone mechanism	Pre-design of flight control	Identify solutions, allocate tasks
3/06	Design and analysis of launcher mechanism	Design and analysis of launcher circuit	Design and analysis of drone mechanism	Planning of flight control, help with launcher part	Focusing on the launcher part, math analysis
3/13	Design and analysis of launcher mechanism	Test and analysis the launcher circuit	Design and analysis of drone mechanism	Design and analysis the flight control, help with launcher part	Focusing on the launcher part, start to look for material and components
3/20	Model and print launcher mechanism	Test and analysis the launcher circuit	Model and print drone mechanism	Design and analysis the flight control	Finalize launcher part, start to print mechanism
3/27 (plan)	Model and print launcher mechanism	Build and check the launcher circuit	Model and print drone mechanism	Design and analysis the flight control	Build launcher part, print mechanism
4/03 (plan)	Finalize the launcher mechanism	Finalize the launcher circuit	Finalize the Drone mechanism	Finalize the launcher circuit	Finalize the launcher drone system
4/10 (plan)	Integrate and test the launcher drone part	Integrate and test the launcher drone part	Integrate and test the launcher drone part	Build and test of the flight control part	Test launcher drone part, implement flight control
4/17 (plan)	Integrate and test the launcher drone part	Finalize and improve flight control	Integrate and test the launcher drone part	Finalize and improve flight control	Test launcher drone part, finalize flight control

Continued on next page

Table 4: (Continued)

4/24 (plan)	Integrate and test the whole system	Integrate and test the whole system	Integrate and test the whole system	Integrate and test the whole system	Integrate and test the whole system
5/01 (plan)	Integrate and test the whole system	Integrate and test the whole system	Integrate and test the whole system	Integrate and test the whole system	Integrate and test the whole system
5/08 (plan)	Modify and improve the system	Modify and improve the system	Modify and improve the system	Modify and improve the system	Modify and improve the system
5/15 (plan)	Modify and improve the system, prepare for the demo	Modify and improve the system, prepare for the demo	Modify and improve the system, prepare for the demo	Modify and improve the system, prepare for the demo	Modify and improve the system, prepare for the demo

5 References

[1] AeroVironment, "Switchblade Tactical Missile System," AeroVironment, 2021. [Online]. Available: https://www.avinc.com/tms. [Accessed: 02-Mar-2023].

[2] J. Zhu, C. Zhang, H. Xie, and J. Zhan, "Research progress in electromagnetic launch technology," Journal of Physics: Conference Series, vol. 1577, no. 1, p. 012008, 2020.

[3] S. Alamri, A. Khaligh, "Design, Development, and Control of an Electromagnetic Launch System for Small Fixed-Wing Unmanned Aerial Vehicles," IEEE Transactions on Transportation Electrification, vol. 5, no. 2, pp. 734-744, June 2019.

[4] Ieee.org, "IEEE code of Ethics," IEEE. [Online]. Available: https://www.ieee.org/about/corporate/governance/p7-8.html. [Accessed: 02-Mar 2023].

[5] M. at D. Laws, "Drone laws in China," Drone Laws. [Online]. Available: https://drone-laws.com/drone-laws-in-china [Accessed: 19-Mar 2023].

[6] Osha.gov, "Occupational Safety and Health Administration" United States Department of Labor. [Online]. Available: https://www.osha.gov/electrical/standards. [Accessed: 19-Mar 2023].

[7] Etsi.org, "Electro Magnetic Compatibility" ETSI. [Online]. Available: https://www.etsi.org/technologies/emc. [Accessed: 19-Mar 2023].