Capacitor Gun

A.k.a (railgun)

Project Plan

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List of Definitions

- **EM** - An abbreviation for electromagnetism.
- **Capacitor** - An electronic device used to store an electric charge to be discharged and used later in a certain application.
- **Solenoid** - A coil of wires acting as a magnet while carrying current. Included is an arm called a stroke which extends at a high speed producing a force on an object.
- **Gauge wire** - A term used to describe the diameter and current carrying capacity of a wire or cable.
- **Lorentz Force** - The force exerted on a moving object by a magnetic force.
- **Muzzle** - Open end of a barrel of a firearm.
- **MJ** - Abbreviation for megaJoule. A joule is a unit of measure for energy. Likewise, KJ is kiloJoule.
- **Breach** - Another term for a door or latch.

1 Introductory Material

1.1 Acknowledgement

The Capacitor Gun Project team would like to thank Iowa State University and the Professors of the College of Engineering for their help and support through this process. Also, thank you to Professor Mani Mina for his mentorship and sharing of expertise in EM. Others who have helped include Professor Neihart who assisted in formulating equations and Mr. Mike Ryan who gave us a workspace to craft and material to craft with. Mr. Ryan also used his vast design expertise to assist us with the design process and give us solutions to consider.

1.2 Problem Statement

Currently, the only option for how firearms (projectile launchers) shoot objects is combustion. While this method is proven and effective, there is a power limit to combustion and also a lack of precision at high speeds due to the lower energy. Railguns have the ability to power projectiles of greater mass at a much higher velocity due to the concentration of energy that is possible with EM propulsion.

We are trying to create a functional railgun so that one day the design could be used to replace current combustion weaponry. As of now, when you think about railguns, you first think about the large-scale military grade ones. These railguns are designed to be very large. Because of their size, they are very complex in their design and need complex components in order to function correctly. Being extremely large also means there needs to be a lot of materials in order to build them, thus making them expensive to build and operate. With that being said, our goal is to design a railgun on a much smaller scale to see if it would be both practical and possible when comparing it to combustion weaponry.

1.3 Operating Environment

Our end design will be operated outdoors so it must be able to withstand different weather conditions. It will also be easily portable for relocation and adjustments. Our end design will need to be heat resistant as well because of the high currents and voltages being used. Because the capacitor gun will contain an immense amount of charge it will have a discharging element to it so someone who comes in contact with it will not get shocked.

1.4 Intended Users and Intended Uses

Our team intends our product to be used by the military or an experienced hobbyist. This project is a weapon that is dangerous to those who are not experienced with its functionality and design. This is the main reason why it is not intended for the general public. Only the military and those with knowledge on the railgun design and safety measures will use this product.

Our project will be a scaled model of what the current United States military uses. Possible uses for our rail guns include replacing turrets and artillery cannons with this technology as well as hand-held rifles. This will improve our weapon systems that are used to protect our nation.

1.5 Assumptions and Limitations

Assumptions:

1. The military needs/wants new technology
2. The difference between magnetic and combustion propulsion is large enough to warrant investment
3. Railguns can be just as accurate as current technology
4. Railguns can be operated in any conditions

Limitations:

1. The cost of this project may be too high for our budget ($1000)
2. Railguns at this stage are single-shot devices
3. The railgun will need a cool-down and recharge period between shots
4. The heat release may be too high for hand-held usage

1.6 Expected End Product and Other Deliverables

By the end of the Fall semester, the final project will be a functional weapon system. It will use EM (electromagnetics) to fire a projectile with the use of capacitors and a high voltage battery. The deliverables will include:

- A capacitor bank
    - The capacitor bank will consist of four 450V capacitors connected using aluminum. The use for the capacitor bank is to store charge in the form of electrical energy. This will be used to induce a current in the metal rails which will create an electromagnetic field.
- A battery
    - The battery will be used to charge the capacitor bank. The battery is where the whole project starts. It will charge the capacitors to our specified voltage in order to create the means to fire the projectile.
- Metal Rails
    - The rails are used to carry current in order to create the electromagnetic field. The rails must be made of a conductive metal because the electromagnetic field is created by a current running through it.
- Wires
    - Wires will be used to carry current from the capacitor bank to the rails. These wires must be able to handle high amounts of current, which is why we decided to use two runs of eight gauge wire. These are a vital part of the design because, without them, it would be difficult to transfer the current to the rails.
- Projectiles
    - The projectile is what makes this a weapon. It must be conductive so that it can experience force by the electromagnetic field. The projectile will enter the field and experience what is known as the Lorentz force. This is created by the current and magnetic field and is what will give the projectile its final velocity when it travels from the beginning to the end of the field.
- Spring Mechanism
    - The spring mechanism will be a spring that will be compressed back and released. During this release, it will push the projectile forward and into the opening of the rails. This will make the projectile enter the rails at an initial speed to avoid getting stuck from the magnetic field that is being created.

This design will not be commercialized or made for public use. It will be strictly for military or otherwise authorized personnel. We first expect to have a small scale model design and it will be functional by the end of the first semester. We also expect to have a final design that is functional and improved compared to the small-scale model finished by the end of the second semester.

2 Proposed Approach and Statement of Work

2.1 Objective of the Task

The end goal of this project is to have a physical, working railgun one-tenth the size of current designs. With the end product will also be a list of instructions for its safe usage. General calculations, estimations, and formulas will also be provided.

2.2 Functional Requirements

- Shoot projectile
    - The requirement is that the project effectively shoots the projectile a minimum of 100ft
    - An additional goal is that we want our projectiles to be shot accurately at a set target
- Multiple rounds
    - Must be able to fire multiple shots in a reasonable time
    - Rails must be able to withstand multiple shots before needing to be changed due to degradation
- Muzzle Energy
    - The muzzle energy of the railgun should show that with our design and sufficient funding, an EM propulsion device can be of similar or greater power to chemical propulsion.

2.3 Constraints Considerations

Safety:

The design of the railgun should be in a way that the end-user could follow general firearm safety guidelines with extended caution for enclosed electrical components. Training for safe operation would only be needed to highlight electrical hazards as well as safety when charging and loading the device.

Operability:

The device should be able to be reloaded quite easily by a single person. If the railgun needs to be moved a group of two to three people would be needed. Sustained fire should be possible with the use of replacement rails when the current rails degrade past the point of operation.

Durability:

The device should be able to withstand calm outdoor weather as well as worse conditions while operating. The railgun will have to dissipate heat in a time faster than or equal to the time it takes to reload and recharge. The rails should be able to handle repeated fire with a change of rails after no less than 10 shots with a goal of over 50.

Standards

There are various standards that we have taken into account during this project. We have all had to read and follow the department's lab safety procedure throughout our college careers and we strive to follow those procedures while conducting lab work[10]. When handling unfamiliar tools and equipment the group deferred to the shop owner who was experienced and knew how to safely operate the equipment. An IEEE article on safety while working with electronics has been useful to us as it outlines the hazards related to working with electricity and how to lower your risk of injury. A section of the article on enclosures and barriers between the user and an energized part of the design has helped us in making sure the material we are using will sufficiently protect the user[11].

2.4 Previous Work And Literature

Currently, there are three main categories of railguns that have been created before: small physics demonstrations, hobbyist creations, military weapons. The small physics demonstrations are usually seen in Youtube videos or classrooms that want to demonstrate the principles of EM motion through a physical device. These devices generally have enough power to move a small projectile a few feet across a classroom at most and are in an open package to demonstrate the different components required. This design really has no advantages other than it can be a useful teaching instrument.

The hobbyist creations are generally in a package size similar to the budget and knowledge of the creator and are used as a fun projectile shooter. These devices are generally designed to shoot a marble to playing card sized object across a yard or about 50ft. This distance is generally limited to the ballistics of the projectile and the power outputted by the capacitors. The advantages to these designs are that they are small enough to be operated by a single person and are well designed to keep the user from getting an electrical shock. Disadvantages to these designs are that the energy emission is often very low compares to a firearm. Also, these designs do not charge very quickly nor do they dissipate heat effectively[3][4][5][6].

Finally, the military railguns that have been created are very large and are designed to replace mobile missile defense systems. These systems operate in the 3-32MJ range and have a footprint that is meant to be on a trailer pulled by a semi or similar sized truck. These designs have an incredible amount of firepower and can currently hit a target 100 miles away and be shot at 5600 miles per hour. Due to the amount of funding at the military's disposal (or companies that sell to the military) these designs can be charged and fired ten times per minute without degradation to the rails or worry about heat release. The only disadvantage to these designs is their sheer size[9].

Our design is going to focus in the kJ range of power. It will be more comparable to a hobbyist railgun due to its size, but it will be designed to hold more charge and therefore have a greater energy release. We drew a couple design ideas from videos and research on other railguns for our design such as the capacitor bank, projectile logistics, and discharging circuit.

2.5 Proposed Design

Our proposed design will be a fully electronic railgun. Previously built projects use software and air compression to provide the initial velocity into the magnetic field. Our team’s design includes a spring mechanism to be used for the initial push. The spring will give the projectile a quick and powerful push into the magnetic field created by the charged rails. It is necessary to have an initial push because the projectile itself acts as a connection in a circuit. If it is not moving, then the massive amount of current going through it will weld the projectile to the rails.

We do have a few design alternatives based on materials and size of our rails and projectile. With the rails, we are going to test whether aluminum or copper is best to use and use the other material for the sled. This way we can determine which pair of materials is best to prevent the most degradation of the rails due to the heat and friction of firing. We will be testing a conductive lube to observe the effects and determine if it is beneficial and prevents the rails from degrading.

Another aspect of our design that will need to be tested is our projectile. Our initial thought is to make it like a sled. It would have been a U shape in design so that we can place any material inside of the sled. That way the projectile does not have to be conductive. This gives us more options for projectile materials. The other alternative to the projectile is to use one piece of conductive metal which will be cut and shaped to a specific design to minimize air resistance and velocity losses. The single body design will be more expensive to manufacture but easier to design and potentially lighter. For our initial testing phase, we will use a single piece of aluminum, once we know the design works we will move onto improving the projectile design.

Our capacitor bank will be charged with a charging circuit (fig. 2) that will have functionality that will allow the user to set the amount of charge they want the capacitors to be charged to. We will be using an LT3571 chip, “High Voltage Capacitor Charger Controller with Regulation”. This chip, along with the rest of the circuit will allow us to charge our capacitors with a 12v deep cell battery. There will also be a discharge circuit to make sure the rails are safe to handle on the electrical side.

The proposed design is as shown below in figure 1. Not all the components are present in this sketch but shown below is a 12v battery and a charging circuit is being used here to charge the capacitors. The positive side of the capacitors is connected to one rail and the negative side is connected to the other rail. A spring mechanism is shown at the end of the rails, this is where the projectile will be loaded, the spring will launch the projectile into the magnetic field. A discharge circuit will be used to make sure the railgun is safe to handle after it has been fired.

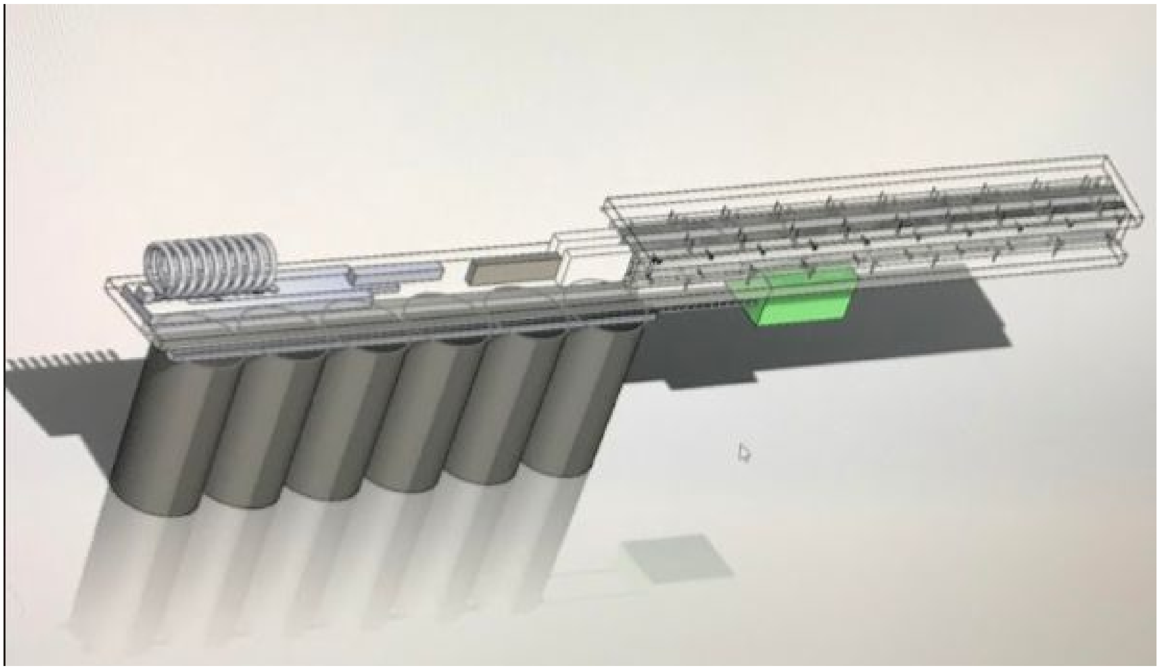


Figure 1. The overall design for the project.

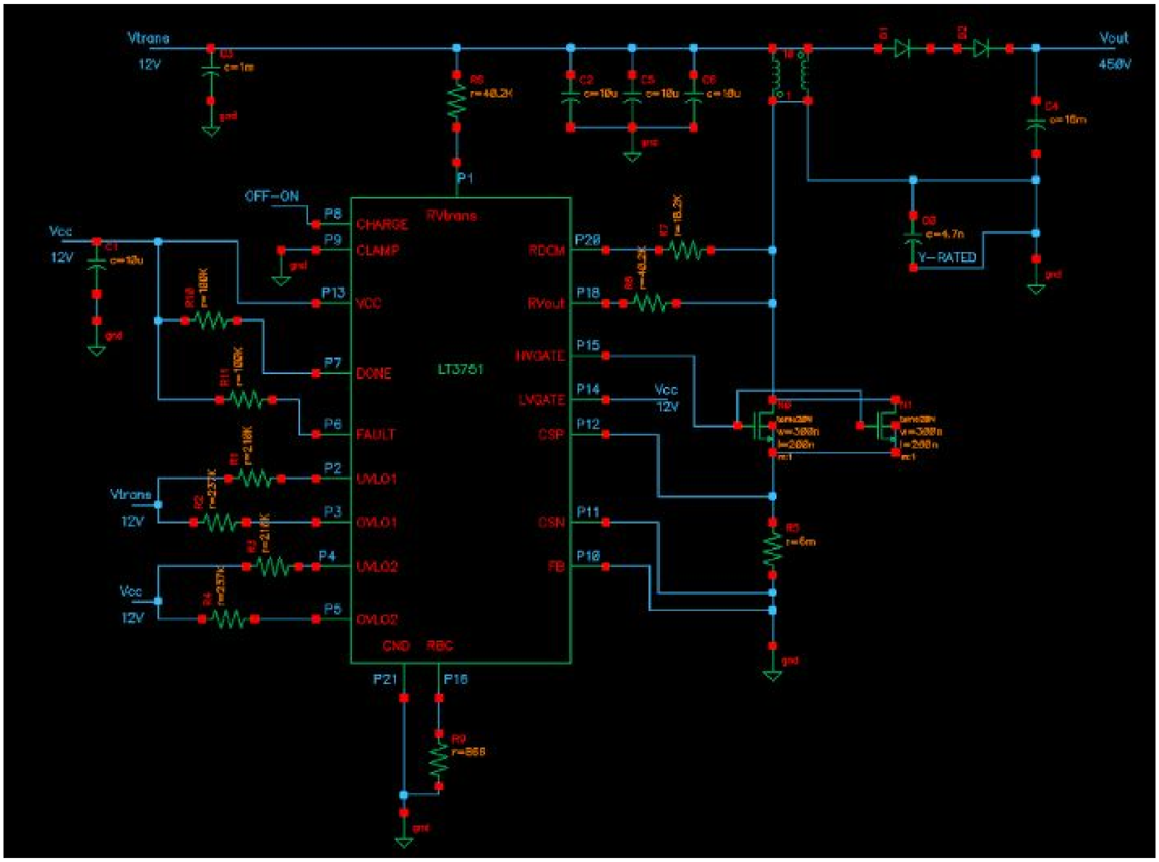


Figure 2: Charging circuit schematic.

2.6 Technology Considerations

The strengths to our a railgun are its superior firepower compared to standard combustion. The power created from the magnetic fields is also more powerful than standard ammunition so better “results” are expected.

Potential weaknesses for our design are that the rate of fire will be slow. After each shot, the railgun would need to be cooled and recharged. Because of a large amount of current being created, the railgun will release lots of heat which could be hazardous if being held by someone. Therefore, this device would need to be placed down before usage.

Possible solutions to the heat problem can be as easy as having a more conductive and heat-resistant metal like titanium. Unfortunately, we will not be able to use titanium because of its cost and our limited project budget. A more advanced coolant system could also be designed, but that also runs into a cost issue and increases the design complexity and likely failure rate.

2.7 Safety Considerations

Concerns we have right now are users carelessness, heat release, and high voltages. This railgun is a serious piece of equipment and must be used only after proper training. The operator must stay away from the muzzle at all times and wear eye and ear protection similar to a standard firearm. The user must also be wearing heat-resistant gloves and refrain from touching the rails until cool. In addition to heat, the risk of electric shock is possible if the rails are charged before reloading the device. This will be prevented by a safety mechanism that will discharge the rails after each shot.

2.8 Task Approach

This block diagram outlines our approach to this project. Research and testing will be very important as we have limited resources for material and we do not want to waste our budget buying parts twice. The diagram shows that we will be going back and forth between building and testing for much of the project as soon as we get the preliminary research completed.

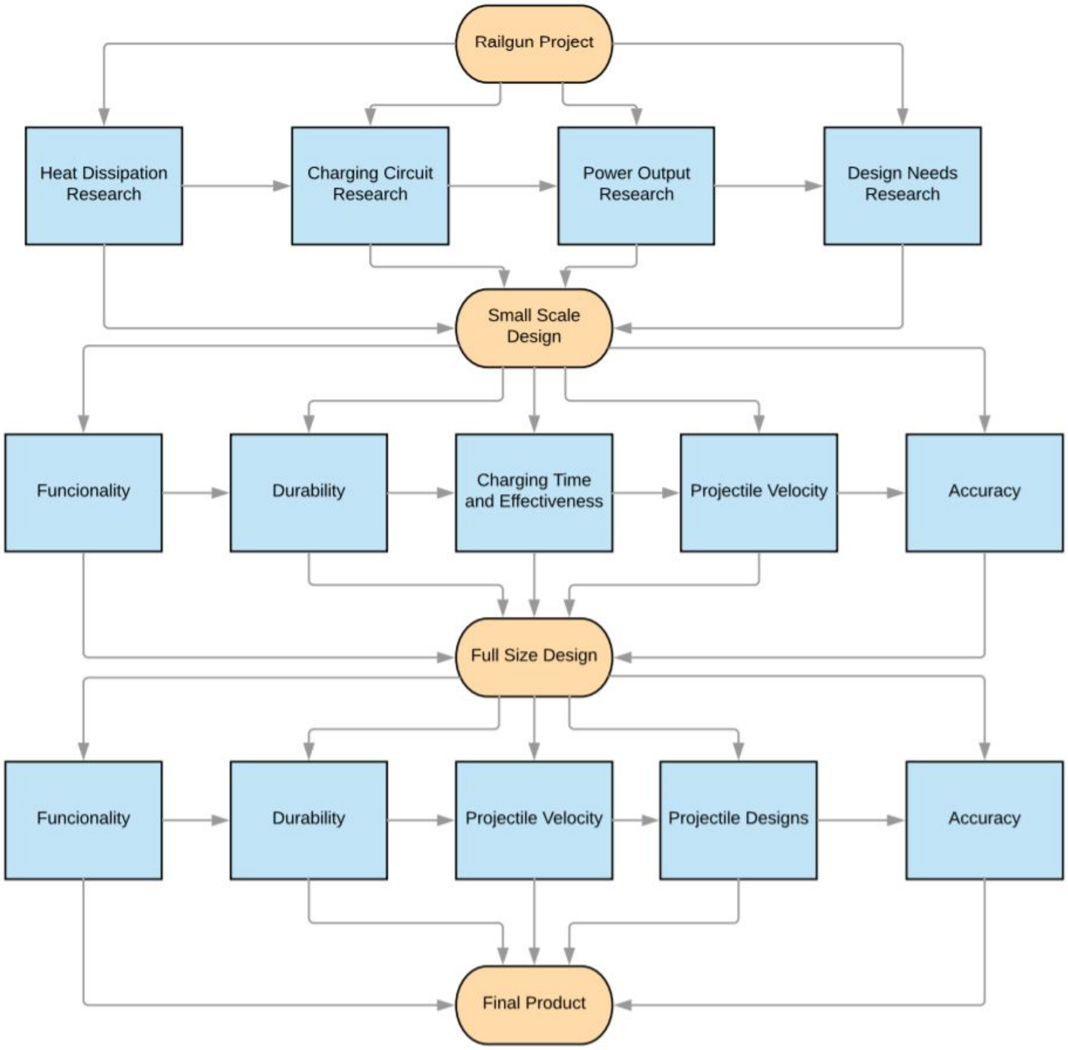


Figure 3: Task Approach Diagram

Test Methods:

1. Functionality: Tests to see if the railgun fires by using it in a controlled environment.
2. Durability: Record how many uses we can get out of our railgun before it degrades to an unsafe state. We will look at the rails mainly and record the damage caused by heat and friction.
3. Charging Time and Effectiveness: We will record how long it takes to use our Charging Circuit to bring our capacitors to 450 volts. We will do this with a timer and voltmeter connected to the capacitors.
4. Projectile Velocity: During each successful usage of our railgun we will record the projectiles exit speed. We will do this using a pre-measured area and a

high-powered video camera to record each shot. With that data, we can calculate its speed quite easily with the velocity equation.

$$V(velocity) = D(distance)/T(time)$$

5. Accuracy: We will take the railgun to a gun range to test its accuracy against targets at a certain distance away.
6. Projectile Designs: We will use different projectiles periodically to see how velocity and accuracy are affected. We will do this to find the best design for ideal functionality.

2.9 Possible Risks And Risk Management

This project will need to have a lot of safety considerations before the product can be used as we are creating an apparatus that could potentially shoot an object at a similar velocity as a conventional firearm. In addition to the actual firing of the railgun, we have a bank of capacitors that will be holding a charge and will be very dangerous so taking that into account will be important. We have taken measures in our design to make sure the system is fully de-energized after each use using a discharge circuit.

The costs of the material will also be a factor that we will have to work around, we have already changed the scope of the project based on our projected budget. Capacitors are the part that will eat up the biggest chunk of our project budget, and if our rails do not hold up to repeated fire well then those will need to be replaced although we have acquired material for the rails and material for the enclosure.

Setting up an area that will be safe to test the railgun is something else we have discussed. For the small version we will use smaller projectiles to shoot for testing but for the final scale version, we will probably use a gun range to safely test our railgun.

2.10 Project Proposed Milestones and Evaluation Criteria

At the end of this semester, we want to have a fireable small-scale rail gun that we will be able to run tests on, this will be our first milestone. Testing will need to be done at a gun range for safety reasons, we will test various aspects of the railgun such as heat dissipation, degradation of materials, and repeat uses of the gun. It will be at this point where we will get a good idea of how hot the rails get and how much energy is lost in the system. We will then take the information we gather from the small-scale model and apply that towards our larger scale model. We want to have a fireable large-scale railgun by the end of the second semester of senior design. We will change the necessary errors from the small-scale and fix them in the large scale. Our end goal is to be able to compare our larger scale model to a combustion firearm, and this will be our second milestone.

2.11 Project Tracking Procedures

It is our goal that by the end of the fall semester we have a small-scale design ready to test. From these tests, we expect to gather data on heat release, current, voltage, magnetic field strength, and projectile velocity. This data will be used to better help us perfect the design when we move to a larger model.

For the end of the spring semester, we expect to have a final, physical product that has been tested. This will hopefully be functional and semi-practical.

Our progress will be tracked mainly through physical data and design work that we have gathered and completed, we will follow the Gantt chart that we created to make sure we are continuously working and pushing forward with the project. We have soft milestones that we set for ourselves which include getting a small scale version operational by the end of the first semester and testable. The second semester will be primarily testing and improving upon our design and eventually creating a final product.

2.12 Expected Results and Validation

The desired outcome for this project is to show that an electromagnetically propelled projectile can compete with a similarly sized conventional firearm using chemical propulsion. The Lorentz force will accelerate a projectile by exerting a force on the projectile using the magnetic field as well as the current in the rails. Each of the rails will be energized by current coming from the capacitor bank. Since the projectile will have constant contact with the rails, it will experience a constant and growing Lorentz force through the barrel. This will increase the velocity of the projectile the farther it travels through the barrel. Also, the fact that we will build a small scale demo first will be beneficial because it will allow us to see how different parts behave and where to improve our design when we build the final version.

We will compare our test results to the performance of a conventional firearm, such as velocity and distance. Show that the railgun can return similar results repeatedly and not overheat and damage the rails. This comparison will also take into account the increase in performance and ballistics if more money was available to create the railgun. After a demo, when the projectile leaves the magnetic field the leftover current and voltage is then routed through our discharge circuit, which will be resistors in series so that there is no charge left in the capacitors or in the rails. This is a safety measure we are taking so that the user will not get injured handling the railgun.

2.13 Test Plan

We will test the small-scale railgun and determine any faults in our design and modifications to be made to our plan from there.

The test will focus on

- Power loss through the current output to muzzle energy
  - Measuring the speed of the projectile as it leaves the “barrel” of the railgun and comparing it to the theoretical speed at which it should be traveling according to our calculations.
- Degradation of materials
  - Fire the railgun once and examine rails and circuits after shot to determine if changes need to be made. If the rails degrade too much and the space between the rail and projectile is too much then no Lorentz force will be created and the railgun will not work.
  - Determine how hot the whole apparatus gets including the circuit.
- Safe operation.
  - These tests will be used to drive changes in the design when scaling upwards in size and will be reevaluated with the final design.
  - We have taken into account all we can to make sure the railgun will be safe to operate but if anything arises that causes concern we will have to make modifications to the design and testing.

We have decided to test different designs while we are in the small-scale version including various projectile shapes and sizes and a different material for rails and projectiles.

3 Project Timeline, Estimated Resources, and Challenges

3.1 Project Timeline

Our project is broken up into two different phases. We are splitting the project into these two phases because there is quite a bit of testing and research to be done in order to create a railgun that can be reusable and fireable in a timely manner.

The first phase deals with learning and understanding what exactly we will be doing. In this phase, we will develop a small scale model to help understand what we are doing. During this, we will be researching and testing because there is a lot of information we could not find through our research so testing will be required to ascertain what design will be the best for our needs. This phase will be during the first semester of senior design. Once completed we will be able to gather information and use that to help with the next phase.

The second phase is making a larger model and this will be done in the second semester of senior design. We will be evaluating the information acquired in phase one and constructing a final product that has been greatly improved through the testing phase and meets our expectations as a group. Please refer to the Appendix to see the Gantt charts for this process.

3.2 Feasibility Assessment

Our project is going to be broken up into two different phases where the first phases include a smaller scale model. Here we will learn from what the smaller scale one does and gather information that will be used for the designing and completing of the larger scale.

The realistic projection for this project would be able to compare our larger scale model with a similar caliber size rifle and show the effects of using EM propulsion versus traditional methods for firing a projectile.

When thinking about the foreseen challenges, we will need to deal with the heat that is going to be generated from the rails. Given the amount of current flowing through the rails, we need to be able to take that heat and dissipate it.

We believe this project is feasible as similar railguns have been shown to work. We will expand upon these by improving heat transfer and ease of use. This will be a challenge but we believe it can be done.

3.3 Personnel Effort Requirements

As seen below in Table 1, we have detailed what we have done so far in terms of tasks and milestones met for the project. The table includes all of the tasks we have worked on so far as well as a small description of what each task entailed. The hours match what we have put into each task as a group, but future tasks are estimates.

Phase One Major Tasks	Description	Estimated Time
Research Capacitor Gun (Railgun)	The team will research information on the railgun to get a better idea what exactly it is.	18 hours
Understand the theory and background how and why this will work	Through gathering the previous information, the team will need to figure out how exactly it will work.	18 hours
Drawing up individual schematics of the project	Taking what the team has researched and understanding the theory behind it, they all will individually come up with our own drawings of the project.	18 hours
Deciding what materials to use	This task, the team will need to get together and started to figure out what materials will be the best to use.	25 hours
Research the different materials discussed	Here, the team will take the different materials discussed, and figure out which ones will be the best for the given situation.	30 hours

Meet up with the metal’s expert	This task will require the team to meet up with a metal’s expert to gain knowledge on which materials would be the best and also run through some potential designs for everything.	15 hours
Projectile Research	Research different types of potential projectiles to use when testing.	25 hours
Charging circuit	This task, the team needs to come up with a charging circuit to allow for the capacitors to be charged in a timely manner.	35 hours
Finalize the materials to use	The team will use all the information learned, calculated and gather, to get a final parts list of the materials going to be used.	50 hours
Creates a final design for the small-scale prototype	This task will allow the team to finalize how the small-scale prototype will look like.	20 hours
Testing of the small-scale prototype	Here the team will test between which projectiles to use, which sets of rails will be the best, and overall if the design needs to be changed.	75 hours
Recording testing information	This task will be used for the design of the larger scale prototype. Taking what we learned for the small-scale and applying it to the larger scale prototype.	15 hours
Phase Two Major Tasks	**Description**	**Estimated Time**
Look back over testing results	This task the team will go over the testing results from the small-scale model and discuss what happened.	20 hours
Design large scale model	Here the team will improve and create a new design for the railgun, making it scaled up compared to the small-scale one.	35 hours
Figure out what materials to use	This task, the team will figure out what materials will be the best to use, while	30 hours

	also staying within the budget.	
Building large-scale prototype	This task, the team will complete the building of the larger scale prototype.	75 hours
Testing of the large-scale model	Here, the team will begin testing the large-scale model.	40 hours
Recording testing information	Here information will be recorded for each test.	35 hours
Validating the information	Here the information that was recorded will be compared to a rifle of similar caliber and seeing if EM is equal to or better then combustion propulsion.	30 hours

Table 1: Major Tasks

3.4 Other Resource Requirements

We will need to purchase most of the materials for this project. The wire, capacitors, circuit materials for charging and discharging the capacitors will need to be purchased and made, and the projectile launch mechanism. We have gained access to a resource, Mr. Mike Ryan, who will let us use material and equipment to construct the structural components of the railgun. If we add other functionality to the railgun components for those additions will be added to the parts list. We have access to a machine shop so machining parts will not be a problem.

3.5 Financial Requirements

The cost estimate for this project is still ongoing as certain aspects of the project are still being designed. So far the most costly part of this project by far will be the capacitors at around $445. A large expense that we will not have to account for will be the rails and the main structure of the railgun as we will be getting those materials from the generosity of Mike Ryan, he will also help machine parts for us which will cut down on costs as well. See the parts list(fig.4) in the appendix for a more detailed breakdown of prices and quantities.

4 Closure Materials

4.1 Conclusion

The goal of this project is to produce a railgun that will compete with a conventional firearm of similar size and to outperform them in distance traveled and energy behind the projectile through electromagnetic propulsion. By obtaining the best material and design of all of the components of this railgun this railgun design will be able to be used by hobbyists at gun ranges. We believe this plan outlines our goals and shows that we will have the necessary deadlines and materials to complete this task.

The team has made significant progress in recent weeks after a considerable amount of time in our research phase. We have built our first railgun design and are currently carrying out tests of our charging circuit. We believe we have a good base to start off with for next semester and a lot better grasp of the project and where to improve the project from there.

By looking to this project plan and following its structure we will be able to create an operational railgun that we can test and determine if it can compete with conventional firearms and also demonstrate the capabilities of electromagnetics.

4.2 References

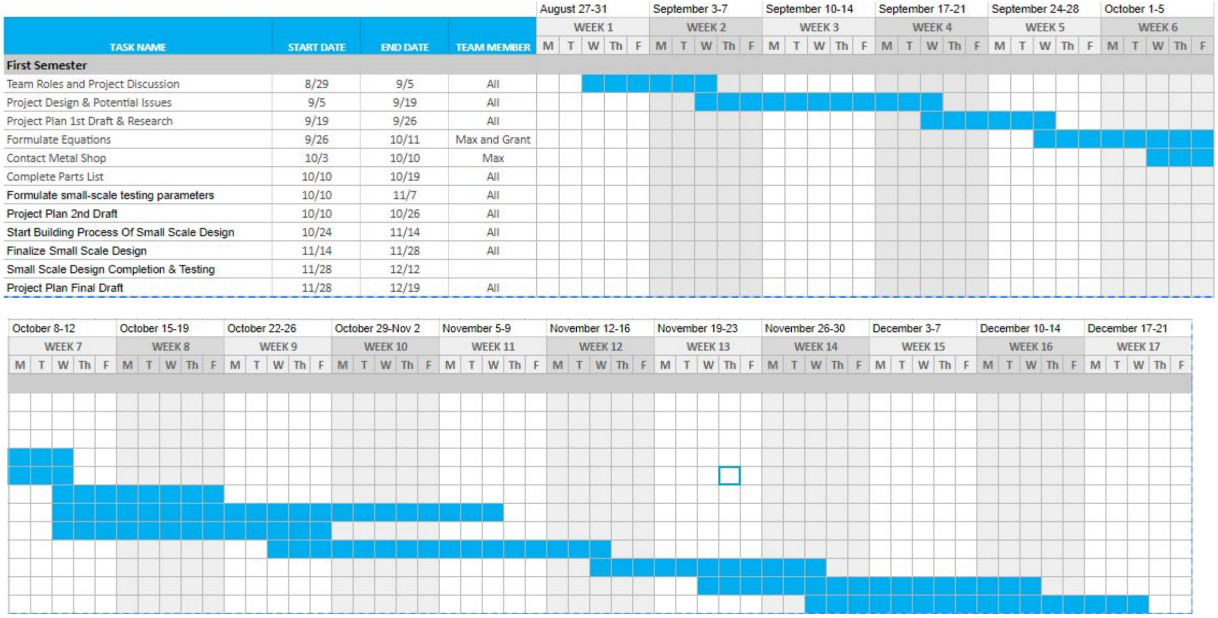
1. “Electrical Power Needed to Melt a Wire?” *Physics Stack Exchange*, physics.stackexchange.com/questions/378748/how-much-electrical-power-is-needed-to-melt-a-wire.
2. http://www.litz-wire.com/New%20PDFs/Fusing_Currents_Melting_Temperature_Copper_Aluminum_Magnet_Wire_R2.011609.pdf
3. “Electrical Power Needed to Melt a Wire?” *Physics Stack Exchange*, physics.stackexchange.com/questions/378748/how-much-electrical-power-is-needed-to-melt-a-wire.
4. “Electrical Power Needed to Melt a Wire?” *Physics Stack Exchange*, physics.stackexchange.com/questions/378748/how-much-electrical-power-is-needed-to-melt-a-wire.
5. “Electrical Power Needed to Melt a Wire?” *Physics Stack Exchange*, physics.stackexchange.com/questions/378748/how-much-electrical-power-is-needed-to-melt-a-wire.

6. “Electrical Power Needed to Melt a Wire?” *Physics Stack Exchange*, physics.stackexchange.com/questions/378748/how-much-electrical-power-is-needed-to-melt-a-wire.
7. “Dictionary.com.” *Dictionary.com*, Dictionary.com, www.dictionary.com/.
8. *McMaster-Carr*, www.mcmaster.com/plastics.
9. “Missile Defense Systems.” *General Atomics & Affiliated Companies*, www.ga.com/missile-defense-systems.
10. “Safety.” Electrical and Computer Engineering, www.ece.iastate.edu/the-department/safety/.
11.”Electrical safety in the industrial workplace: An IEC point of view”, https://ieeexplore.ieee.org/document/6766906

4.3 Appendices

Gantt chart

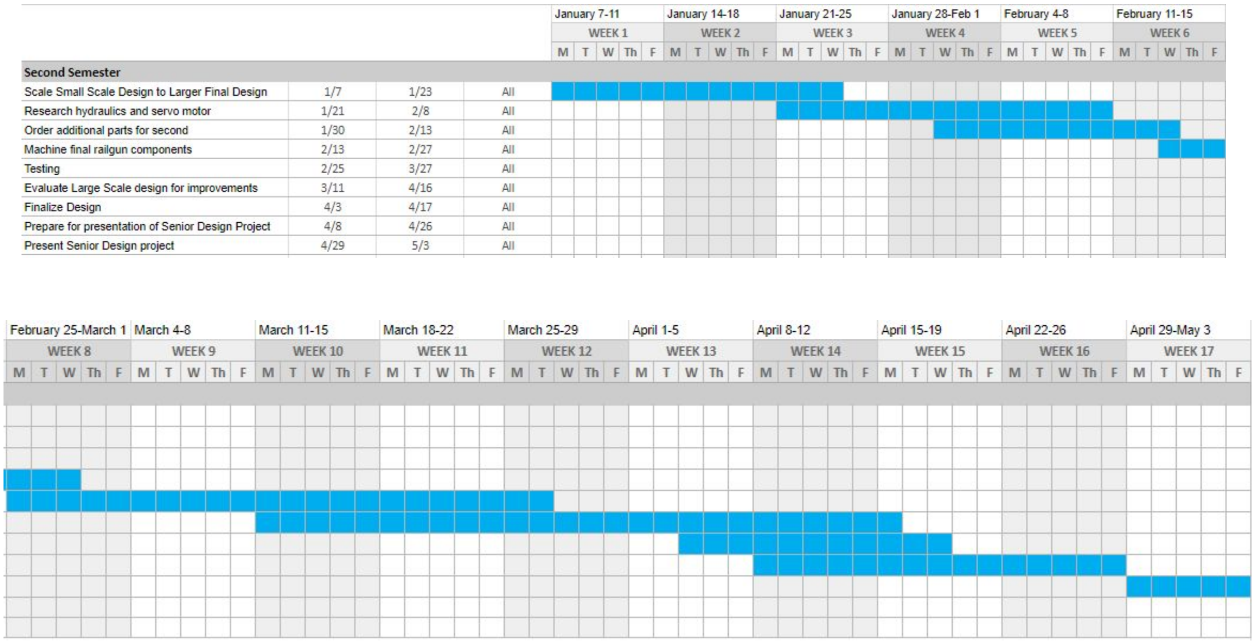
<u>First Semester</u>



TASK NAME	START DATE	END DATE	TEAM MEMBER
First Semester			
Team Roles and Project Discussion	8/29	9/5	All
Project Design & Potential Issues	9/5	9/19	All
Project Plan 1st Draft & Research	9/19	9/26	All
Formulate Equations	9/26	10/11	Max and Grant
Contact Metal Shop	10/3	10/10	Max
Complete Parts List	10/10	10/19	All
Formulate small-scale testing parameters	10/10	11/7	All
Project Plan 2nd Draft	10/10	10/26	All
Start Building Process Of Small Scale Design	10/24	11/14	All
Finalize Small Scale Design	11/14	11/28	All
Small Scale Design Completion & Testing	11/28	12/12	
Project Plan Final Draft	11/28	12/19	All

Figure 4: Gantt Chart

Second Semester



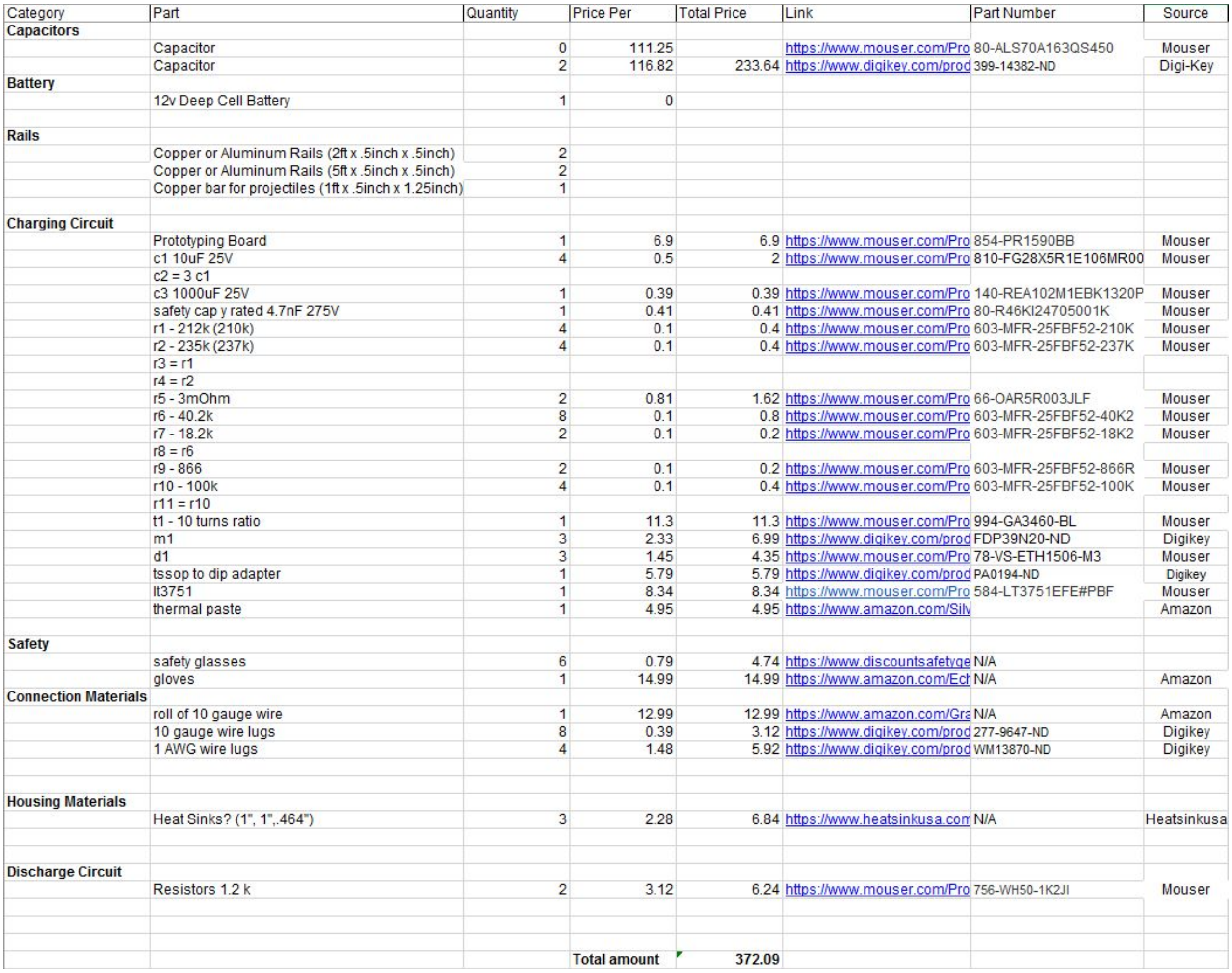
Second Semester			
Scale Small Scale Design to Larger Final Design	1/7	1/23	All
Research hydraulics and servo motor	1/21	2/8	All
Order additional parts for second	1/30	2/13	All
Machine final railgun components	2/13	2/27	All
Testing	2/25	3/27	All
Evaluate Large Scale design for improvements	3/11	4/16	All
Finalize Design	4/3	4/17	All
Prepare for presentation of Senior Design Project	4/8	4/26	All
Present Senior Design project	4/29	5/3	All

January 7-11	January 14-18	January 21-25	January 28-Feb 1	February 4-8	February 11-15
WEEK 1	WEEK 2	WEEK 3	WEEK 4	WEEK 5	WEEK 6
M T W Th F	M T W Th F	M T W Th F	M T W Th F	M T W Th F	M T W Th F

February 25-March 1	March 4-8	March 11-15	March 18-22	March 25-29	April 1-5	April 8-12	April 15-19	April 22-26	April 29-May 3
WEEK 8	WEEK 9	WEEK 10	WEEK 11	WEEK 12	WEEK 13	WEEK 14	WEEK 15	WEEK 16	WEEK 17
M T W Th F	M T W Th F	M T W Th F	M T W Th F	M T W Th F	M T W Th F	M T W Th F	M T W Th F	M T W Th F	M T W Th F

Figure 5: Gantt Chart

Parts List



Category	Part	Quantity	Price Per	Total Price	Link	Part Number	Source
Capacitors							
	Capacitor	0	111.25		https://www.mouser.com/Pro	80-ALS70A163QS450	Mouser
	Capacitor	2	116.82	233.64	https://www.digikey.com/prod	399-14382-ND	Digi-Key
Battery							
	12v Deep Cell Battery	1	0				
Rails							
	Copper or Aluminum Rails (2ft x .5inch x .5inch)	2					
	Copper or Aluminum Rails (5ft x .5inch x .5inch)	2					
	Copper bar for projectiles (1ft x .5inch x 1.25inch)	1					
Charging Circuit							
	Prototyping Board	1	6.9	6.9	https://www.mouser.com/Pro	854-PR1590BB	Mouser
	c1 10uF 25V	4	0.5	2	https://www.mouser.com/Pro	810-FG28X5R1E106MR00	Mouser
	c2 = 3 c1						
	c3 1000uF 25V	1	0.39	0.39	https://www.mouser.com/Pro	140-REA102M1EBK1320P	Mouser
	safety cap y rated 4.7nF 275V	1	0.41	0.41	https://www.mouser.com/Pro	80-R46KI24705001K	Mouser
	r1 - 212k (210k)	4	0.1	0.4	https://www.mouser.com/Pro	603-MFR-25FBF52-210K	Mouser
	r2 - 235k (237k)	4	0.1	0.4	https://www.mouser.com/Pro	603-MFR-25FBF52-237K	Mouser
	r3 = r1						
	r4 = r2						
	r5 - 3mOhm	2	0.81	1.62	https://www.mouser.com/Pro	66-OAR5R003JLF	Mouser
	r6 - 40.2k	8	0.1	0.8	https://www.mouser.com/Pro	603-MFR-25FBF52-40K2	Mouser
	r7 - 18.2k	2	0.1	0.2	https://www.mouser.com/Pro	603-MFR-25FBF52-18K2	Mouser
	r8 = r6						
	r9 - 866	2	0.1	0.2	https://www.mouser.com/Pro	603-MFR-25FBF52-866R	Mouser
	r10 - 100k	4	0.1	0.4	https://www.mouser.com/Pro	603-MFR-25FBF52-100K	Mouser
	r11 = r10						
	t1 - 10 turns ratio	1	11.3	11.3	https://www.mouser.com/Pro	994-GA3460-BL	Mouser
	m1	3	2.33	6.99	https://www.digikey.com/prod	FDP39N20-ND	Digikey
	d1	3	1.45	4.35	https://www.mouser.com/Pro	78-VS-ETH1506-M3	Mouser
	tssop to dip adapter	1	5.79	5.79	https://www.digikey.com/prod	PA0194-ND	Digikey
	lt3751	1	8.34	8.34	https://www.mouser.com/Pro	584-LT3751EFE#PBF	Mouser
	thermal paste	1	4.95	4.95	https://www.amazon.com/Silv		Amazon
Safety							
	safety glasses	6	0.79	4.74	https://www.discountsafetyge	N/A	
	gloves	1	14.99	14.99	https://www.amazon.com/Ech	N/A	Amazon
Connection Materials							
	roll of 10 gauge wire	1	12.99	12.99	https://www.amazon.com/Gra	N/A	Amazon
	10 gauge wire lugs	8	0.39	3.12	https://www.digikey.com/prod	277-9647-ND	Digikey
	1 AWG wire lugs	4	1.48	5.92	https://www.digikey.com/prod	WM13870-ND	Digikey
Housing Materials							
	Heat Sinks? (1", 1",.464")	3	2.28	6.84	https://www.heatsinkusa.com	N/A	Heatsinkusa
Discharge Circuit							
	Resistors 1.2 k	2	3.12	6.24	https://www.mouser.com/Pro	756-WH50-1K2JI	Mouser
			Total amount	**372.09**			

Figure 6: Parts List