Heavy Lifting: The Underlying Math and Computer Modeling of an Asymmetric Capacitor

New Mexico
Supercomputing Challenge

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Team Number 57

McCurdy School
261 McCurdy Road
Espanola, NM 87532

Sarah Armstrong
Joseph Koby
Vanessa Trujillo
Juan-Antonio Vigil

Teachers
Eva Abeyta
Robert Dryja

Mentor
Nick Bennett

Page

Executive Summary

A lifter is an electrically charged asymmetric capacitor; built from balsa wood with copper wire and foil. The first step in this project uses classical electric field physics to explain the math in terms of analytical geometry. This project focuses on a geometric interpretation only because calculus is beyond its scope. The second step is to create a dynamic model using StarLogo software. Several lines of force are represented as well as the movement of ionized air particles in the electric field.

The preceding math and the computer models are evaluated in a third step by constructing and testing several lifters. Testing partially confirms the math and computer modeling. There is unexpected complication relating to the impact of reduced air pressure at a higher elevation. The various lifters cannot generate the same level of thrust as is possible at sea level.

Introduction and Problem Statement

All over the world, a strange hobby is the making of cheap, lightweight craft out of aluminum foil, balsa wood, and thin wire which thrust themselves silently upward in defiance of gravity. The models superficially resemble triangular kites. They have no wings, propellers, or moving parts. What is the power source for such craft? Nothing more than a ground-based high-voltage power supply (30,000 volts and above), often scavenged by students from old computer monitors. The internet-linked hobbyists compete to see how much mass (weight) of payload their lifters can carry. (1, 2)

In terms of the physics, lifters rely upon the creation of a strong electric field which ionizes nearby air particles. The physical design of a lifter results in ionized air particles being thrust downward. In turn, the lifter is rise upward. (3) The thrust is not very efficiently directed downward. This becomes evident when the lines of force of an electric field are visualized. A great deal of the electrical energy is directed in curving paths rather than in straight lines.

StarLogo software can be program to show the dynamic, curved nature of the electric field created in a lifter. (4) StarLogo also can be used to show the movement of ionized air particles as they move in the electric field. The StarLogo program developed here is based upon the mathematics available in a high school physics textbook. (5) However, actual experimental testing of lifters shows that the StarLogo program used here needs to take into consideration air density if it is to more realistically model how a lifter operates.

This project is concerned with two types of problems. First, can the mathematics for electric fields as presented in physics textbooks be translated in a computational computer model? Second, how well does the resulting computational model reflect experimental reality? In effect this project is concerned with both theoretical and experimental results.

Mathematics of Electric Fields

The mathematics of electric fields is based on Coulomb's law with adjustments for two or more points in a field. The mathematics can be divided into five steps.

1. Apply Coulomb’s law to define the magnitude of a force at a distance from a single charged point.

2. Expand Coulomb's law to consider two or more points.

3. Apply vector analysis to each point among many.

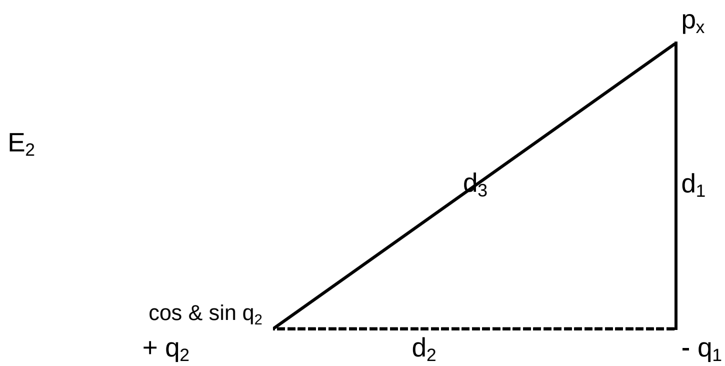
4. Sum the vectors for their net or combined force.

5. Use the Pythagorean theorem to determine the force for a particular point.

The preceding steps are reviewed in more detail as follows:

Firstly, Coulomb's law is analogous to Newton’s law of the gravitational interaction of two masses. According to Coulomb's law, the electric force between two charges is proportional to the magnitude of the charges and inversely proportional to the square distance between them.

Visualize basic calculation



Charge $q_1 = q_2$ in magnitude, but opposite in polarity.
$k_c = 8.99 \times 10^9$ for Coulomb constant
d_x is the distance
p_x = electric field strength at point p

Calculation steps for point E_{px}

$$E_x = k_C \, (q_x / d_x^2)$$

Secondly, the force used in this law is a vector quantity and must be treated accordingly. The resultant electric force on any charge is the vector sum of the individual charges.

Frequently, more than two charges are present, and it is necessary to find the net electric force upon them.

Thirdly, adjust the vectors for each x and y axis of a single charged point. At this point the direction of each component must be taken into account. Use the subsequent equations.

E_1 **Adjust for x and y vector components:**

For E1:

$E_{x1} =$	0	(px directly vertical to q1)
$E_{y1} =$	E1	(px directly vertical to q1)

For E2

$E_{x2} =$	$(E2) (\cos d_2/d_3)$	(Horizontal vector)
$E_{y2} =$	$- (E2) (\sin d_1/d_3)$	(Vertical vector)
		(Negative because q_1 negative)

Fourthly, the sum of the vectors for all charged points must be calculated. Once the calculation is made individually for each point, then the fields are added together as vectors. Use the following equations:

Magnitude of total field strength:

$E_{xtot} = E_{x1} + E_{x2}$

$E_{ytot} = E_{y1} - E_{y2}$

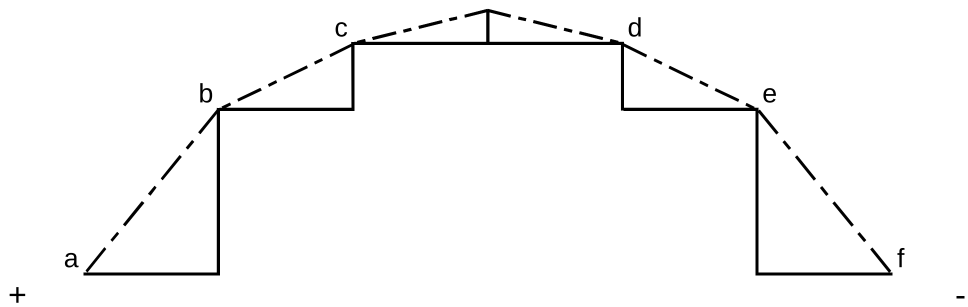
As with electric force, the electric field due to more than one charge is calculated by applying the principle of superposition.

Fifthly, apply the Pythagorean theorem to solve for the magnitude of the resultant electric field strength vector.

Use Pythagorean theorem to find resulting electric field strength victor:

$E_{tot}^2 = E_{xtot}^2 + E_{ytot}^2$

The proceeding is an example for calculating the force level at a distance from two point charges. This vector approach can be extended to multiple charge points. A set of point may appear as follows.



Calculating the shape of an an electric field at various points (*a* through *f*) in which the points have the same equal strength.

Point *a* represents the wire in cross section and positive.
Point *f* represents the foil in cross section and negative.

The mathematics of this section is concerned with calculating the unknown force resulting from the charges of two or more points. The result is a static picture. The computer math model to be presented in the next section reverses this situation. Whereas the preceding mathematics can be used to calculate an unknown force level, the following model starts with known force levels. The goal is to then visualize the force levels in a dynamic way on a computer screen.

Computer Modeling

To create a computer-generated model of the process that powers a lifter, StarLogo is used. StarLogo is a Java based program that is designed to produce visualizations based on code entries. It was selected because of its simpler programming language. Despite being simpler than Java, it was necessary to have some help to formulate a model and then work out programming issues. The team would like to thank Nick Bennett for devoting so much time to assisting the project. (6)

The current model consists of several different groups of units (called "turtles" in StarLogo) that have each been programmed to follow certain commands. Each group is given a name, or "breed" in Star logo terminology. For instance, turtles of the breed labeled charges are used to define one or more points on a grid so as to show the location and magnitude of an electrical charge. In the current model, there is one strong positive charge (representing the wire) and a line of weaker negative charges (representing the foil). The resulting formation resembles a lower case "i" lying on its side. The points in this formation define where the electric field originates and terminates.

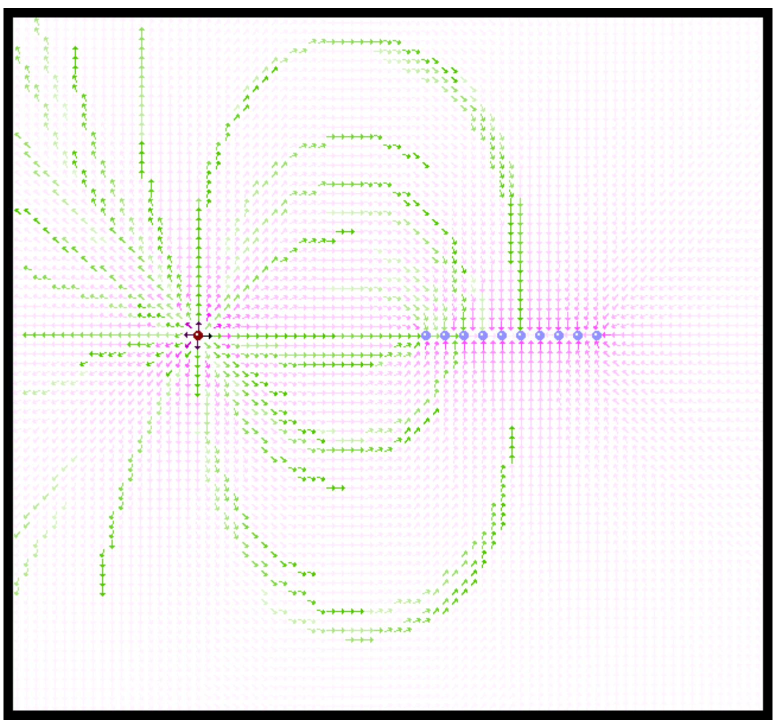
The next step is to approximate the electric field with mathematics. This is done by using the mathematics explained earlier to set boundaries. These boundaries are later traced by another breed of turtles. There are actually two breeds of turtles that do the tracing, both of which are activated and deactivated by clicking a button on the screen. The first breed is called massless particles, which serves the sole purpose of sketching the parameters set by the mathematical commands already entered. In other words, these particular turtles follow the lines of the already calculated electrical field. The command lines for this procedure are as follow.

```
to emit-massless-particles
if ((random 100) < magnitude) [
hatch [
initialize-massless-particle
]
]
end

to initialize-massless-particle
```

setbreed massless-particles
setcolor green
setshape arrow
setheading (random 360)
forward (2 + random 3)
end

The reason for the name “:massless particles” is the turtles do not represent anything physical, but rather they are used to map out an area. The other breed that works simultaneously with the massless particles is called tracers, which mark the area where a massless particle has traveled. These tracers are programmed to gradually fade and eventually disappear, so that the screen does not become too full of lines. The end result is a collection of green lines that roughly sketch the electric field produced by a lifter.



Screen shoot of lines of force

The final step is to model the effect that the electrical field has on neighboring air particles. The process involves creating another breed called ions that represents air particles that get drawn into the electrical field. These particles, unlike the massless particles, have mass, friction, and other properties of physical matter. Therefore they do not follow the electric field perfectly, but rather they merely interact with it. In addition there is some random interaction among the turtles of this breed (turbulence).

This model is only the latest of several attempts made (with Mr. Bennett's assistance). Earlier attempts consisted of a model that worked like a very complicated graphing calculator. Once an equation was entered, a massive number of scattered turtles would gradually converge on the line or lines. Unfortunately when the program was run it was discovered that equi-potential lines were being created instead of lines of force. This means that instead of an image of the classic electrical field lines forming, two interacting sets of concentric rings were produced. Although this was not the intended result, considerable experience was gained.

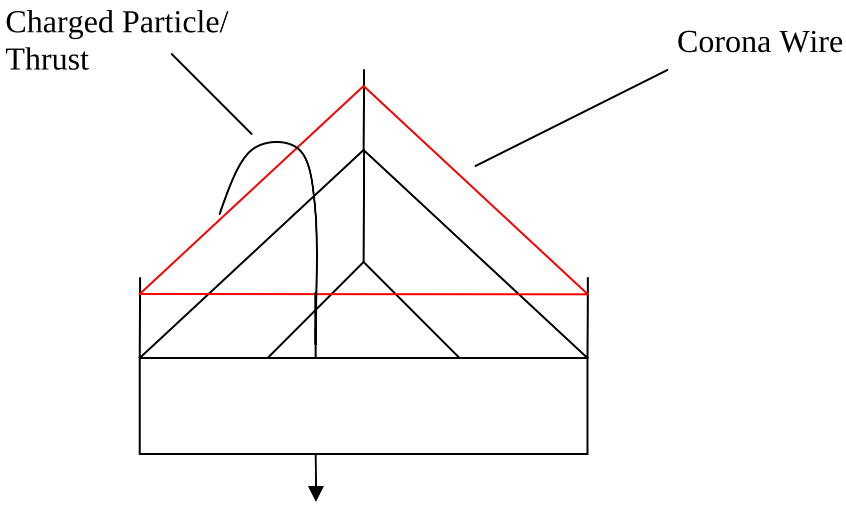
The second attempt was the precursor to the current model, and was based on a similar process. The only major difference was that instead of creating a breed of turtle to trace out the calculated field lines, the units of the grid itself were used to trace the lines. However, StarLogo does not allow one to do this. So instead of a set of field lines appearing, the entire grid turned pink. At this point the model was nearly working, but some last bugs needed to be fixed. A few days later the needed modifications were completed, and the third (and current) model became the final product.

In conclusion trigonometry has been used successfully to approximate an electrical field. The current model works as it should from a mathematical viewpoint.

The process of incorporating the effect on surrounding air particles into the model is also complete.

Engineering: How It Really Works

A corona wire is charged from a power supply with 25-30,000 volts. The air particles around it are charged and fly through the air to an aluminum foil which is grounded back to the power supply to complete the circuit. The downward thrust of the air particles results in an upward movement of the lifter.



The thrust is only linear in the space going directly from the corona wire to the edge of the aluminum foil. A significant portion of the thrust follows the curves of the electric field.

Building a Model

Most lifters are made of three basic components: a frame, a “skirt,” and the two wires. The design of the frame basically determines what the lifter will look like and where the “skirt” and the wire will be placed, but what is the most important is how much it weighs. The shape of the frame can be a triangle, a square, and even a circle. However, the shape does not make a difference in how much thrust is created. A reference states that it is only the length of the perimeter of the skirt that affects the amount of thrust created. Thrust is proportional to the length of the perimeter. (3) There are some limits to the shape of the frame because of the materials that are used, but one must keep in mind that the lifter must be as light as possible. For example, if balsa wood is used for the frame, it would be possible, but very difficult, to make a circle.

If other materials, such as plastic are used to create the circle, it could make the frame too heavy. Another part of constructing the frame is to consider what is going to hold it together. Tape is easier to work with and lighter than some glues, but it might not hold. For example, duct tape will hold the frame together, but the amount of tape that is used could weigh more than the frame itself. Scotch tape or even masking tape is lighter than duct tape or even glue, but it will not hold together.

So the best choice is to use glue, but what kind of glue? If hot glue is used, it will add a lot of weight and will not hold as well as epoxy or rubber cement. Although epoxy and rubber cement will hold better than hot glue, they are heavier than hot glue or super glue. So, super glue is the best choice because it is the lightest and its strength is between hot glue, epoxy or rubber cement.

The next part of constructing a lifter is the metallic “skirt.” This is probably the most important part of a lifter itself, setting aside the power supply. Of the three parts of the lifter, this takes up the most surface area and on some models, creates the most weight. It has to be light enough as to not hold the lifter down, but it also has to have enough conductivity surface to make it rise. It also has to be easy to mold so it does not get wrinkled. Wherever there is a wrinkle, there is a potential that electrons will be discharged into the air, which will make the lifter less efficient.

One possibility for this skirt is Mylar. It is one of the lightest materials available to us and it is very easy to work with. However, there is not enough aluminum in it to conduct sufficient electricity, providing the energy to make the lifter rise. Another possibility is copper or aluminum foil. Copper foil is a better conductor than aluminum, but it is difficult to obtain and weighs a lot more than aluminum. Aluminum foil is used for the lifters in this project.

Another issue is how to attach the aluminum "skirt" to the frame. This skirt goes around the bottom half of the lifter. There can be no wrinkles or sharp edges on the foil and the foil skirt must be continuous. If the skirt is constructed in sections which are electrically separated, then sections of the skirt may not be grounded back to power supply. For this reason scotch tape is used to connect the foil. To attach the top edge to the frame, it is simply wrapped around the horizontal pieces of balsa wood.

The next most important pieces of the lifter are the two wires. The corona wire is connected to the power supply. The corona wire wraps around the lifter up to 40 mm directly above the foil. Stainless steel and two gages (26 and 30 gauge) copper wire have been used in this project. The 30 gauge copper wire works best. The corona wire is clipped onto the power source and is strung out to the lifter. It then is wrapped around every corner. The ground wire is taped to the foil with scotch tape and clipped to the power supply. The top wire does not touch the foil. The electrons then have to move from the wire to the foil which then is grounded. The ionized air particles in the vicinity of the electric field ultimately create the thrust.

Power Supply

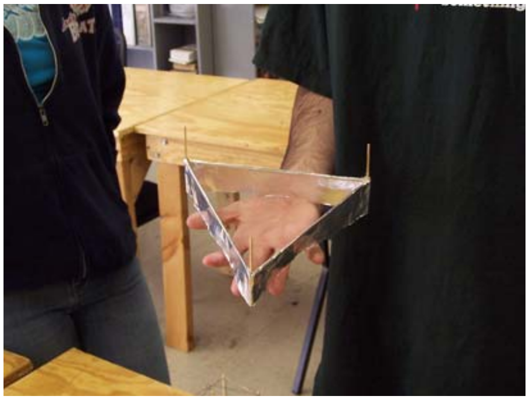
The power supply is the most important part of this entire project. It is what gives the lifter the power to create thrust. Two different supplies have been used. The first is a CRT power supply from an old computer monitor which is estimated to produce approximately 25-30,000 volts. For safety reasons and because of having no way of measuring how many volts or amperes it generates, a second power supply has been used. The second power supply is designed to provide a known voltage and amperage levels. This second power supply has been used to test one of the lifters, however, the results have been no different from the computer monitor. This second power supply has been accidentally destroyed when an estimated 450 watts went through its power transistor. The power transistor was designed for a maximum of 50 watts. Since the electrical power is no different, even if not measured, the project has returned to using the computer monitor. The CRT cover has been removed to obtain more control of the internal wires and to keep them from short-circuiting.

The Lifters

Two triangle lifters and two square ones have constructed. The first lifter is a triangle using thin wooden sticks and glued together with hot glue. The

horizontal sticks are eighteen inches long and the vertical posts are three inches high. A double layer of aluminum foil is attached and hangs about one inch below the horizontal sticks. Twenty-six gauge copper wire is attached to the corners of the lifter about one inch above the foil. For this lifter the CRT power supply was used. There were no results because it weighed 19.8 grams—much too heavy. The first model uses 26-gauge stainless steel wire which is placed 40 millimeters above the foil. It creates a breeze and a purple glow (corona effect), but there is no lift.

The second lifter produces the best results. This lifter is the same triangular design, but with reduced size. It is about 20 centimeters in length along it perimeter and about eight centimeters tall. The second model is made of thin pieces of balsa wood. Super glue is used instead of hot glue to hold it together. Aluminum foil is used again, but instead of wrapping it over the center stick in a double fold, it is wrapped around the entire bottom half of the lifter.



There are two lifters based on square designs. The first square lifter is designed to determine if a more efficient flow of air can be created. This involves a box-within-a-box

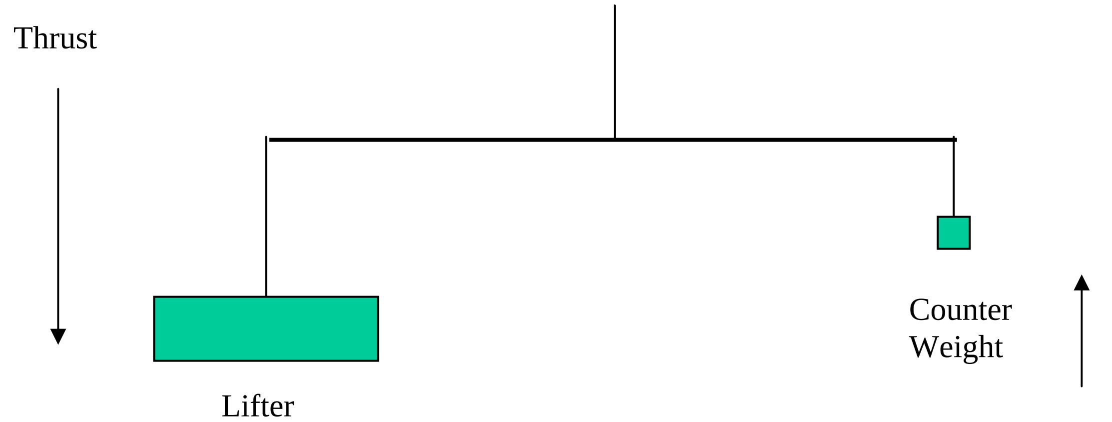
arrangement. Ionized air is forced physically to move between parallel sheets of aluminum foil rather than follow the curves of the electric field. However, doing this also doubles the weight. When it is tested, nothing happens. This shows that even if the air is channeled, there still is not enough thrust to make the lifter rise.

The second square lifter emphasizes maximum weight reduction. Whereas the first triangular lifter weighs 19.8 grams, this square lifter weighs 4.5 grams. The amount of foil is changed in particular by using a thin sheet. When the electrons move from the wire to the foil, they stay only on the edge closest to the wire; they do not disperse all over the foil. A wider sheet is used in many lifters, but is not necessary.

Measuring Thrust

The thrust of the lifters is measured in two ways. First, a lifter is hung sideways from the ceiling so that it thrust moves horizontally. At 0% thrust, (no power), the thread holding the lifter hangs down from the ceiling is at a 90˚ angle. When the power is turned on a lifter typically swings to create approximately a 30˚ angle to relative to ceiling. This provides an estimate that only about 30% of the needed thrust for take off is created.

A second way to measure thrust is to use a balance beam with the lifter on one side and weights in the other.



One of the references (3) reports about 7 to 8 grams of thrust being created for a lifter which successfully takes off. The second triangular model used in this project is based on this reference but only generates about 1.3 grams of lift.

Discussion of Results

In the end, it has not been possible to make a lifter rise except as part of a swing or a balance beam. This is occurring after making four types of lifters and using two kinds of power supplies. The conclusion is that no matter what one does, a lifter will not work at an elevation of 1,720 meters (5,590 feet). Air density decreases by approximately 30 percent and this elevation and so does not provide sufficient air particles to generate movement. Successful lifters evidently are used nearly sea level.

The StarLogo model therefore needs to be modified to take into account the impact of air density. The present model is useful for showing electrical fields and the flow of ionized air particles, but excludes two key operational variables—air mass and thrust.

Achievements

In relation to the math and computational modeling

The team has a greater appreciation of vector analysis. The math in the physics textbook considers only two points. A multi-point vector analysis based on the textbook is very challenging and laborious. StarLogo has provided a way of addressing this issue.

Indeed, the team would not learned about computational modeling with any computer language if it had not conducted this project.

Ideal and Applied Reality

The mathematics and computational models reflect idealized circumstances. Key variables may be missed in a computer model unless compared with operational results.

In relation to project and teamwork

The team members have a much better appreciation of the time needed to complete a project such as this and the amount of reading needed. The individual members of the team now have an appreciation of what is needed for successful projects. The team members understand one another's view points better.

References and Acknowledgements

(1) Web Site: "The Lifter Project" http://jnaudin.free.fr/lifters/main.htm

(2) Web Site: "American Antigravity" http://www.americanantigravity.com/lifters.shtml

(3) Luke Uribarri: "Flying Triangles: An Investigation of the So Called "Lifter" Phenomenon" Princeton, NJ 2002.

(4) Web Site: “StarLogo” http://education.mit.edu/starlogo

(5) Raymond A. Serway and Jerry S. Faugn: Physics Holt, Rinehart and Winston, 1999, pages 628 – 663.

(6) Nick Bennett, StarLogo consultant for the Supercomputing Challenge