ELEC390: Main Project

Project Title: Electromagnetic Accelerator

Team Number: 4

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Date: April 4^{th}, 2019

I confirm that the team has consulted me regarding the project and the material described in this proposal

Abstract

Satellites orbiting the planet play a key role in many important technologies in use today, such as weather prediction and large-scale environmental research. Launching these satellites into orbit using traditional methods is costly and wasteful. Electromagnetic accelerators are extremely versatile, capable of launching payloads into lower earth orbit, and can do so without releasing harmful emissions into the stratosphere and mesosphere. The proposed solution is a large-scale accelerator that uses the gaussian principles to accelerate a ferrous projectile to orbit velocity, improving the efficiency and decreasing environmental impact of the current process. This accelerator is designed to have multiple accelerators, each consisting of a power bank, microcontroller, coils, projectile sensors and a switching circuit. An operational model of the accelerator will be created using a modular design in which each aspect of each acceleration stage is tested in isolation before being assembled and then further assembled into the final accelerator. Using this testing and design method, it is hoped that the final prototype can meet specifications of a projectile energy of 8 Joules, a projectile velocity of 30 m/s, and an efficiency of 10 percent. The working prototype will be accompanied by a report detailing common issues and processes, and a simulation that will provide a good estimate of exit velocity and distance when provided with the necessary information. Although this prototype is geared towards space applications, this concept can be repurposed for industries such as the military, commercial construction and high-speed transportation sectors.

Table of Contents

Problem

More satellites are required to support the advanced technological infrastructure that society has become reliant on. [1] Sending these satellites into orbit is a very extensive process which is expensive as well as requires an immense amount of resources. The majority of the cost is due the amount of fuel needed to send the satellites into space which in turn has a direct correlation with the overall weight of the rocket. As of right now it costs approximately $10,000 USD per pound to put an object into Earth’s orbit. [2] Satellites also have several negative environmental impacts. There are two main negative environmental impacts of launching satellites into orbit. These are the emissions produced from the rocket fuel that is used to propel the satellites into orbit and the space debris that is left in space. Space debris consists of the satellite itself as well as the spent rocket bodies that were used to propel the satellite which remain in the Earth’s orbit long after its life cycle. [3] Thus, it is desired to come up with a method of launching these satellites into space while minimizing cost as well as the negative environmental impact.

Impact

Coil guns, also known as Gauss rifles, can be used for a variety of purposes, each of which has a different impact on the projectile being launched. For the purpose of ELEC 390, a small-scale coil gun is being developed to demonstrate how small projectiles can be launched using this technology. The goal is to create the small-scale replica which can then theoretically can be scaled up to launch small cube satellites into space. CubeSat, with dimensions of 10cm x 10cm x 10cm would be the perfect size projectile to launch using a coil gun. Launching a CubeSat into space using a coil gun is a daunting task, yet, the benefits of using a coil gun greatly outweigh the traditional rockets. For one, traditional rocket launches produce a lot of harmful emissions. It was calculated the Saturn V rocket, containing Neil Armstrong and Buzz Aldrin used 4,578,000 pounds of fuel. For reference, this mass of RP1 (kerosene) is approximately the weight of 763 elephants. [4] This release of emissions is particularly concerning because they are released in the mesosphere and stratosphere which has a larger environmental impact compared to when the pollutants are released in the lower levels of the atmosphere. Using a coil gun would result in a significant reduction in the amount of pollutants released into the atmosphere because the initial rocket stages would not be necessary. Although the coil gun would not use a fossil fuel directly, there is still a negative environmental impact. The second largest source of energy production within the United States remains to be coal at 30% in 2018. [5] When coal is burned to process electricity is creates air pollution along with ruining the habitat and environment for any animal species in the area. To further reduce the environmental impact, the coil gun launching mechanism is reusable which will help to reduce waste created by a launch. Up to now, there are only very few rockets which can be reused, the most famous being the SpaceX Falcon 9 reusable first stage.

Along with having less environmental impact, the coil gun will also be more economically feasible compared to traditional rockets. This is due in part to the coil gun being reusable which enables it to be cheaper for each individual launch. As mentioned previously, traditional rockets require a significant amount of expendable fuel whereas the coil gun’s only expenditure is the metal housing which is propelled through the chamber along with the large quantity of electricity required.

Social implications from using this type of technology extend beyond launching small satellites into space. The device can be repurposed and used to launch any ferromagnetic projectile. (Any device mad of iron). For non-ferromagnetic projectiles, the object would have to be housed in a casing made of iron in order for the Gauss forces to create enough momentum in the projectile to have a successful launch. An alternative use for coil guns is using is using them onboard navy vessels instead of traditional armaments. A projectile launched using a coil gun would be preferred over traditional rounds because the rounds of a coil gun do not contain any explosive propellants. This is due in part the projectiles would rely exclusively on the kinetic energy created from travelling through the electromagnetic forces of the firing mechanism.

Some cultural implications and risks could be potential from making coil gun technology readily available and found. Some risks include individuals manipulating their use and making weapons to fire projectiles of their choosing along with low-speed large mass catapult launchers. It is anticipated individuals will change the coil gun design into a personal weapon because they will see it as an alternative for a personal firearm. If mass produced, governments might have to consider changing modern gun laws to accommodate and cover coils guns as well. This is especially true since owners of coil guns would not have to follow traditional gun laws or purchase from a registered establishment. Ultimately, there would be unintentional injuries if the devices if they are not designed and created properly which would lead to possibly bodily harm. Having individuals manipulate the original usage of the coil gun technology being readily available brings up the ethical issues which can arise. Many individuals and concerned citizens will want extensive research to be completed to determine how easy it is to turn the coil gun projectile launcher into a device which can be used to hurt or harm another individual.

Using the bottoms-up approach to calculate the total addressable market (TAM) [6], assumptions are being made about the market boundary along with estimating revenue sums and market growth. The total addressable market is calculated by multiplying the number of customers within the entire segment of a target market and multiplying it by the average revenue.

$$TAM = (Total\ Number\ of\ Customers\ in\ Target\ Market) \times (Revenue)$$

Based on the fact worldwide there are a total of 20 active rocket launch sites along with the estimated cost of a coil gun to be $500,000,000 wholesale, the estimated TAM is $10,000,000,000 as shown in equation 2 below.

$$TAM(Coil\ Gun) = (20) \times (500{,}000{,}000) = \$10{,}000{,}000{,}000$$

This is what was determined to be the total addressable market for a coil gun which is used to launch small CubeSat's into a low earth orbit.

Solution

As mentioned in the problem description, it is desired to come up with an alternative method that minimizes the cost as well as the environmental impact of launching satellites into orbit. With this is mind, our team will be developing a coil gun or Gauss rifle that would launch satellites into orbit effectively replacing the other conventional methods such as rocket launches. To understand how this proposed solution will address the problem stated earlier, we must first have a basic understanding of how a coil gun works.

What is a coil gun?

A coil gun is a linear magnetic projectile accelerator that is capable of firing projectiles at rapid velocities. A coil gun consists of 5 main parts; a power source in the form of battery banks, a barrel made out of a nonconductive material that would house the projectile, a series of conducting coils that are arranged along the barrel, a switching circuit for the power source and a trigger switch/mechanism. The coil gun operates using key principles of magnetism. For a better understanding of the operation of a coil gun we will only be examining a one stage coil gun. A stage in this context refers to a series of coils that is connected to an individual capacitor bank.

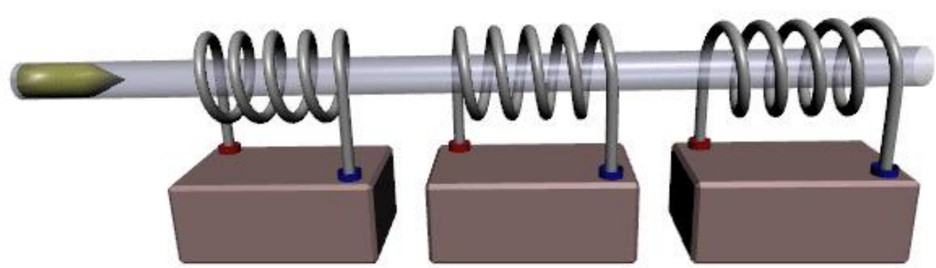

Figure 1- Multistage Coil Gun Example [7]

As mentioned above, a series of conducting coils is arranged along the barrel of the accelerator and connected to a battery pack. Initially, the coils are not energized as the connection between the capacitor bank and the coils is open. Once the trigger switch/mechanism of the coil gun has been activated the connection between the capacitor bank and the coil in the first stage becomes a short. In other words, this means that the coil is now energized. Now that there is a current that passes through the coil, it begins to induce a magnetic flux which can be seen in the figure below.

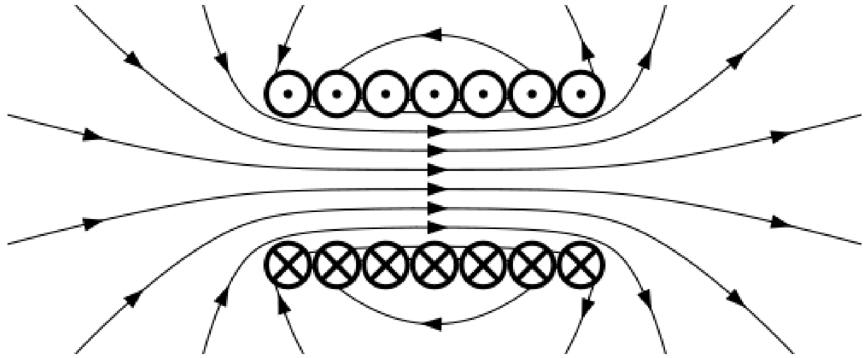

Figure 2- Illustrated are the Gaussian Forces [7]

Since the coil is now energized it creates a magnetic field which attracts the conductive projectile towards the center of the coil. As the projectile moves closer to the coil a positive feedback loop is then created resulting in a stronger pull on the projectile towards the center of the coil. This positive feedback in conjunction with the magnetic field intensity becoming greater causes the projectile to accelerate towards the coil. A peak velocity is reached by the projectile when it reaches the center of the coil. Therefore, further travel of the projectile in this scenario would result in deceleration of the projectile, as its moving away from the center of the coil. To avoid this undesired result, the current through the loop is abruptly eliminated as the connection between the coil and battery bank becomes open again through the use of a switching circuit. If additional stages were present, the next stage would then be activated (connection becoming a short between the next coil and battery bank) when the projectile reaches the front edge of the next coil using an identical switching circuit.

Benefits of a coil gun

Now that we have a basic understanding of what a coil gun is and how it works, we can discuss how the coil gun would address the current problems.

Cost

A coil gun would eliminate the need for rocket fuel during the launch of the satellite into space. It is important note that this would not eliminate the overall need for rocket fuel as the satellites would still require an orbital injection burn and a method of navigating once in orbit. However, this would still result in a substantial decrease in rocket fuel needed for a satellite that will be sent into orbit, the vast majority of the rocket fuel used by a satellite takes place in the duration of the launch into orbit. Now that the amount of rocket fuel needed is significantly reduced, the weight of the rocket as well will be able to be considerably decreased. Thus, a coil gun would notably reduce the cost per launch of a satellite as the amount of fuel needed and weight of the satellite will both be significantly reduced.

Environmental Impact

As mentioned in the section above, a coil gun would drastically reduce the amount of fuel needed for the launching of the satellite into the orbit. With the reduced amount of fuel needed, it is evident that the amount of carbon emissions that are released into the atmosphere would also be reduced as well as less fuel is being burned.

Non-rocket satellite launch solutions present

Weather balloon aid

Weather balloons, like the name suggests, are balloons that are sent up into the atmosphere for the purpose to take measurements to provide scientists with information with regards to the weather patterns. Therefore, it is possible for weather balloons to be able to transport satellites to the edge of the stratosphere. [4] However, in order for this to be possible the weather balloon would have to be enormous in size in order to carry the weight of the satellite.

With this knowledge, it is evident that there is a major constraint using this method as the satellite would have to be relatively small in size in order for this method to be viable. Another important thing to note about using this method is that the satellite would still need to be accompanied by several stages of rocket bodies in order to help the satellite reach orbit thus still requiring the burning of a fair amount of rocket fuel. [4]

Aircraft aid

This method consists on a large aircraft, such as the Boeing 747 aircraft, carrying a rocket that encloses a satellite into the atmosphere and then launching the rocket towards orbit. [5] This method has several of the same constraints as the weather balloon method discussed above. These constraints include the limit to the size of the rocket and in turn the satellite. This method also requires the adequate use of burning rocket fuel as well as jet fuel. Another interesting thing to note about this method is due to current technology present, the aircraft would be required to be manned by an individual which in turn means additional risks associated with this method.

SWOT analysis of proposed solution

Strengths	Weakness	Oppourtunities	Threats
• Would signifcantly reduce cost to launch a satellite into orbit • Reduced emssions put into upper atmosphere • Reduced amount of parts that could become space debris	• Large upfront cost to build the coil gun • Could be misused for military purposes • Would require a large power source near launch site	• Coil gun launch method allows for bigger satellites to be launched as majority of the weight of satellite was a reult of the feul needed when using the convential rocket launch method • Reduced cost per satellite launch allows companies to allocate more resources towards other areas of intrest	• Cost of launching satellites • Proposed solution potentially not feasible • Large up front cost

Components and Design

Features

For the purposes of this project, the team's goal is to create a small-scale model of the coil gun described above to determine its real-world feasibility and as a basis for defining requirements for the final solution. A list of planned features for this small-scale model can be found in table below.

Table 1- Feature table defining features of solution.

Feature	Benefits	Effort
Modular Design Approach	• Highly scalable • Allows the technology to be easily adapted to many applications	• Requires extra development effort
High Efficiency	• Lower energy consumption per shot • Less expensive components required	• More simulation time required to arrive at optimal design.
User Friendly testing software	• Improves accuracy and efficiency of data collection	• Matlab programming required
Reliability	• System is dependable and is not costly to maintain	• Ensure all selected components are operating well within specifications.
Safety	• Team members don't get hurt in design and testing process	• Extra design considerations required to ensure isolation from high voltages/currents or fast-moving objects.

Design goals and Component Specifications

The team decided upon several design goals for the project including a projectile energy of 8 Joules, a projectile velocity of 30 m/s, and an efficiency of 10 percent. These goals were decided upon through a combination of calculations, research into existing devices, and budget constraints.

The first step in designing the device was to derive a set of generalized equations relating input power, muzzle energy, projectile mass, and barrel length. The following equations were used when deriving the coil gun equation.

$$1)\quad E_k = \frac{1}{2}\, m\, {v_f}^2$$

Where E_k is Kinetic Energy, M is mass, and v_f is the projectile velocity.

$$2)\quad E = Pt$$

Where E is energy, P is power, and t is time.

$$3)\quad d = \left(\frac{v_i - v_f}{2}\right)t$$

Where d is distance over which power is applied, vi is initial projectile velocity, v_f is final projectile velocity, and t is time.

Subbing equation 3 into equation 2, we arrive at the following equation:

$$4)\quad E = P\left(\frac{2d}{v_i - v_f}\right)$$

Knowing that the projectile is initially at rest, v_i is 0. Rearranging equation 1 for v_f and substituting into equation 4, we arrive at:

$$5)\quad E = \left(Pd\sqrt{2m}\right)^{\frac{2}{3}}$$

This equation relates the power delivered to the load, the distance over which said power is applied, the mass of the projectile, and the final energy of the projectile. Obviously, this is idealized and does not account for friction or inefficiencies in the transfer of energy between the batteries and the projectile. It also fails to account for coil timing inaccuracies as well as residual magnetic fields in coils as the projectile travels through resulting in 'suck back'. Due to the complexity required to model such phenomena and the preliminary nature of this report, a general efficiency of 5% is assumed. With further future research into the topic and the use of advanced modelling and simulation software this assumption will be replaced with more realistic models.

Looking into equation 5, the energy is proportional to the cube root of the mass indicating that it is more efficient to deliver energy to projectiles with higher mass. This design consideration was noted and lead to the decision to use a longer and thus heavier projectile rather than a smaller, faster one. The length of the projectile is calculated using the following equation.

$$m = \pi r^2 \times l \times \rho$$

Where m is the mass of the projectile, r is the radius of the projectile l is the length of the projectile, and ρ is the density of the material.

Rearranging for l, we arrive at the following equation:

$$6)\quad l = \frac{m}{\pi r^2 \times \rho}$$

For now, it is assumed that the projectile material of choice is steel due to its magnetic properties, price and abundance. Using equation 1 and the design goals of 8 J muzzle energy and 30 m/s projectile velocity we arrive at a projectile mass of 18 grams. The density of steel is known to be $8050\frac{Kg}{m^3}$. These values along with a barrel diameter of 6.35mm (1/4") were subbed into equation 6, yielding a projectile length of 7.06 cm.

Since the optical triggering design relies on a coil length equal to that of the projectile length, the length of each coil element is also 7 cm. Assuming a space requirement of 1 cm between each stage for optical sensors the length of each modular coil element on the barrel is 8cm. Due to budget constraints the prototype is limited to 6 coil stages which yields a minimum barrel length of 48 cm.

Using the available acceleration distance of 42 cm (negates the length of each optical trigger mechanism as no acceleration occurs here) along with equation 5, the required power delivered to the projectile was calculated to be 283 Watts. Assuming a power transfer efficiency between the battery and the projectile of 5%, the batteries and power management system must be capable of delivering pulses of 5670 Watts. This is quite realizable using modern Lithium polymer batteries. These batteries are capable of delivering current up to 100 times their rated capacity for short time durations. The total power delivered by the batteries can be calculated easily using the equation below.

$$7)\quad P = n_{cells}V_{cell} \times 100Q_{cell}$$

Where P is the power delivered by the battery, n_{cells} *is the number of series cells of the battery,* V_{cell} *is the voltage of each cell, and* Q_{cell} *is the capacity of each cell in Ah.*

It was decided that to minimize power losses in the system, the voltage should be as high as is feasible. In this way, the current required to meet the power specification is minimized. From this decision it was decided to use a 12 cell LiPo battery. To calculate the required battery capacity, Equation 7 was rearranged to solve for Q_{cell}.

$$8)\quad Q_{cell} = \frac{P}{n_{cells}V_{cell} \times 100}$$

Using the power calculated above of 5670 Watts, a 12-cell battery and a nominal cell voltage of 3.7 V, the required capacity of the battery was calculated to be 1.3 Ah or 1300 mAh. At the nominal voltage of 44.4 V, the battery must provide approximately 130 amps to meet the power requirement.

Sub-systems and Block Diagram

Building off of the previous explanation of how a coil gun works, the block diagram in figure below highlights the specific hardware subsystems required to build such a device.

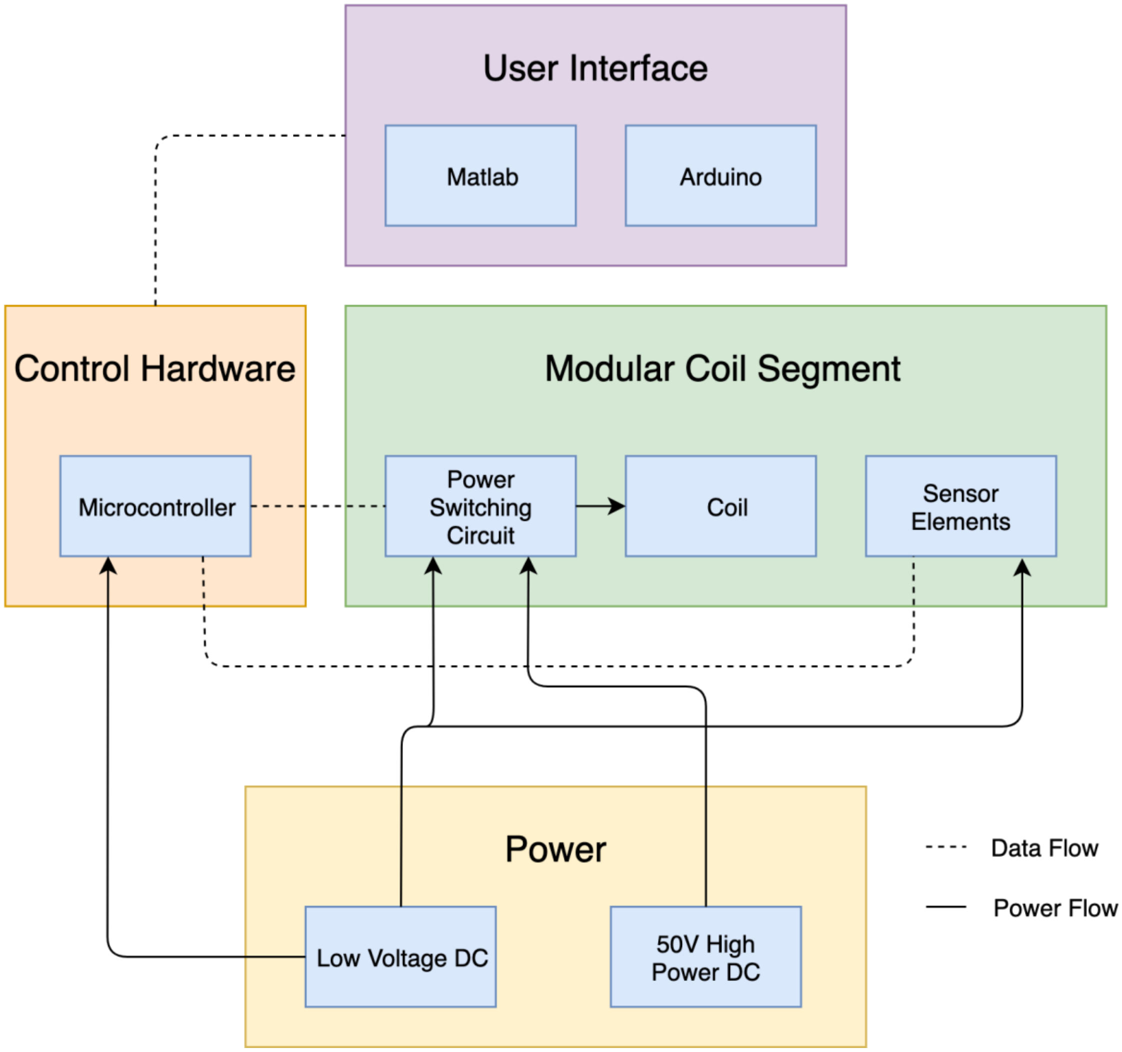

Figure 3- System block diagram of a basic, single staged coil gun.

The subsystems can be broken down into three sections; power electronics, control systems, and user interface.

The power-handling electronics necessary for the coil gun's operation are a power switching module, a coil, as well as a 50 V power supply. The required specifications for these modules were calculated previously. The selected battery is made up of two 6-cell 2650 mAh lithium polymer batteries connected in series. This gives a significant margin over the required specification which should negate any error in the calculations for battery current as well as provide a much longer battery life. The coils used in the accelerator were calculated above to be 7 cm long. Since the resistance of the system must be minimized to ensure the maximum possible current flow, 18 AWG wires were selected for this application. These wires are 1 mm in diameter with a resistivity of 6.39 Ω per 1000 feet. Using the coil length of 7 cm and assuming three layers of windings per coil, it was calculated that each coil would require 8.25 meters of wire to make. This calculation did take into consideration the increased diameter of each sequential layer. The resistance of each coil should be approximately 200 mΩ. [8]

The power switching module will be designed around an STP310N10F7 N-channel MOSFET. Using the series resistance of each cell of 10 mΩ, the coil resistance of 200 mΩ, and assuming no voltage drop in the power delivery wires or MOSFET switch, the maximum possible current flow in the system was calculated to be 156 amps. Inspecting the data in figure below, the maximum safe pulse current of the device can be calculated.

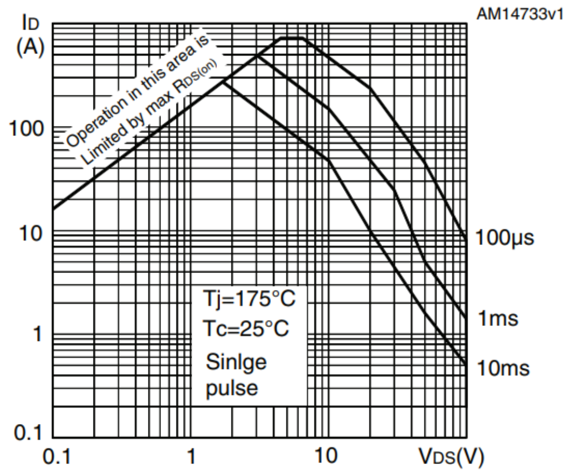

Figure 4- STP310N10F7 Safe operating area [9].

Assuming an on time of 10ms, it can be seen that the maximum drain current of this MOSFET is approximately 250 amps. This is assuming an initial junction temperature of 25 degrees Celsius. Even as the device temperature begins to rise, device should be more than capable of meeting the demands of the coil gun. [10]

The control systems used in the coil gun will consist of a microcontroller and a projectile position sensor. The microcontroller used will need to control the timing of the MOSFET's and take inputs from the sensor elements while also collecting data and transmitting it to a computer. Since the projectile is travelling at a high speed and the timing of the coils is incredibly important to the efficiency of the system, the microcontroller needs to be able to respond to and produce very fast pulses. Using the goal projectile velocity of 30 m/s and aiming for the coils to be enabled after the projectile travels 1mm past the sensor, we can determine the maximum time delay in the system.

$$9)\ \ t = \frac{d}{v}$$

Using the above equation, the minimum time delay in the system is 33 microseconds. A common microcontroller available for use is the Arduino Mega. This board uses a 16 MHz clock speed meaning that each instruction takes 62.5 nanoseconds to complete. This means that the Arduino can complete 533 instructions before exceeding the minimum time delay in the system. Since the triggering code is relatively simple (output reacting directly to an input with some filtering) this is easily attainable. The projectile position sensor is used to determine when to enable and disable power flow in each of the coil segments along the barrel. The team plans to use an optical triggering mechanism where a light beam is created using an IR LED and is shone radially through the barrel. This light beam is detected by a photodiode on the other side of the barrel. As long as the beam is not broken, there is no projectile in this segment of the accelerator. As soon as the beam is broken, the signal from the photodiode goes low, indicating the position of the projectile to the microcontroller. This position data is used to provide power or the corresponding coil and is used to measure the velocity of the projectile for data collection. The wires to the photodiode will be sensitive to electromagnetic interference. Since the coilgun is switching high powers to create an intense magnetic field, it is expected to produce strong EMI. To avoid erratic switching as a result of interference, the wires will need to be twisted together and potentially shielded. The microcontroller will also need to incorporate code to limit the max pulse duration to avoid damage to the MOSFET's in the case of sensor failure or interference.

Risk Analysis

With designing and building a device such as the coil gun does present some risks to both the user and individuals who are standing nearby. One of the risks associated to designing such a launch system is to make sure the multi-stage set of coils turn on and off when the projectile reaches the mid-point of the stage. If the projectile passes through the area of current and the next coil of wires does not activate and the first stage is still activated, then there is a risk that the Gaussian forces applied on the projectile from the first set of capacitors will begin to act the opposite way and cause the projectile to be accelerated in the opposite direction of firing. The risk associated has to deal with possibly damaging the projectile and the payload which the projectile carries along with damaging the barrel within the gun.

Another risk with creating such a device to launch a small satellite into space is the acceleration of the projectile before it leaves the barrel. Humans can withstand temporary gravitational forces up to 47 G's and the projectile shot out of the barrel would be too large for a human to survive. Studies show humans would not be capable of reaching space using this method. [3]

A major obstacle which is considered a risk is coordinating when the coils are energized. If there is a time delay when activating the signal to when the coil is energized, then the Gaussian forces will once again operate in the opposite direction desired and have a detrimental impact on the projectile.

Along with having to charge up the capacitors prior to being launched, there is a risk that the strong electromagnetic fields which will exist around the coils could possibly interfere with the signals sent to and from the controller unit which could cause an error within the electronics which would lead to an unexpected result.

Some major assumptions which were made in order to fully develop the design deals with the atmosphere which the device is being ejected into. As a result, Professor Gazor told us to not consider air resistance as it is out of the scope of the project. Another consideration was how ideally a kilogram needs only 9 MJ of energy to be sent into orbit. This assumption is based on studies which show the Delta-v is between 9km/s and 11km/s for a low Earth orbit. [2] Finally, we are assuming the coil gun can acquire the pulse energy necessary from a power source to proceed with the launch. The pulse energy is required for a very small period of time but a very large quantity of energy will be drawn.

Budget

The cost of the project can be split into several categories including energy storage, power switching, control circuitry, coil components, and sensor elements. The cost breakdown for a coil gun using 7 modular coil elements is shown below.

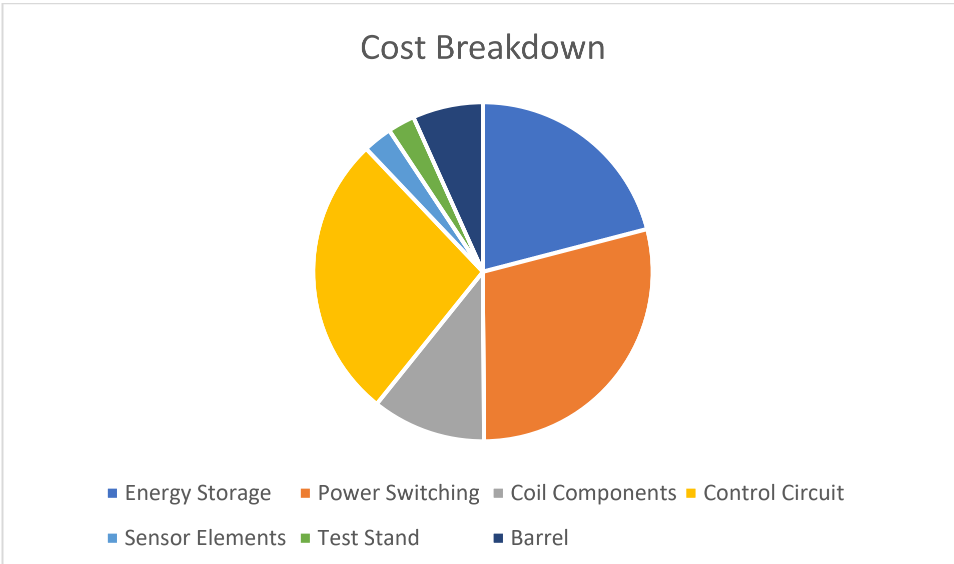

Figure 5- Cost breakdown for a 7 stage coil gun.

Note that the energy storage and power switching sections account for nearly 50% of the total cost. Lithium batteries are quite expensive, and the power switches contain the most expensive transistors and diodes used in the project. The component selection was mostly explained in the design and components section of the report. All components were selected with at least a 1.5x safety margin to reduce the chance of damage. This cost projection does not include the cost of any damaged parts or account for any trial and error in the design. It is likely that the final cost will be higher than is estimated here.

Table 2- Cost of each category for a 7 stage coil gun.

Category	Cost
Energy Storage	$ 81.00
Power Switching	$ 112.00
Coil Components	$ 42.00
Control Circuit	$ 105.00
Sensor Elements	$ 10.71
Test Stand	$ 10.00
Barrel	$ 26.00

Total Cost	$ 386.71

Table 3- Cost breakdown per category.

Energy Storage	#	cost	source
Battery	2	$ 33.00	https://hobbyking.com/en_us/zippy-flightmax-2650mah-6s1p-40c.html
Conductor (bus bar or heavy gauge wire)	1	$ 15.00	https://www.princessauto.com/en/detail/3-4-x-1-8-in-aluminum-flat-bar/A-p1450105e
Total		$ 81.00	
"-----------------------------Per Stage----------------------------"			
Power Switching	#	cost	source
MOSFETs	1	$ 10.00	https://www.digikey.ca/product-detail/en/STP310N10F7/497-13233-5-ND/3598099
Protection diode	1	$ 2.00	https://www.digikey.ca/product-detail/en/diodes-incorporated/10A07-T/10A07-TDICT-ND/2242773
Zener clamp diode	1	$ 4.00	https://www.digikey.ca/product-detail/en/on-semiconductor/1N5366BG/1N5366BGOS-ND/918048
Total		$ 16.00	
Coil Components			
18 AWG magnet wire	1	$ 6.00	https://www.remingtonindustries.com/magnet-wire/magnet-wire-200c-18-awg-polyamideimide-7-spool-sizes/
Total		$ 6.00	
Control Circuitry			
Arduino mega (used)	**1**	$ 5.00	
Assorted components	1	$ 10.00	
Total		$ 15.00	
Sensor Elements			
IR LED	**1**	$ 1.00	https://www.adafruit.com/product/387
Photodiode	1	$ 0.53	https://www.digikey.com/product-detail/en/on-semiconductor/QSD2030/QSD2030-ND/1050960
Total		$ 1.53	
Barrel			
Polycarbonate	**1**	$ 26.00	https://www.eplastics.com/Clear-Polycarbonate-Rigid-Tubing-1-4-ID-x-3-8-OD-x-1-16-Wall-x-8ft

Total		$ 26.00	

Development Plan

The development plan can be split into the following main categories:

- Define the problem
- Propose a solution
- Research
- Design subsystems
- Build prototype
- Test prototype
- Finalize design

Each team member will split the role of researching, designing and completing their assigned tasks. Breaking down the project in this manner ensures that each team member can contribute to the design process and understands their role and the time they must complete this task by. Having clear goals set for each contributor will make the team function more efficiently and reduce the time spent coordinating. Each team member will understand their responsibilities and when their tasks must be complete. A Gantt chart detailing each task, subtask and the team member it is assigned to can be found in Figure 6 below.

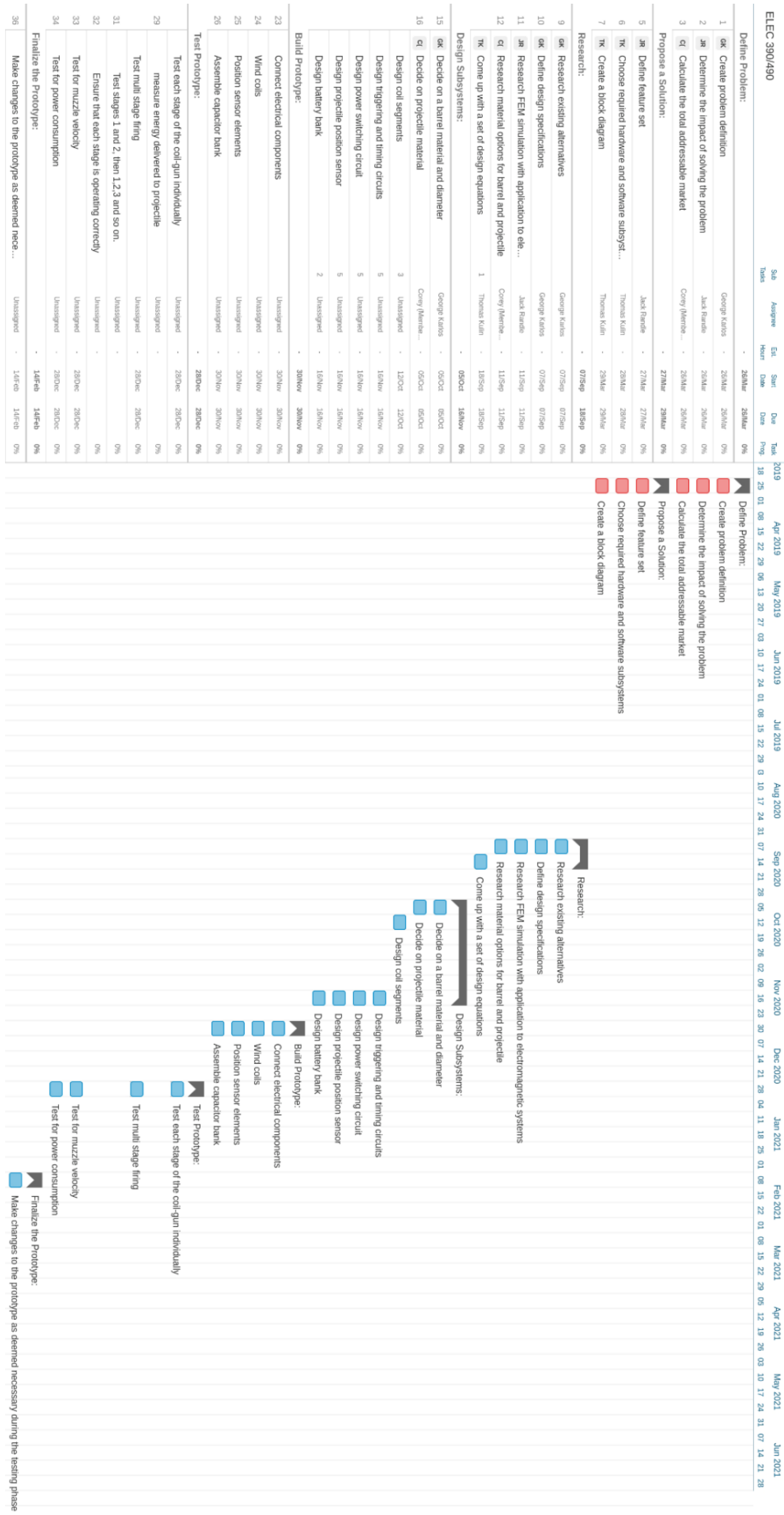

Figure 6- Gantt chart outlining project plan

It is important that each category of the development plan is completed on time in order to progress forward into the next section since each category is dependent on the completion of previous segments. Looking forward, the first stage to be completed is designing the individual subsystems. This can be broken down into deciding on materials, designing circuit diagrams, and designing printed circuit board (PCB) layouts. Material choices will be made through use of FEMM (Finite Element Method Magnetics) simulation to determine the optimal cost/benefit ratio. The circuit diagrams and PCB layouts will be created using Autodesk Eagle computer aided design (CAD) software. Design of the test apparatus and other small components will be done using SolidWorks CAD software with components being manufactured using the 3D printers and computer numerical design machine (CNC) available at SparQ Studios.

Once the components are designed, the next step is to begin the manufacturing of each component and subsequently the entire prototype. This will consist of either etching or using a CNC machine to create PCB’s at SparQ studios, soldering components to these circuit boards, manually winding each coil, 3D printing the required physical components, and assembling the parts. Relying on the machines at SparQ is risky since they are available for hundreds of students to use. There is no guarantee that the equipment will be available for use or even in a functional state as students often make mistakes and break things. This risk can be mitigated by booking equipment ahead of time and having our parts manufactured early to increase the chance that the machines are working.

Once the prototype is assembled testing can take place. The first step in testing the device will be to test each component individually. This will consist of measuring the resistance of the coils, performing low-power testing of the power-switching circuits, triggering circuits, as well as checking the response of the position sensor. After each component is confirmed to be working, the next step is to test the performance of the system. This will consist of testing the efficiency, projectile velocity and projectile energy after each stage.

Based on the results of the test procedure, adjustments can be made to the prototype to help it better fit the specified design goals or to fix unwanted behavior.

Test Plan

To ensure that the coil gun operates properly and safely, each component of the accelerator will be tested individually. It is a multistage accelerator and each stage is made up of several components, each of which will be tested in isolation before being added to the prototype. Each stage has five main components, which all play a pivotal role in accelerating the projectile to the desired specifications. This battery pack will be tested, ensuring that it operates at the desired voltage level of 50.4 V and generates current pulses of at least 130 A. The charging system will also be tested, to ensure that the battery pack will be able to charge to the firing voltage in a timely fashion. After the battery pack has been successfully charged, a consistent and precise discharge mechanism is needed for each stage of the accelerator. The discharge apparatus will connect the battery pack to the coils of a specific stage, short circuiting the system and generating a large amount of current through the coils. This discharge system needs to be very precise, and quickly react to the projectile position in order to maximize efficiency of the entire accelerator. This aspect of the system will be tested for reaction time, as it needs to be able to open and close the short circuit very quickly. After it has been established that the discharge method can react quickly to inputs, it will be tested in tandem with the projectile trigger in order to establish the efficiency of that stage. The projectile trigger will need to sense the position of the projectile as it passes down the barrel and convey this information to the rest of the system. This trigger will be tested in isolation with the projectile and barrel, as providing the correct inputs to discharge mechanisms is of the utmost importance. Once it is established that the sensor is collecting the correct placement information, it will be connected to the discharge mechanism to trigger the activation of different stages of the accelerator.

Once the charging system has been connected to the battery pack and the discharge mechanism has been paired with the projectile trigger with good results, the entire stage can enter testing. The discharge system will be connected to the battery pack and will be receiving information from the projectile trigger of the prior stage. The stage will be tested multiple times in isolation to make sure that all aspects are working properly before being integrated into the other stages. Once multiple stages are in series, the full testing of the 'Coil Gun' can begin. Many issues will likely arise at this stage, pertaining to the calibration of each stage relative to the last one. It will be extremely difficult to reach a desirable efficiency unless the projectile sensors are working perfectly with the discharge systems from other stages. The natural induction in the coils of the accelerator are also something that needs to be accounted for, as there may still be some lingering current in the wires slightly after the discharge mechanism has been disconnected. There are many small issues that can ruin the efficiency of the accelerator, which we hope to mitigate by calibrating each piece of each stage individually prior to assembling the final prototype.

Team

The members of the team are George Karlos, Thomas Kulin, Corey Meehan and Jack Randle. As a group, we believe each of us bring of vital importance to completing a project with this large of a scope. In the table below are the brief backgrounds of each member, along with the extracurricular contributions and a breakdown of with which report sections where completed by who. We felt that each team member completed each section based on the skills which they brought from school along with courses or extracurricular projects which they have completed.

Thomas	Component Selection Physical Design Has experience designing and creating different electrical appliances. Previous projects include electric longboard and tesla coil
Jack	Testing the prototype Industry Analysis and application due to also taking some commerce electives Experience with power tools due to contractor experience
Corey	Completed Impact of our solution Created Risk Analysis

	Has previous experience with different power tools and recognizing industry applications and determining how to market a product to be sold to customers
George	Problem Definition Solution Project Management and Software Has previous circuit design with Eagle

Project Management Software

A variety of project management tools will be used by our team for the duration of the project. These tools can be broken down into a few subsections such as task management, collaborative documentation and communication. It is important to note that for our project we will not be working with any software or code thus not needing to make considerations for that when discussing the tools that will be used.

Task Management

Task management as the name suggests, is the process of managing tasks through the course of a project. Task management can be further broken down into four subsections; planning, testing, validation and reporting of results. Thus it is imperative that the team use a tool that would incorporate all 4 of the subsections mentioned above. The team will be using Asana in correlation with Instagantt. This software allows for the breakdown of individual tasks, documenting the results from testing of components, as well as the creation of a detailed timeline of deliverables that need to be met during the different lifecycles of the project. This software was chosen as the ideal task management tool for our group as it was the only task management tool that had an easy to use interface combined with all group members having had some prior experience using the software tool.

Collaborative documentation

For collaborative documentation, the team will be using Microsoft Word Online as the primary tool. Word Online allows for real-time collaboration amongst team members. This aspect allows for other team members to see what the individual is working on and can simultaneously work on the same section of reports without the worry of overlapping. Another factor that was considered when deciding on using Microsoft Word was the easy to use interface as well as the extensive experience that each team member had using this software before.

Communication

Communication is one of the most important aspects when looking at project development, thus it is important to make sure that everyone is always up to date and on the same page. For communication purposes the team will be using two different tools; Slack and Facebook Messenger. The reason for this is that Slack is better suited for discussing components of the project whereas Facebook is better suited for setting up meeting times as all team members check Facebook more frequently than slack.

Deliverables

After spending the next two years researching the applications, developing and testing the accelerator, several deliverables will be completed. Perhaps most importantly, a six-stage electromagnetic accelerator will be fully operational by the time of capstone presentations. This model will be able to operate under the specifications calculated above, propelling a projectile with energy of 8 Joules, a projectile velocity of 30 m/s, and an overall efficiency of 10 percent. These specifications should be able to be achieved by developing the six-stage design described in the design section.

Alongside the finished accelerator, a simulation will be created allowing the user to estimate the behavior of the accelerator under certain conditions. This simulation will take input values such as voltage, current and barrel angle; and provide the user with results such as the exit velocity and distance travelled by the projectile. To summarize our experience, describe the process of the accelerator and walkthrough the simulator, a report will be written. This report will contain in depth analysis

Beyond Capstone

Midsized Launcher for Space Applications

After reading the above report, the most exciting function of our model is that it could theoretically be used to propel small and moderately weighted packages into low earth orbit. Although this application of the accelerator may seem impractical, there are several studies that have concluded that there would be many upsides of shifting to electromagnetic acceleration. For everything short of human travel and large resupply launches, using a large scale 'Coil Gun' can reduce the fuel usage, which is currently one of the greatest costs of launching. The accelerator would theoretically also reduce the turn-around time between launches and reduce the manpower needed to prepare a payload for launch. This function of the accelerator likely has many years until it is used commercially but the upsides of the design are undeniable when it comes to low-orbit space launches. [11]

Jet Acceleration

There are many possible applications of an electromagnetic accelerator. Although for this class, we have designed a prototype for the purposes of space delivery, the general concept can be repurposed in many different industries. One of the most interesting applications that can be realized by scaling the prototype, is accelerating jets to their takeoff velocity when they are kept on military vessels at sea. As these vessels do not have the length to install a full runway, the jets are currently propelled to their takeoff velocity using a steam compression system. This system could be replaced by a large electromagnetic accelerator system, allowing the vessel to avoid potentially dangerous situations associated with highly pressurized structures. [12]

Small Scale Handheld Devices

As soon as the basic idea for a 'Coil Gun' was established, many people's thoughts immediately went to handheld military applications. There are currently many issues with this, the main one being that the current gunpowder driven guns are simply more efficient, durable and effective.

Even if a soldier was given a ‘Gauss Gun’, the capacitor bank they would need to carry in order to match the power of current munitions would be far too large to be practical. Although that precise application is not realistic, it does not mean that small scale handheld accelerators are completely useless. There have been several handheld prototypes invented that can fire many times and at high velocities before needing to be recharged. These small-scale functions of the concept could be repurposed to reinvent several everyday tools and construction applications such as nail or staple guns. [13]

Military Applications

It was mentioned above that handheld military applications of an electromagnetic accelerator are not likely to become useful in any capacity in the near future. However, that does not mean that this technology is not currently being explored for military purposes. Most recently the USS Zumwalt, the flagship of a new class of advanced stealth destroyers, was commissioned with the expectation that an electromagnetic accelerator would be used on board. The US Navy has been testing a large-scale accelerator for years now, the technology is enticing due to the very impressive muzzle velocities that can be reached. In large scale military functions, the launcher can easily accelerate a forty-pound projectile to speeds of over two kilometers per second. The projectile does not need to be explosive, as the damage will be done upon collision when the kinetic energy from the projectile is quickly transferred to the target. These weapons have been proven to be effective, the question is whether or not it is worth using an electromagnetic accelerator over traditional methods. The ‘Gauss Gun’ prototype on board the USS Zumwalt needs 25 MegaWatts to function properly and although the destroyer is capable of delivering this power, many other current weapons could serve a similar function using less. [14]

High Speed Vehicle Propulsion

Perhaps the function with the most immediate potential impact is using the concepts of a ‘Coil Gun’ to accelerate vehicles to very high speeds. This concept has been relevant in the transportation industry since 1984, when the first ‘magnetic levitated’ train was created in the UK. Although the acceleration technique is often referred to as ‘Magnetic Levitation’ or ‘Linear Induction Motor’ in the transportation trade, it operates using the exact same principles as the other applications discussed above. The base of the train is created out of magnetically permeable metal and is levitated when a field is created by the track. Then, just as with the ‘Coil Gun’, stages in front of the train activate a magnetic field to drag the train forward and then deactivated as the train passes over them, creating a constant acceleration. Examples of vehicles accelerated in this manner have already been employed in Japan, South Korea and China, able to reach extremely high speeds due to the lack of friction during propulsion. [15] This concept is trying to be innovated on further by Elon Musk, currently developing ‘Hyperloop Trains’ [16] that would be capable of even greater velocities. The upsides of using this technology for transportation are great as higher speeds, lower friction and better efficiency are all being realized using this method.

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