ECE 445

SENIOR DESIGN LABORATORY

PROPOSAL

Electromagnetic Launch System with Switchblade Drone : Proposal for ECE 445

Team #4

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March 7, 2022

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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

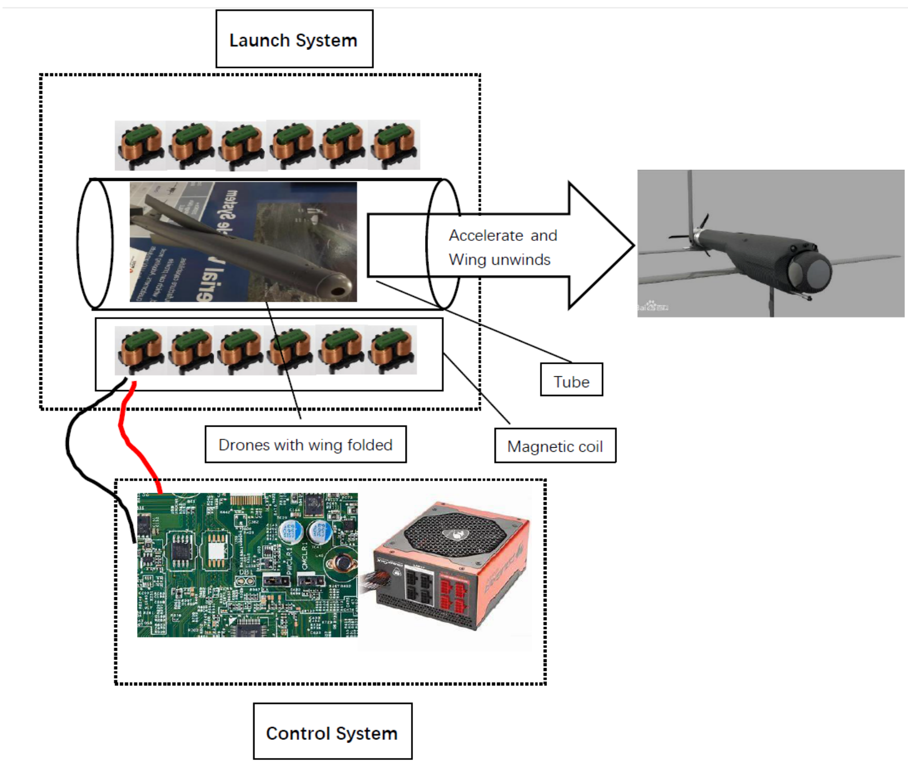

Figure 1: The Visual Aid of Electromagnetic Launch System with Switchblade Drone

1.4 High-level Requirements List

1. The drone should accelerate continuously and finally gets a speed of 5-10 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 drone should fold its wings on the launch trajectory 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

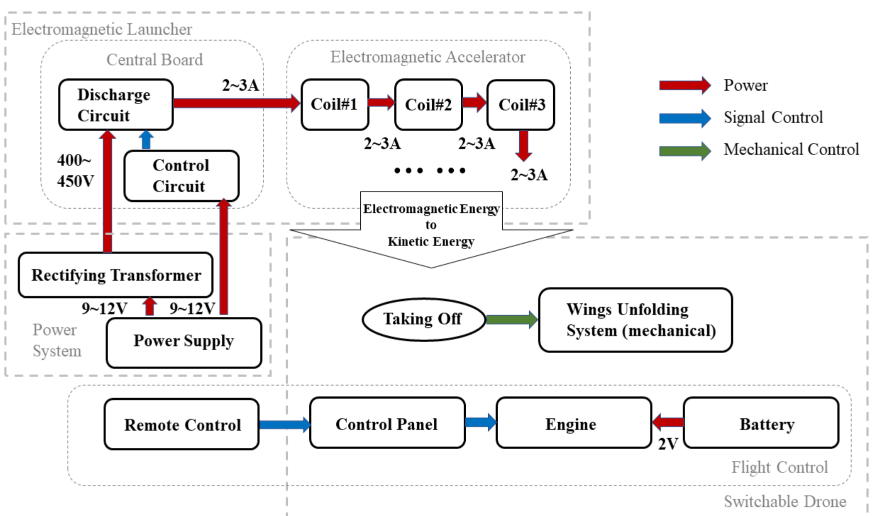

Figure 2: Block Diagram

2.2 Subsystem Description

2.2.1 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.
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.

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

2.2.2 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.

2.2.2.1 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.

2.2.2.2 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. **Aluminum Profile**: 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.

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.

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.

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

2.2.3 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.

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

2.2.4 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 3. 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.

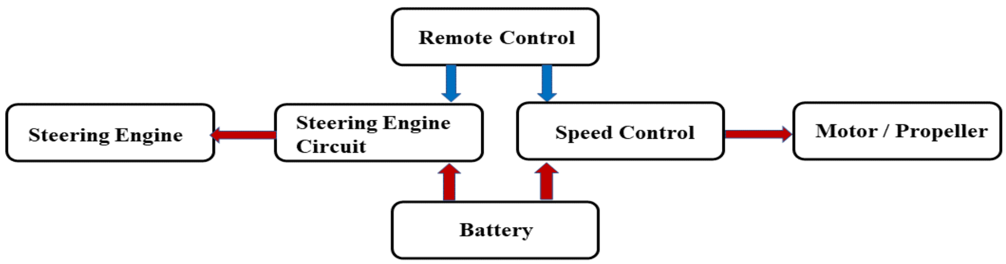

Figure 3: Subsystem Diagram of Flight Control Subsystem

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

2.3 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.

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

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

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

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

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

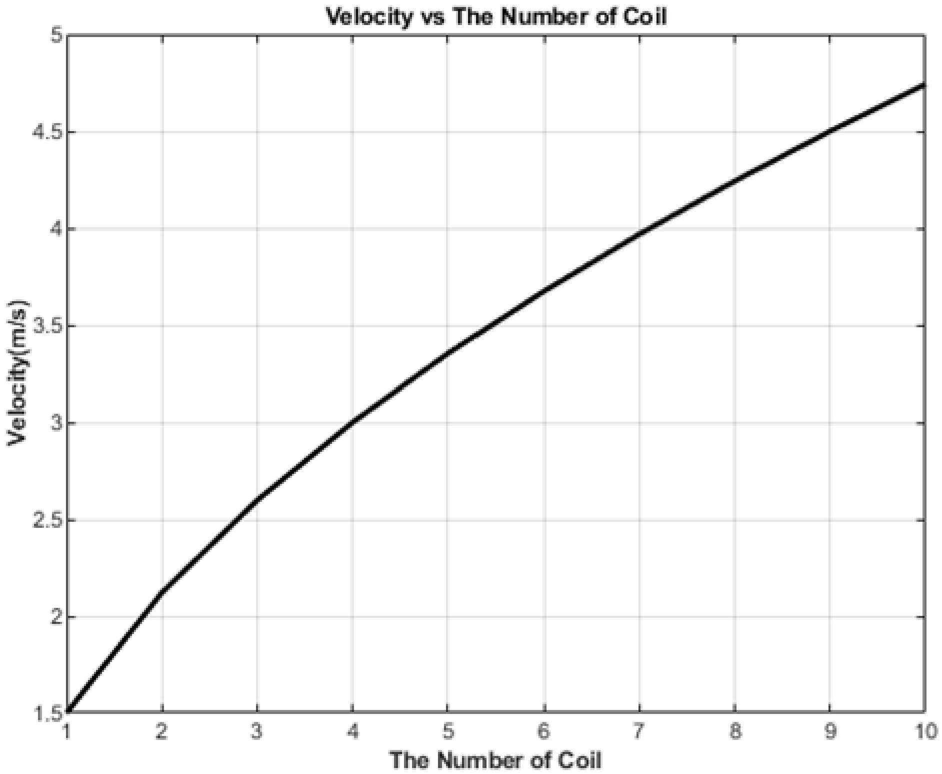

Figure 4: Velocity vs The Number of Coil

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.

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

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

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 4 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 References

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