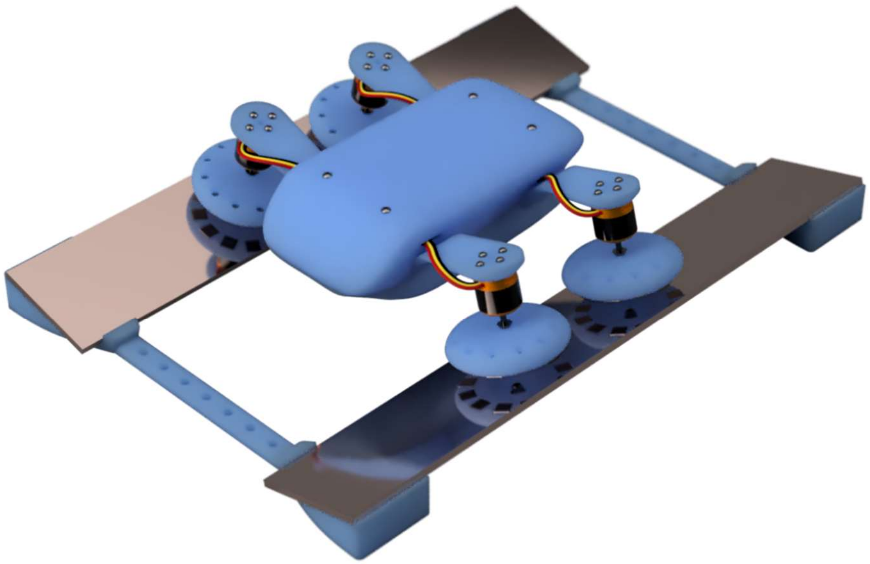
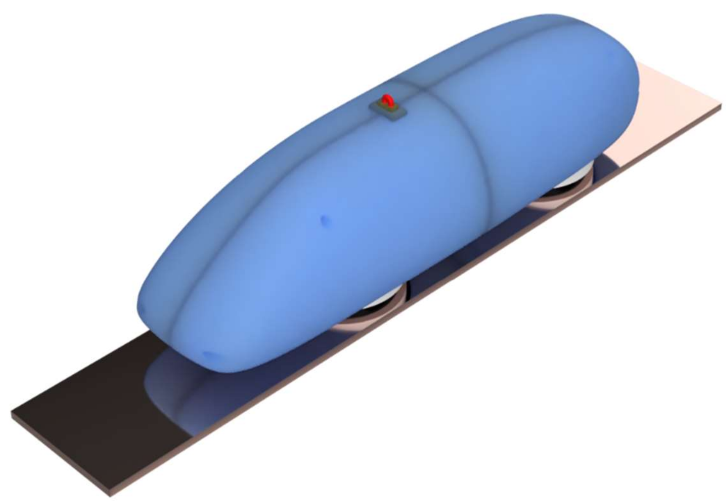
Hyperloop Vehicle Levitation





Troy Otter

Problem

As the world becomes further urbanized and industrialized, the transportation of people and goods will continue require more of our precious energy resources. Humans need to find a cheap, fast, and environmentally friendly method of transportation.

Engineering Goal

To construct a model of a hyperloop pod capable of levitating over a non-ferrous metal using spinning Halbach arrays.

Background Research

Magnetic Levitation

Magnetic levitation technology today is based on two systems, Electrodynamic Suspension (EDS) and Electromagnetic Suspension (EMS). Electromagnetic suspension is the method most often encountered with Maglev trains. In this system, the train uses electromagnets to lift itself from the bottom of the track, and as such appears to wrap around the track. EMS trains also use guidance electromagnets located on the side of the train to keep centered on the track. These magnets require power to function, and as such the trains use lots of electricity and require heavy backup batteries to bring the train to a stop in the event of a power failure. Electrodynamic Suspension trains use superconducting electromagnets on the train to push against a magnetic track, lifting the train up. This method can levitate a train as much as 4 inches above the track, however this requires the train to be moving over 60 mph, so the trains must have wheels for traveling at lower speeds. EDS vehicles must also use a cryogenic system to cool the coils, increasing overall complexity Both methods have issues with the price of the system and the track.

A much cheaper and more efficient system is known as the Inductrack. These vehicles operate in a similar fashion to electrodynamic suspension systems, however use powerful room temperature permanent magnets functionally similar to fridge magnets, as opposed to the electromagnets or the cryogenically cooled superconducting magnets of typical EMS and EDS vehicles. The permanent magnets lack the power of more advanced magnetics, making it more difficult to lift objects.

Halbach Arrays

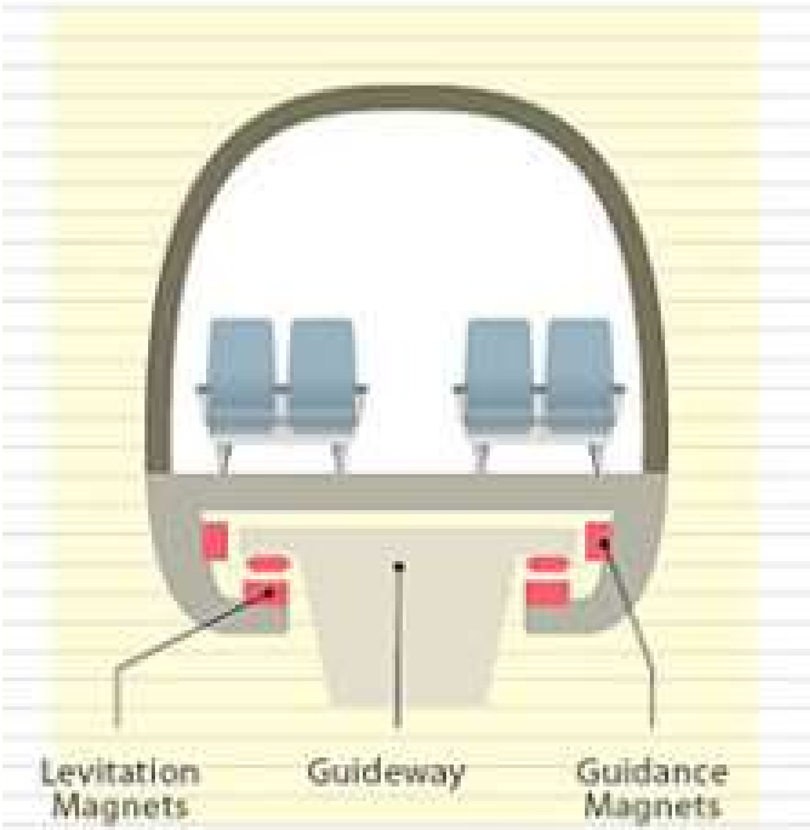
To overcome this, the magnets are arranged in an order known as a Halbach array. Halbach arrays arrange the magnetic poles in the magnets in such a way that the magnetic field is concentrated on one side of the array, and almost cancel on the opposite side. This arrangement greatly increases the pulling strength of the magnets, and is used in most fridge magnets to reduce material use. It is possible to make a Halbach array in almost any geometric shape, such as Halbach cylinders, which concentrate their magnetic field lines on the inside or outside of a cylinder.

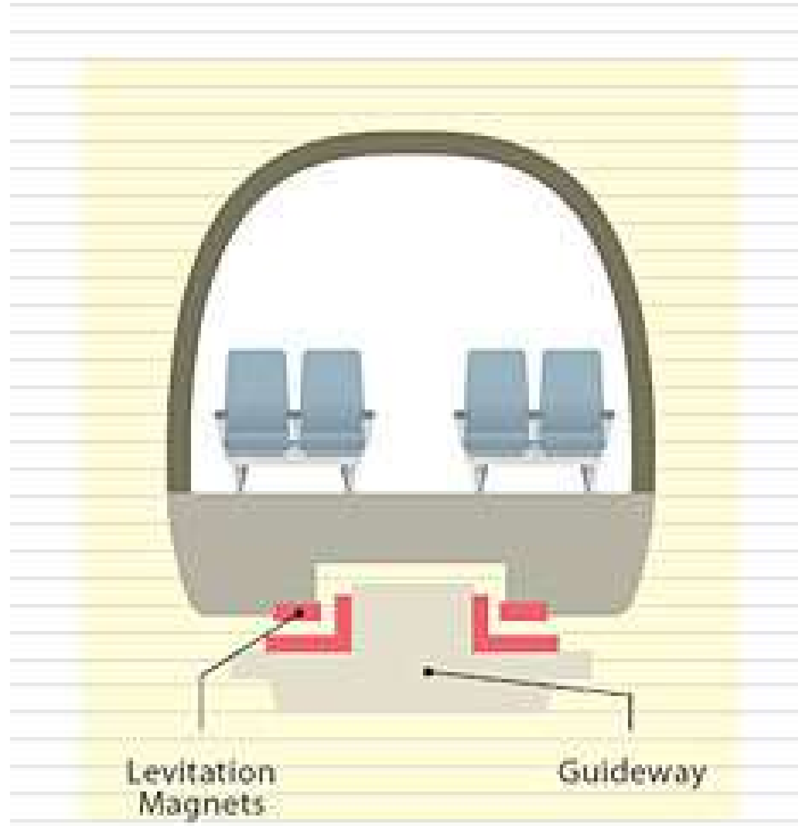
Electromagnetic Induction Faraday's Law, and Lenz's Law

Inductrack systems levitate in a different way than those of the other systems. Instead of attracting or repelling magnetic metals to create levitation, the Inductrack system levitates on coils of copper wire, a non-ferrous metal. The reason this can work is a result of Faraday's Law. Faraday's Law states that a changing magnetic field induces an electromotive force in the conductor. This principle is the method by which all electric generators work. When magnets are spun around copper coils, the magnets induce an electric current in the wire, creating electricity. However, effect does not directly explain the reason why the magnets levitate. To explain this, we use Lenz's law, stating that an induced electromotive force is always in the direction that opposes the original change in flux that causes it. This means that the electric current generated in the metal will have a magnetic field that directly opposes the magnetic field that created it. The poles of the magnetic fields will repel, causing levitation. Unlike in a situation with two opposing magnets, the poles do not become misaligned enough to cause the magnets to "fall off" of each other because of how quickly the effect works.

Back EMF and Eddy Currents

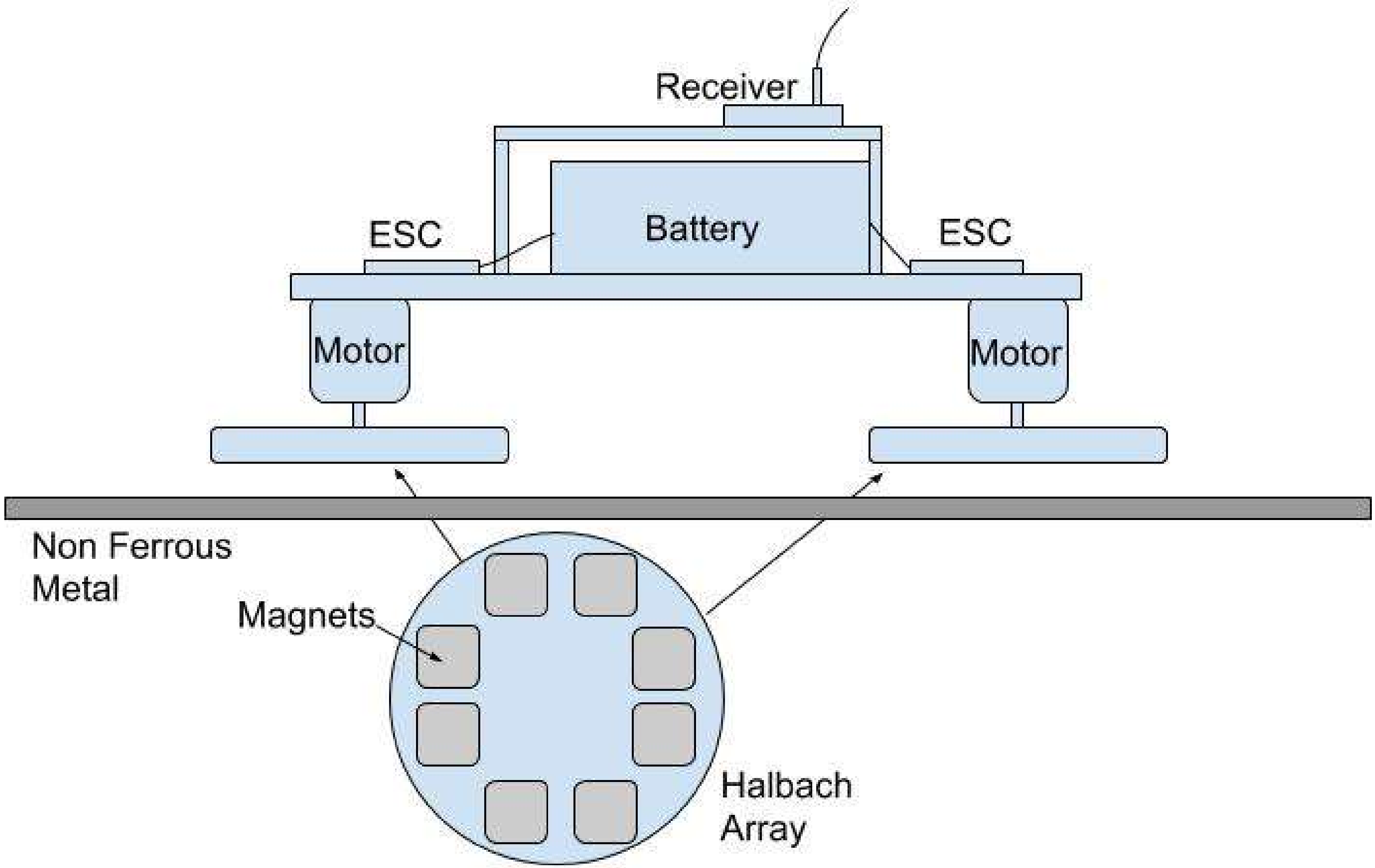
This type of levitation is clearly not without drag effects, else motors could accelerate infinitely with a given torque. The induced currents in the metal are slightly ahead of the direction of motion of the magnets, causing a force opposing the direction of motion. These currents slow down the motion of the magnets, and also release energy in the form of heat into the metal. This effect is the same seen in use in places such as roller coasters, and is the method by which metal detectors work.


Levitation Magnets
Guideway
Guidance Magnets


Levitation Magnets
Guideway

Design

This project required two iterations to achieve safe, stable magnetic levitation. The first idea was to create a device similar to a quadcopter in nature, with 4 rotors spinning over a metal track. I used CAD software, Fusion 360 to design all structural parts for 3d printing. The structure of the first iteration was made entirely of 3d printed parts, and included angled rotors to increase stability on the track. After the structural failure of the first iteration, the second design switched to a bi-rotor system of levitation, and to using PVC pipe to reinforce the rotors. Both iterations used off the shelf hobby components, like those found in quadcopters and RC planes. The magnets used for both designs are ½” cube N52 magnets, rated at 29 lbs. of pulling force and 14,000 gauss.


Receiver
ESC
Battery
ESC
Motor
Motor
Non Ferrous
Metal
Magnets
Halbach
Array

Materials and Tools

- 48 N52 ½” Cube neodymium magnets
- 4 Electric brushless motors
- 4 Prop adapters
- 4 Electronic speed controllers
- LiPO battery
- Power distribution board
- Radio Receiver
- Radio Transmitter
- LiPO Balance Charger
- Spare XT-60 connectors
- 3 ft 14-gauge wire
- 20 16mm M3 screws
- 20 M3 Nuts
- 2” PVC pipe- 3” diameter
- 8 3/8” O-rings
- CAD Software (Fusion 360)
- 3D printer & filament
- Hammer
- Coping Saw
- Epoxy
- Superglue
- Thread locker
- Zip ties
- Soldering Iron
- Solder
- Sandpaper
- Filler Primer & Spray Paint

Procedure

1. Collect materials
2. Design and print 3d components
3. Prepare 3d printed parts
    a. Remove rafts and supports
    b. Sand with 100 grit sandpaper
    c. Sand with 220 grit sandpaper
    d. Apply 2-4 coats of filler primer
    e. Sand with 220 grit sandpaper
    f. Apply 1-2 coats of spray paint
4. Glue magnets into rotors in halbach array
5. Assemble Frame
6. Attach components to frame
7. Secure rotors to prop adapters using thread locker or superglue.
8. Solder XT-60 female plug to power distribution board
9. Solder kill switch, and attach

Testing

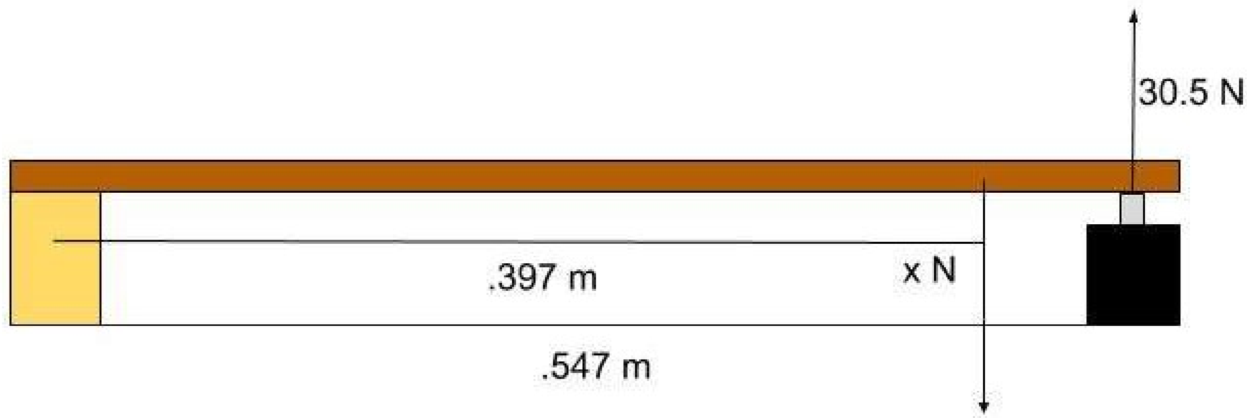
1. Hold vehicle above copper track and turn on motors
2. Lower vehicle towards track, increasing throttle as the motor slows
3. Push down on cart with force sensor until it can no longer levitate. Repeat.

Data/ Results

To calculate the maximum levitation force the vehicle is capable of producing, I used a LabQuest force sensor setup below one side of the copper plate, supporting the other side with a 2”x4”. Using the measured force, and radius from the fulcrum, it is possible to calculate the actual force exerted by the vehicle.

Distance from fulcrum to force sensor= 0.547 m
Distance from fulcrum to vehicle CoM= 0.397 m
Maximum measured force= 30.50 N

Using the principles of static torque:



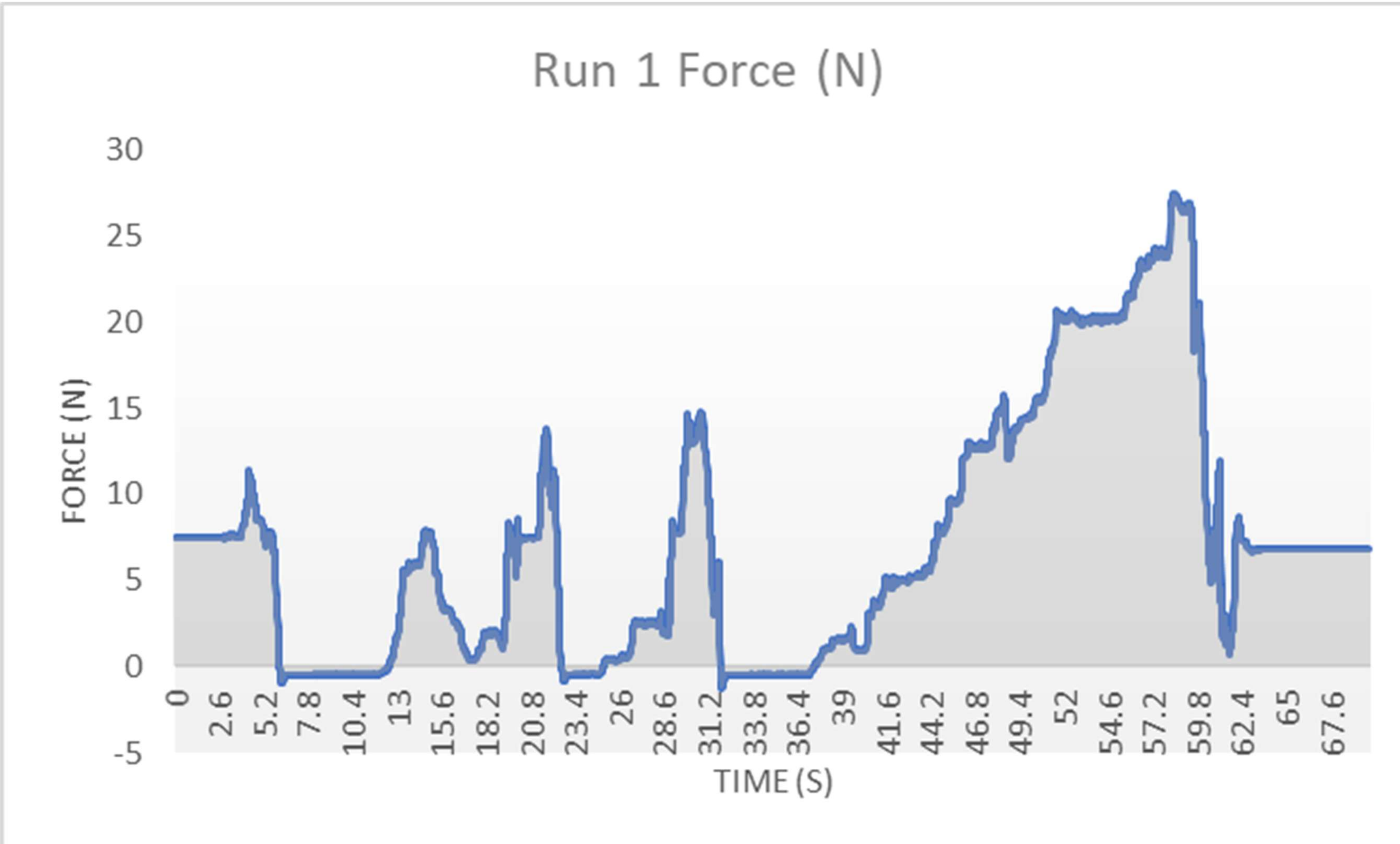
$$.397\ m * N = .547\ m * 30.5\ N$$

$$N = \frac{.547*30.5}{.397}$$

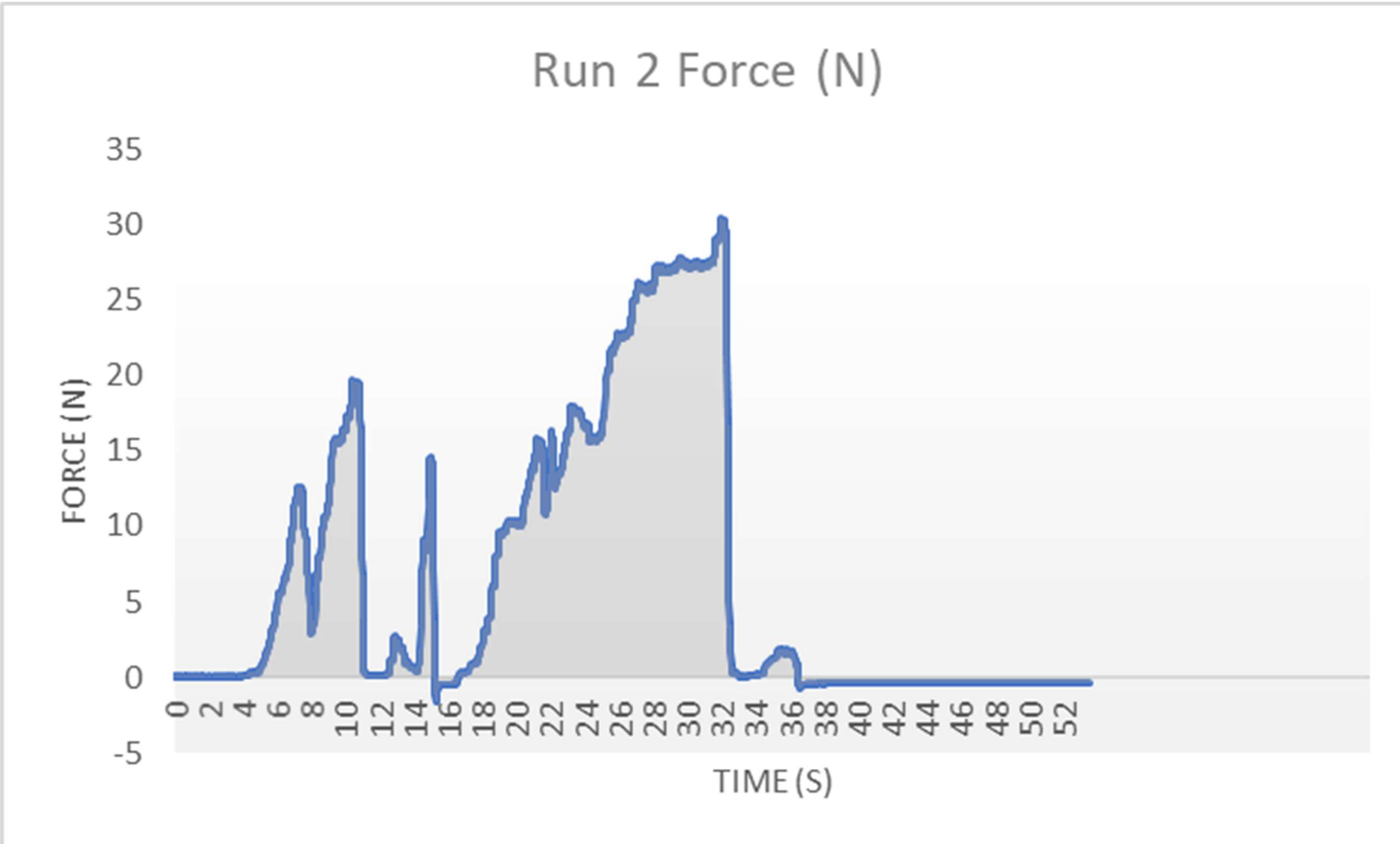
$$N = 42.0\ N$$

42/9.81 = 4.28 kg (9.4 lb)

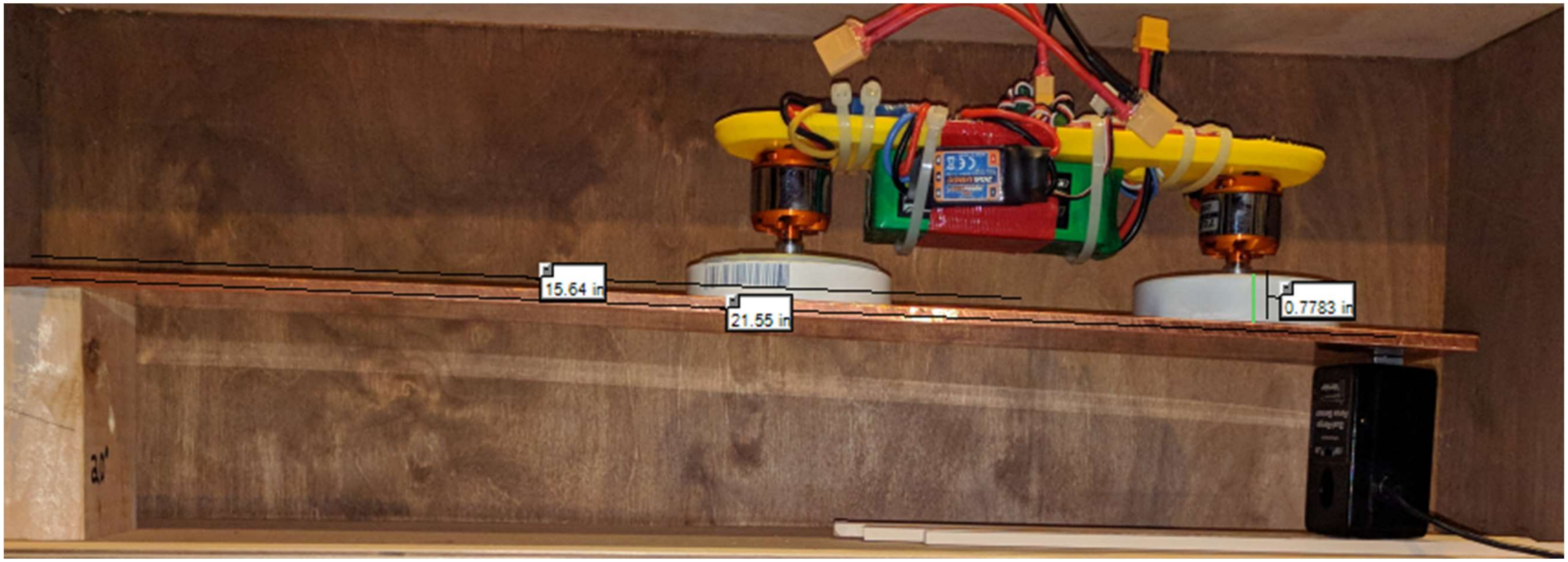
At near to max thrust, the vehicle is capable of producing 4.28 kg (9.4 lb) of lift.



Max Force = 27.47 N



Max Force = 30.50 N


15.64 in
21.55 in
0.7783 in

Conclusions

Overall, this project was a success, proving it was possible to create a small-scale version of a magnetically levitating cart using passive magnets in Halbach arrays. The failure of the first design iteration came as a result of the 3d printed parts breaking under the stresses of rotation. By supporting the rotors with PVC pipe in the second iteration, the structure was much more robust, and able to withstand the stresses of operation.

Given the opportunity to redo this project, I would choose to purchase higher torque motors. As the rotors move closer to the copper, the drag caused by the eddy currents increases, and therefore the power required to turn the motors increases. While pushing down, the motors did not have enough strength to continue to turn, giving rise to the possibility of the motors burning out if they slow down enough, which could be dangerous. Motors with a higher torque would be better able to handle the increased drag as I added weight, but most hobby motors do not have the required torque. I would also be interested in exploring the possibility of machining the parts, rather than 3d printing them. This could reduce weight, and increase the lifespan of the vehicle by reducing harmful vibrations due to imbalance, and by simply increasing the overall rigidity of the system. This would also allow me to make a stronger self-supporting levitating vehicle, instead of making one that requires outside support to stop from tipping over.

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