Electrifying Extraterrestrial Transport

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Supercomputing Challenge

Final Report

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Executive Summary: The goal of my model is to assess the feasibility of using electromagnets as a propulsion device to enable extraterrestrial colonization. Thus far in human and technological history, the colonization of other planets has been impossible. Largely, this has been due to the high cost of rockets. However, if we could eliminate the rockets, and develop a reusable ship, the cost would be dramatically decreased. This kind of system, sometimes referred to as a space gun, has been theorized about for many years. The idea is that electromagnets would be used to propel a ship or other object into space. Until now, most of the theoretical work has been done to evaluate the launching of satellites at significantly lower costs. But is it possible to use this technology to transport humans to enable extraterrestrial colonization? This is what this model was designed to study.

The idea of extraterrestrial colonization has been in the thoughts of number of people in the scientific community over the years. Today NASA as well as companies such as Space-X are trying to design technology to enable the colonization of Mars. The colonization would be building a series of moderately sized structures to enable mining and scientific inquiry, that might otherwise be impossible to do. [13]

To determine the feasibility of such a system, a number of things had to be evaluated. Determining the escape velocity from the earth's gravitational field was the first step. Through a series of physics equations, and educated estimates, it was determined that this spacecraft would have to be travelling at a speed of 351 meters per second. This speed was determined through a series of calculations to evaluate the work done against gravity, and the work done against drag, on a flight to the moon. The velocity could be determined by assuring that the object had as much kinetic energy (energy of movement) as the total amount of energy required to overcome gravity and drag.

However, just simply knowing a starting velocity does not determine feasibility. With this initial data, the code then determines the G-Force that a human aboard this craft would be exposed to. While the initial idea was that the craft would be accelerated almost instantly, the model showed that this would not work, as the passengers would be exposed to a gravitational force of more than 61 thousand times that experienced at sea-level. A typical person can withstand as many as 5 or 6 G in a vertical direction. In part because of some mistakes in early calculations and versions of the model, the distance of the launch barrel was set to 3.1 kilometers. However, this turned out to be a very good distance, because with this distance a human would only experience slightly more than 2 G, completely safe for almost everyone. With such a mild acceleration, it is a very feasible and realistic system. [11]

Even though the forces are survivable, and a barrel of this length is constructible, it is all no good if the energy consumption is too high. So, the third step of the code, was to determine the energy consumption. The system would use $2.35 * 10^{11}$ coulombs. Using this much energy per launch would cost just under 6.1 million dollars. This cost can be reduced, however. According to NASA, in 2015 the average cost to launch a space shuttle was 450 million dollars, meaning the energy to power the electromagnet would cost just over 1.35% of the full cost of a rocket fuel mission. It would also lower carbon emissions. [7]

The model was validated throughout by using the most accurate and reliable real-world data available for each parameter. The exact parameters are available in the appendix, along with their respective sources.

The data produced by the model appears to be conclusive, however the model could be improved significantly through the production of case specific parameters, such as more accurate air densities, and dimensions and specs of the aircraft in question. This model was intended simply as a proof of concept, however. Exact dimensions and further calculations will be necessary before a mission is conducted. To have exact dimensions, the craft and supplies must be engineered, down to the last bolt. From the data produced by this model, it can be concluded that electromagnetic propulsion is a viable method of extraterrestrial colonization, and has the potential to significantly reduce the cost of space travel.

Introduction: The goal of my project was to assess the theoretical feasibility of using electromagnetic propulsion to send manned spacecraft to the Moon. Theoretically, if an electromagnetic system is used, goods and people could be transported to the Moon and back at significantly lower costs, both financially and environmentally. This drastic cost decrease could make colonizing the Moon a tangible possibility, bringing prophecies of "one day reaching the Moon", much closer to reality. I chose this project because I think that it would be cool to one day have extraterrestrial colonies, not just on the Moon, but also on Mars. When I initially set out to do this project, I had the goal in mind of assessing the feasibility of travel to Mars. My plan was that if we got travelers to the Moon, it would be relatively simple to send them on to Mars. Due to a tight time frame, as I changed projects in the end of February and had never used MATLAB before, modeling travel to Mars was not realistic. Even though the model is only to the Moon, given more time the same type of calculations could be used to model travel from the Moon to Mars.

Electromagnetic propulsion has been evaluated for launches a number of times [12]. The key difference is that in each of these other models the goal of the research was the launch of satellites. This model considers the launch of human transport crafts. A satellite weighs significantly less than a craft aimed at colonization, and can often withstand far greater forces than a human body. As far as I could find, no one had yet done any close study of this human transport case.

An electromagnet is a coil of wire that under normal circumstances is magnetically negligible, then an electrical current is added through the wire, and a magnetic field is produced, the size and force are directly proportional to the amount of energy running through the coil. Electromagnetic propulsion takes advantage of the fact that two similarly charged materials (negatively or positively charged) will repel each other. Because an electromagnet does not have much of a magnetic field until it is charged, a launch can be precisely controlled, by not only controlling the size and force of the field, but also being able to instantly turn it on and off.

To calculate how fast an object must move at launch, if no energy is added afterward, one must determine the energy required to overcome the Earth's gravitational pull, in addition to calculating the energy required to overcome the drag, or air resistance, on the object. These are then added together to determine the total energy of the object. The velocity is then determined by use of the kinetic energy formula, which relates the mass and the velocity together to determine the kinetic energy. At launch, the craft must be travelling fast enough that the kinetic energy will equal the energy required to reach the Moon.

Project Description:

Model Parameters:

Cd	.045	Airfoil shape [1]
Density in space	1 atom/cm^3	Average density of outer space [2]
Relative gravity	$G_1/G_2=(R_2/R_1)^2$	Change in gravity based on altitude [3]
Moon	384400	Altitude to moon
Troposphere density	1.485E19 atom/cm^3 24.66mols/m^3 .362kg/m^3	Average density in troposphere Based on top/bottom [5] [6]
Stratosphere density	.00108 kg/m^3	Based on top [10]
Shuttle	104400 kg	Mass of a NASA space shuttle[4]
shuttle	63.62 m^2	Frontal area for drag
Magnet Gap	1cm	Gap between ship and magnet
Magnet voltage	1000 volts	This is just an example voltage; a truly accurate voltage is only determinable with end product.
kWh cost	$.093	Average US kWh cost for transportation [8]

Parameters Explanation: The parameters were determined based on available data, whenever possible utilizing NASA data, as they tend to have accurate data pertaining to spacecraft. In some instances, averages and estimates had to be made. If the number might go high or low, I always aimed to go high, because this is a proof of concept project, and it is simple to lower the energy requirements or the cost, if my results show that the system is still feasible. If these same numbers were estimated lower, and then it was discovered that some of the calculations are inaccurate, the system could very well no longer be feasible. After exiting the stratosphere, I no longer calculated drag, because even the calculation in the first two layers produced mostly insignificant quantities, and the air density decreased drastically, to be almost nothing after the stratosphere. The distance of the magnets from the craft was set at 1cm, a relatively small distance. However, if the distance were to be made smaller, it would decrease the overall energy usage. 1cm gives engineers a fairly large range to play with, without overly increasing the energy usage.

Method and Equations: In order to determine the energy use, the first calculation was that of the work that would be required against gravity. Because as elevation rises gravity decreases, the first step was to program in the new gravitational force at each new altitude. The increment was set to calculate once every kilometer, and the basic idea was that it would calculate the work done against gravity during that kilometer and then add it to the total work done against gravity (see code below).

```
function gav = gravity_local(current_altitude, starting_altitude, g1, inc, target_altitude)
    gav = 0;
   while current_altitude < target_altitude
    g2 = g1 / (current_altitude/starting_altitude)^2;
    gav = 104400 * g2 * inc + gav;
    current_altitude = current_altitude + inc;
   end

end
```

In this function, the variable *gav* is equal to the work done against gravity, derived using starting and ending elevations.

Once the work done against gravity was calculated, then the drag could be calculated. To determine the drag, one had to first determine the velocity. Therefore, the initial drag was set to zero, and the program calculated the velocity required without air-resistance. With this initial velocity, we could then calculate the drag, and finally recalculate the velocity now including the work done against drag. (see code below)

```
function aw = flight_drag(frontal_area, drag_coefficient, bottom_elevation, altinc)
    aw = 0;
    gav = gravity_local((6400+bottom_elevation), 6400, 9.8, 1, 388400);
    while bottom_elevation < 16
        vel = (2*aw/104400 + 2*(gav)/104400)^(1/2);
        time = altinc / vel;
        aw = 1/2 * drag_coefficient * .362 * vel * frontal_area * time + aw;
        bottom_elevation = bottom_elevation + altinc;
    end
    gav = gravity_local((6400+bottom_elevation), 6400, 9.8, 1, 388400);
    while (16 <= bottom_elevation) && ( bottom_elevation < 50)
        vel = (2*aw/104400 + 2*(gav)/104400)^(1/2);
        time = altinc / vel;
        aw = 1/2 * drag_coefficient * .00108 * vel * frontal_area * time + aw;
        bottom_elevation = bottom_elevation + altinc;
    end
end
```

The work done against drag is equal to the variable *aw*. The drag coefficient came from outside sources. The frontal area was determined by estimating the size of the craft at its widest point as 9m in diameter. The bottom_elevation is the starting elevation of the specific layer, and the altinc is the change in altitude as the spacecraft climbs up.

Once the drag had been determined the velocity was determined using this function. As already described, *gav* is the work against gravity and *aw* is the work against drag: `vel = (2*aw/104400 + 2*gav/104400)^(1/2)`

After determining the velocity (*vel*), I then proceeded to determine the speed of acceleration, considering that it would be done over a period of 3.1 kilometer. This distance was accidentally determined because of some preliminary calculations that were incorrect. Upon consideration, however, since it would be feasible to construct such a long launcher, and it would lower the forces that the passenger would be exposed to, I kept the distance. The acceleration was determined using this equation: `acc = .5*(vel^2)/3100`

Once the acceleration (*acc*) was established, I then proceeded to determine the G-Force that each passenger would be exposed to, by use of this formula: `gf = acc/9.8`

The final step was then to determine energy usage. I started by determining the coulombs that would be used, and then estimated the number of watt hours, based on a 1000 volt system. The function *eng* was used to determine the coulombs. (see code below)

```
function eng = energy_consumption(mass, acceleration)
    eng = mass * acceleration * 12.566 * 9.0e+09 * .001^2;
end
```

Then once *eng* had been determined, I used this formula to estimate the kilowatt hours that would be used, so as to estimate the cost: `kwh = eng / 3600000 * 1000`

Using the average cost of energy in the US per kilowatt hour for transportation, which is 9.3 cents per kilowatt hour, I estimated the per launch energy costs.

Materials: For this model, I tried to find all my values from NASA, and only used other sources when I could not find NASA data. As much as possible, I tried to use more reputable sources, and for sources where the information was less certain, I made sure to carefully study it to make sure that it seemed reasonable. In terms of software, I used my computer's built in calculator to check my work, and I did all my coding in MATLAB r16b. To run my model, I used a laptop with a dual core intel i5 processor with 8 gigabytes of non ecc memory.

Results: After calculating with the above processes and formulas, and checking to make sure that my calculations seem right, such as acceleration, my model produced good results. The model did, in fact, show that electromagnetic propulsion is a viable method of passenger spacecraft propulsion. My model determines exact numbers in the propulsion of the spacecraft. The viability was determined because of its reasonable amount of force, energy, and cost, although not including that of the launch apparatus.

Table of results

value	Calculated result
Work against gravity (Jules)	$6.44*10^9$
Work against drag (Jules)	8.34
Velocity (m/s)	351.26
Acceleration (m/s^2)	19.9
G-force (G)	2.03
Energy requirement (coulomb)	$2.35*10^{11}$
Estimated kilowatt hours	$6.53*10^7$
Estimated energy cost	$6.07*10^6$

Validation of Results: In order to validate my results, I backwards calculated a number of values to make sure that variables such as acceleration, G-force, and acceleration distance were accurate. It was with this validation process that some errors in these values were found and corrected. For example, the acceleration was 390 m/s^2, and as a result the G-force was calculated as 40. Once the formulas were repaired, however, the model calculated the much more reasonable acceleration of 19.9m/s^2 and resulted in a G-force of about 2.

Error Propagation: There is a chance for errors, such as in the velocity and work done against drag, since the calculations start with a drag of zero. This means that the first number of kilometers will be causing more drag related work than calculated, and, as a result, the initial velocity may need to be slightly higher due to this additional drag. Yet more error in the drag calculation would be possible because of insufficient meteorological data on the layers of the Earth's atmospheres and their respective densities. Further, I only calculated the drag caused by the first two, most dense, layers of the atmosphere. As this is only a proof of concept model, and is not based on the exact specifications of the launching apparatus, and the dimensions of the spacecraft, some of the calculations could be inaccurate.

One of the most likely causes of error, would be related to the goal of landing the ship on the Moon exactly. However, in part due to travel times, and in part due to astronaut safety, the goal would be to have the spaceship land on the Moon with a tangible velocity. Should there be an error in the trip planner's calculations, the travelers will have a greater chance of actually landing on the Moon, in addition to making the Earth-Moon trip faster.

Conclusions: The simple conclusion is that Electromagnetic propelled space travel is indeed achievable. While designing and constructing the launching apparatus and the spacecraft could potentially be very expensive, it could pay for itself with repeated uses. The most modern NASA produced space shuttle is estimated to cost a total of 1.7 billion to construct. Each launch costs about 450 million dollars in jet fuel, etc. This new system, while it may cost more than 1.7 billion dollars to design and build, would have an estimated per launch cost (one-way to the Moon) of about 6 million dollars. With repeated launches, the new electromagnetic system could pay off rather rapidly. Beyond enabling NASA to significantly increase the quantity of spaceflights in a year, with its limited budget, each flight could also have a significantly lower carbon footprint, as the electricity can come from renewable energy sources, possibly decreasing the preflight cost even more.

Even if a system is cheap enough, if the people onboard would be killed in launch, then the system would fail in its goal of colonizing the Moon or Mars. However, in this system the model estimates that the astronauts would be exposed to less G-force in this spacecraft than they are exposed to in a standard rocket ship. One reason why the G-force would be less, is because the drag experienced and weight lifted by the rocket ship are less than those experienced by the electromagnetic space spaceship (ESS). The ESS would have a lower weight because it would not have to have the very heavy rockets and fuel tank that are currently used. The drag would be decreased, because without the need for rockets at the bottom, the ESS could use a new body shape that significantly decreases drag.

The most significant original achievement of this project is mathematically proving that it is possible to use electromagnetic propulsion to go to the Moon, and possibly one day to Mars. While some studies have been conducted on using these systems to launch satellites into orbit, as far as I could find, none had yet seriously studied this system for spacecraft with human passengers as they believed it impossible. [12]

Additionally, a significant achievement was being able to produce a working model in MATLAB, with formulas I was studying and learning as I worked. Before starting this project, I had never worked in MATLAB. While MATLAB is not an overly complicated system, it does have some quirks that took me time and practice to figure out and understand. While my code may seem simple and short, it is very intricate, and many of the routines are repeated thousands of times. One of these is the work against gravity calculation, which had to recalculate itself 384 thousand times, because the altitude interval was 1 km. Then it had to be rerun another 50 or more times to determine other variables that also took a very large number of calculations. This project required computer modeling, because should the calculations be attempted to be done by hand it would probably take hundreds if not a thousand or more hours to complete. Should a mistake be found, the model can recalculate in seconds, whereas the person doing it by hand would have to redo a massive number of calculations, especially if it had to do with gravity.

Recommendations: My biggest recommendations would be to do real-world testing to get more accurate and case specific parameters, as well as creating scale models of the spacecraft, to more accurately determine things such as drag coefficient, mass, and size. Of these case specific parameters, one of the most prominent parameters would be the pressure in kg/m^3. Additionally, if the model were to be rebuilt using integrals to determine the work done against gravity, the model would produce more accurate results. Finally, there should be a velocity study done, to ensure that the spacecraft is still moving at a decent pace when it arrives at the Moon, because with this model it is only supposed to go just fast enough to reach the moon, and nothing more.

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