Thermoelectric Project Technical report

Group 20

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Executive summary

This report aims to explain how thermoelectricity can be used to make a vehicle go up a ramp using a tea light and a Peltier device. The vehicle will also use a heat sink and a motor to make the car run, along with other design elements to ensure a functioning vehicle. This report will also cover some of the testing done to ensure the vehicle runs, along with showing calculations of the efficiencies. Additionally, this report will cover the theoretical maximum heights and accelerations of thermoelectric vehicles. A CAD image of the file will also be provided.

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Introduction

There are multiple ways that one can get the electricity needed to power a vehicle. We want to know if it is possible to run a thermoelectric vehicle with only a tea light for heat and no batteries, chemical reactions, pressurization on mechanical potential energy. Not only is the goal to create a running vehicle, but for the vehicle to make it up a 20-degree ramp. This report will cover thermoelectricity, and its uses in powering a vehicle. The main parts of creating such a vehicle are the thermoelectric generator, the heat sink and the motor.

Thermal energy can be transformed into electricity using a thermoelectric generator. There are many types of thermoelectric generators that function in different ways, but this report will focus solely on the Peltier generator. The Peltier device is a small, thin, square device with two wires sticking out of it. When one side of the Peltier device is heated up, and the other one is cooled down, then the Peltier device turns the change of temperature into electricity because it is made of thermoelectric materials [1]. Thermoelectric materials are conductive and allow for electrons to move from the hot side of the device to the cold side, via the Seebeck effect, and the moving electrons become electricity [1, 2]. The greater the temperature change is between both sides of the device, the more electricity the device will produce.

The main issue with the Peltier device is that the action of the electrons moving from the hot side to the cold side heats up the cold side. This means that as the Peltier device runs, the temperature on the cold side increases, which reduces the temperature difference making the Peltier less and less effective. To avoid this, the cold side needs to either be cooled off or needs to have a way to dispel the extra heat. One way to dispel the heat is to use a heat sink. Heat sinks are pieces of metal designed to cool the surface under it by transferring the heat into the air around it. Heat sinks are made from heat conducting metal, like aluminum or copper, and have fins that increase its surface area. An increased surface area is important to allow the heat to transfer to the ambient air and leave the heat sink. These fins are usually walls that all run in the same direction, but other shapes are also available. As the bottom of the heat sink heats up, the heat transfers to the fins who then transfer the heat into the air, effectively cooling the surface under it. A heat sink is not perfect, and it will also heat up over time, but it will allow the Peltier device to run for longer, and more efficiently, than with nothing.

A lot can be done with the energy created from a thermoelectric generator, including making a vehicle. It would be easier to make a vehicle going in a straight line than one that can go up a ramp because a car going up a ramp must counteract gravity. Because of this, the motor needs a higher gear ratio. A higher gear ratio allows the motor to have more torque, which will allow it to have more power, at the cost of being slower.

List of Tests and Procedures

Test 1: Peltier with varying water temperatures.

Goal: Determine voltage produced across the Peltier device with respect to a temperature applied independently of any heat mitigation system.

Procedure:

1) Heat water in a flat bottom port until boiling.
2) Place pot on Peltier, connected to a multimeter and place thermometer in the water.
3) Record the voltage and temperature at regular intervals as water cools.

Test 2: Temperature differential created by powering Peltier device.

Goal: Determine temperature differential created by different voltages applied to the Peltier device.

Procedure:

1) Using a microcontroller thermometer, attach thermocouples on each side of the Peltier.
2) Record initial temperature readings of both thermocouples.
3) Connect AA 1.2V battery to the device.
4) Record temperature on both sides.
5) Repeat with 9V battery.

Test 3: Temperature/voltage testing of vehicle at different chassis inclinations.

Goal: Determine the voltage and temperature differential obtained from different inclination of the chassis going from flat ground to a 20-degree incline.

Figure 1. Position of the two thermocouples on the car.

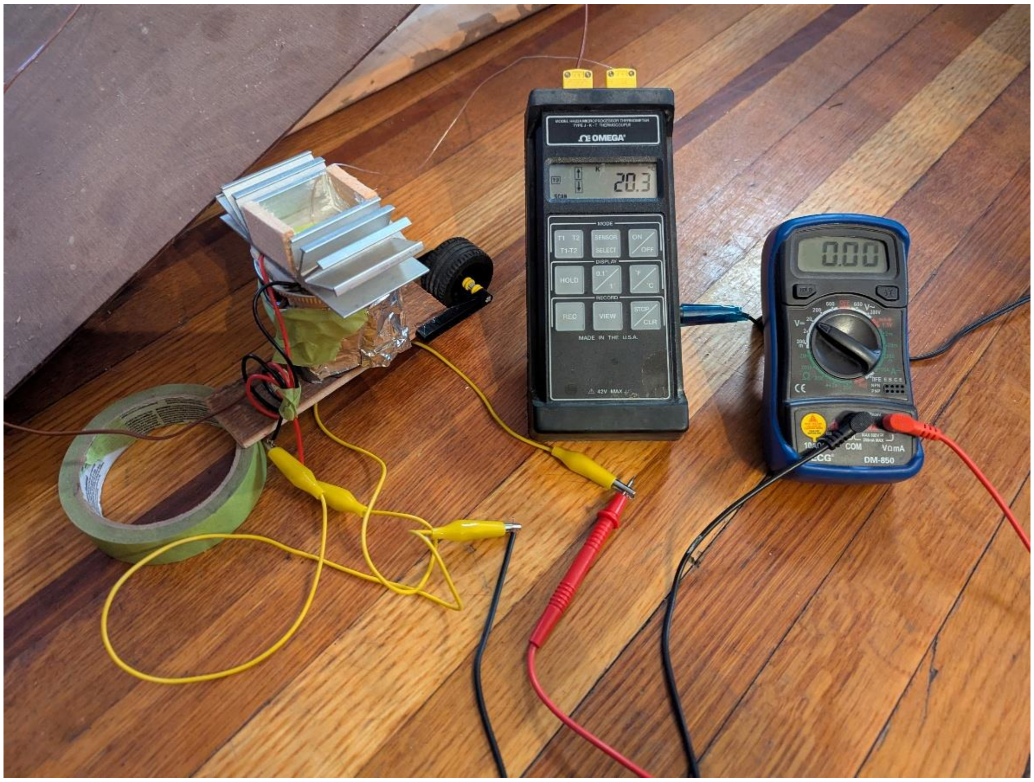


Figure 2. Test setup of car on horizontal surface.

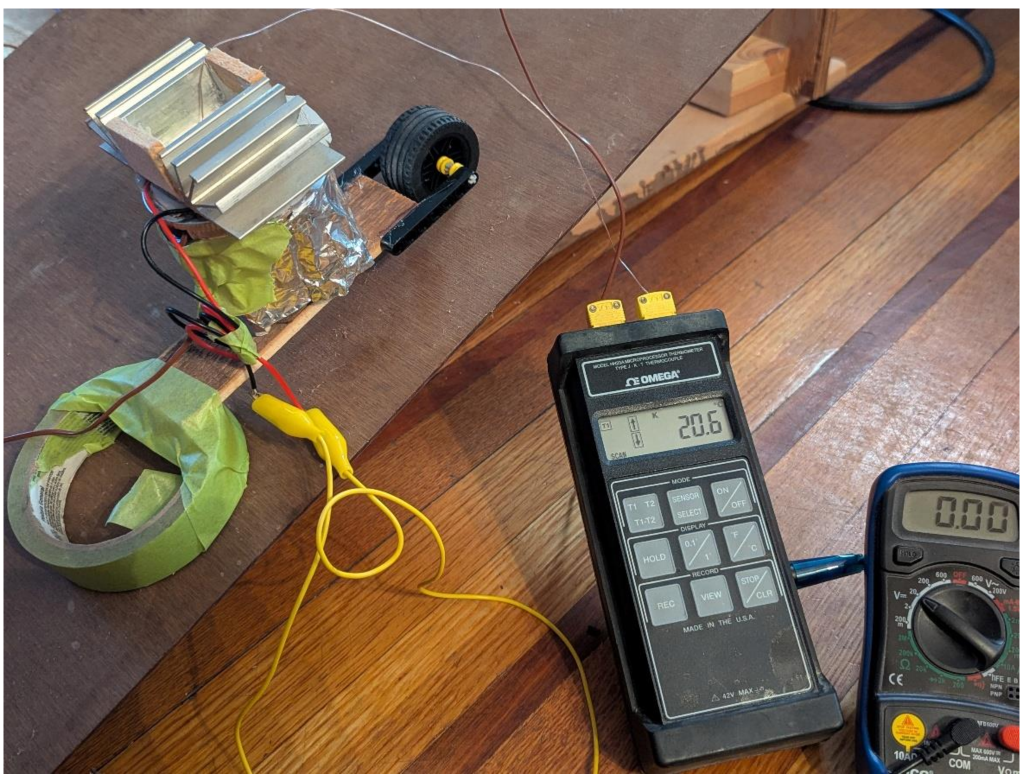


Figure 3. Test setup of car on 20-degree surface.

Procedure:

1) Set the vehicle on the desired incline by raising the back.
2) Using a microcontroller thermometer, attach thermocouples to the bottom side of the Peltier device and the base of the heatsink.
3) Connect the Peltier device to a multimeter.
4) Light the tealight and record a video of both displays of the thermometer and multimeter.
5) Once values stabilize, move the vehicle onto the 20-degree incline.
6) Repeat with the vehicle inclined at 10 and 15 degrees.
7) Plot temperature and voltage w.r.t time from the video recording.
8) Take a reading of amperage in both positions at the ideal inclination chosen for final car design.

Analysis of results

The vehicle data from test 3 (see Apx. 3) indicates that with our given setup, a car inclination of 10 degrees from the horizontal result in the highest sustained voltage both on the flat ground and 20-degree incline ramp. This despite the same temperature difference being measured in the 10-degree and 20-degree tests. We believe this is caused by a more even heat distribution across the Peltier device when it is less inclined, allowing for more heat to be turned into electricity.

Design Details

The thermoelectric vehicle that we built is designed to go up a ramp at 20 degree incline successfully. This means that our design had to be built with a few things in mind.

First, the vehicle must be light, so the motor can bring the car up the ramp. We knew that the Peltier device would not easily produce a high voltage, and if it did, it would not last long, so we had to build the vehicle as light as possible. The lighter the vehicle, the less power the motor needs. This means that we did not want to use water as a heat sink since we would need a relatively large amount of water, and water is dense, so it would make our vehicle too heavy. This left us trying to find an aluminum heat sink that was as efficient as possible. We settled with one that has four fins that are placed at varying angles from the same point. This means that there is a large surface area that is in contact with the air while having a bigger space between the fins. Additionally, the heat sink has a space in the middle of it with no fins, so we added some wooded slabs sealed with silicone caulking to create a space to place an ice cube. The ice cube will cool off the heat sink, creating a higher temperature difference and a higher voltage. Caulking is important since the heat from the flame will melt the ice and it is important to not have water fall onto the tea light since water will extinguish the flame.

Secondly, it is important to create as much heat as possible on the other side of the Peltier device. This was done by creating a sort of chimney to force all the air upwards towards the Peltier without letting the heat escape through the sides. This was done by having dowels hold up some tape in the form of a cylinder. The chimney is made of duct tape then surrounded by aluminum tape to insulate the space around the candle. This container forces the heat to rise instead of getting lost on the sides, making the Peltier hotter. The top of this contraption is the lid of a mason jar because this part of the cylinder will get very hot, so it needed to be nonflammable, and it needed extra support. Fire needs air to keep on burning, so the base of this aluminum cylinder is opened to the air so that the fire can breathe. There is also an opening on the top of the cylinder so the expended air can leave the system after heating up the Peltier. This hole is in the back of the vehicle so that when the car is going up the ramp the hot air does not go directly out of the opening but heats up the Peltier. Having the vent on the back of the chimney would also expel heat away from the fins of the heatsink above, reducing how quickly it heated up and how much heat it had to dispel. We noticed after a few tests that the heat of the candle was heating up the heat sink while heating the Peltier which brought down the voltage. To fix this, we created a clay divider as an insulator that goes around the Peltier so that the heat sink is not heated up by the candle but rather the heat going through the Peltier. To ensure this, the Peltier is connected to the heat sink by thermal paste because the thermal paste creates a more conductive connection between the two surfaces which makes the heat transfer more effective.

Now that the change in temperature in the Peltier device is maximized, and in turn, so is the voltage, we can connect it to a motor to run the vehicle. The chosen motor is the FF-180 DC Motor, a compact and lightweight brushed motor commonly used in small electronics and hobby projects. We intentionally chose smaller wheels so that the cat moves faster. Since the motor drives the wheels, smaller wheels will allow the car to move faster since they weigh less and are easier to rotate. In the tests the back wheels were slipping when going up the ramp, so we added rubber bands to the wheel to give them more grip and stop the car from sliding down.

For the design of the chassis of the vehicle, we tried to make it as light as possible. To achieve this, we decided to 3D-print the chassis because plastic is light, and we can get the exact dimensions that we want. Additionally, we decided to only put 3 wheels on our vehicle. With three wheels instead of four we can get rid of the weight of one wheel while keeping the vehicle balanced. We will also place the motor, so it only drives the back two wheels to avoid the complications of having to build a front axle or a gear ratio to run the front wheel, which would also add more weight. We also realized that when the vehicle is going up the 20-degree ramp that the tea light flame is no longer directly on the Peltier, so, after testing (see Test 3 and Apx. 3), we put the entire chassis on a 10-degree angle in the opposite direction of the ramp. This means that when the car is moving on the flat surface or going up the ramp, the maximum angle the candle will have is 10 degrees. If you look at the test section, 10 degrees is the ideal slant because otherwise the flame of the candle is not evenly heating up the Peltier in one or either of the inclination conditions.

Maximum Efficiencies

Maximum Velocity with Ideal Car

We know that a candle creates 34 BTU per hour [3]. The average tealight burns for about 4 hours, give or take depending on the specific tea light.

$$\frac{34\ BTU}{hour} x\ 4\ hours\ x\ 1.055 \frac{KJ}{BTU} = 143.48\ KJ$$

So a standard tea light produces 134.48 KJ of energy. If we want the maximum height any vehicle can have using the tea light for power, we need to assume that the Peltier device is perfect and has a 100% efficiency. On top of this we need to assume that there is no energy loss due to friction and slipping. In short, we assume that all of the energy created by the tea light is used to power the forward motion of the car. The energy from the tea light will be potential energy that the vehicle had access to.

$$E_{tea\ light} = PE$$

$$E_{tea\ light} = mgh$$

For an ideal vehicle, we want it as light as possible we know that a Peltier weights 26g and the average motor of the right size for the vehicle is 30g the lightest the car can possibly be is 0.056 kg [4, 5]. With this in mind, we can solve the potential energy equation.

$$143480\ J = 0.056kg\ x\ 9.81 \frac{m}{s^2}\ x\ h$$

$$h = 261176.64\ m$$

so the maximum height any vehicle can travel is 261 km if the Peltier device and the vehicle itself is running in ideal conditions so that the power from the tea light directly transfers to the car.

The maximum speed our car can go is based on the power actually created by the Peltier device, so we cannot assume that all the power from the tea light is transferred to the car. This can be done using the following equations.

$$P = U\ x\ I = F\ x\ v$$

Where U is voltage in volts, and I is current in amperage. F is the force and v is the velocity. If we draw a free body diagram, we can see the minimum force needed to move the car up the 20-degree incline is as follows.

$$F = mg\,(sin\ 20)$$

Combining these equations gives us the following.

$$U\ x\ I = mg(sin20)\ x\ v$$

$$\frac{1.85\ V\ x\ 0.0322A}{(0.056\ kg)\ x\ 9.81\frac{m}{s^2}\ x\ \sin\ (20)} = 0.305\ m/s$$

Where 0.305 m/s is the maximum velocity, a car can reach at the sustained observed power of the Peltier with the lightest possible car.

Discussion

Theoretical Velocity with our Actual Design

Our car, unfortunately, has a much larger mass than the theoretical one mentioned above at about **0.259 kg**. Substituting that in the previous calculations, we should, in theory, be able to move the car at a velocity of about **0.069 m/s.**

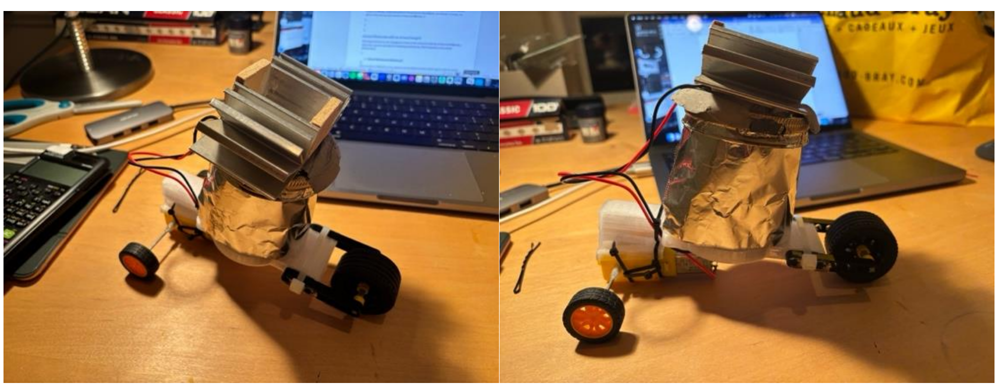


Figure 4: Final Car Design

Actual Efficiencies with our Design

We observed that our car managed to move up the ramp at a velocity of about **0.0162 m/s.** Given this, we can calculate the following mechanical, thermodynamic and overall efficiencies.

- **Actual Mechanical efficiency:**

The mechanical efficiency of our system can be determined by obtaining the ratio of useful mechanical output energy of our car with the measured electrical energy output from the Peltier device. Given the following data, we can determine the mechanical efficiency.

$$\eta_{Mechanical} = \frac{Useful\ Mechanical\ Output\ Energy}{Electrical\ Energy\ output\ from\ Peltier} * 100 = \frac{mgvsin(\theta)}{UI} * 100$$

$$\eta_{Mechanical} = \frac{(0.259\ kg)\left(9.81\ \frac{kg * m}{s^2}\right)\left(0.0162 \frac{m}{s}\right) * sin(20°)}{(1.85\ V)(0.0322\ A)} * 100 = 23.63\%$$

- **Actual Thermodynamic efficiency of the Peltier device:**

The thermal efficiency of the Peltier device can be calculated by obtaining the ratio of the measured electrical energy output from the Peltier and the thermal energy output from the candle.

$$\eta_{Peltier} = \frac{Electrical\ Energy\ output\ from\ Peltier}{Thermal\ Energy\ output\ from\ candle} * 100 = \frac{UI}{34\ \frac{BTU}{h} * \left(\frac{0.293\ Wh}{BTU}\right)} * 100$$

$$\eta_{Peltier} = \frac{(1.85\ V)(0.0322\ A)}{34\ \frac{BTU}{h} * (\frac{0.293\ Wh}{BTU})} * 100 = 0.6\%$$

The obtained thermal efficiency is thus very low. Perhaps, due to quite a lot of heat lost and due to the design of our thermal car.

- **Actual Overall thermodynamic efficiency:**

The overall thermodynamic efficiency of our vehicle can be obtained with the product of both the mechanical and thermodynamic efficiency of the Peltier device.

$$\eta_{Overall} = \eta_{Mechanical} * \eta_{Peltier} = 0.2363 * 0.006 = 0.14\%$$

- **Comparison with theoretical values:**

Firstly, the theoretical maximum speed of the rover was calculated to be 0.069 m/s while our car only managed to climb the ramp at a velocity of 0.0162 m/s. Although, the theoretical velocity assumed 100% mechanical and thermodynamic efficiencies which are impossible as losses are, of course, inevitable. Were we have more time, it would be useful to possibly redesign the Peltier system as it was clear with our 0.6% heat utilization of the candle that an overwhelming majority of the energy was lost in the process and could possibly be more efficient.

References

[1]https://sites.suffolk.edu/rcmiranda/2016/03/04/thermoelectrics/

[2]https://www.physics.utoronto.ca/apl/xrf/APPENDIX%20E.pdf

[3] https://highlandcandlecompany.com/will-candles-heat-a-room-how-many-do-you-need/

[4]https://www.mouser.ca/ProductDetail/Mikroe/MIKROE3828?qs=Cb2nCFKsA8o%252Bwx%252Bfwr1hxg%3D%3D

[5] https://bc-robotics.com/shop/3-6vdc-hobby-gearmotor/?srsltid=AfmBOor_oCPlb5z4KTERyRhel2Ik3HnsdfGjSr3blF180-cs8iLxTeYK

Appendices.

Appendix. 1. Test 1 Results

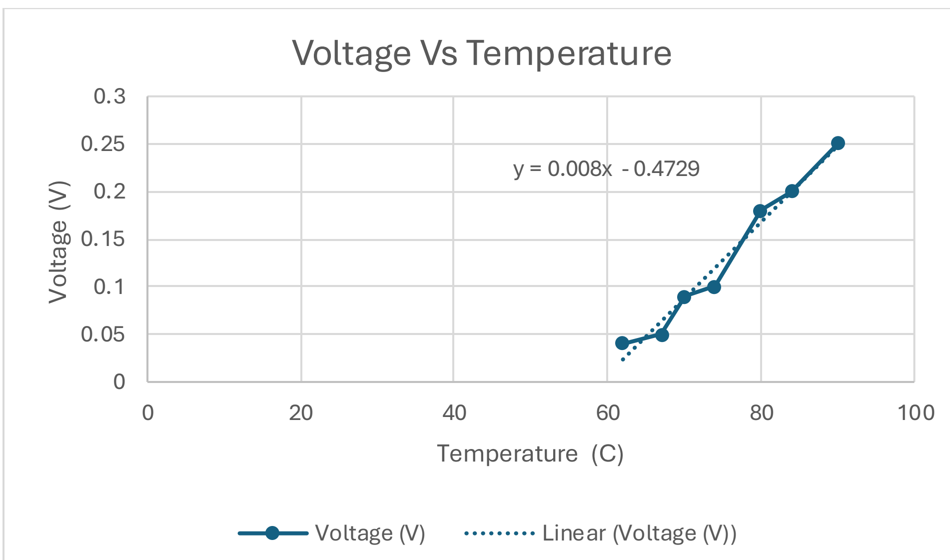
Table 1: Temperatures of hot and cold side with applied voltage

Voltage	Hot side (˚C)	Cold side (˚C)
1.3V	28.2	24.4
9V	31.2	22.0

Apx. 2. Test 2 Results

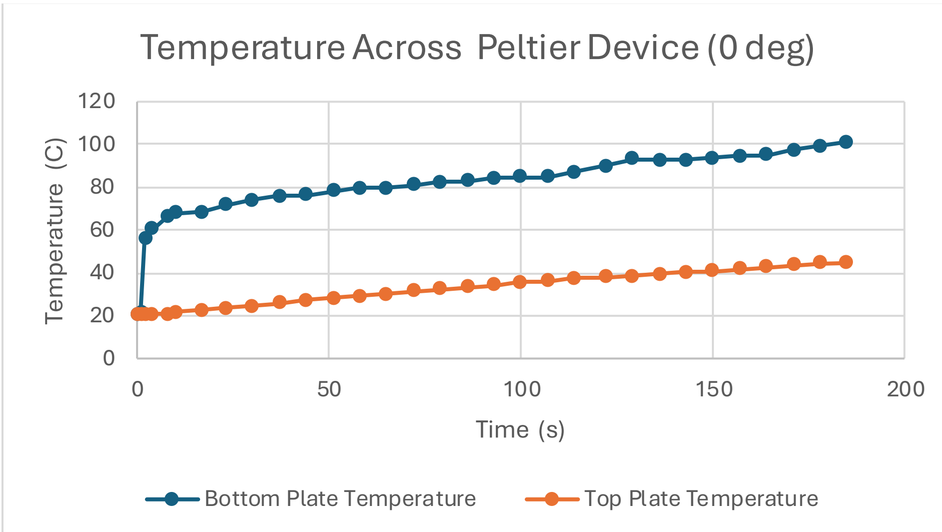
Table 2: Voltage change with one sided heat application

Temp. (˚C)	90	84	80	74	70	67	62
Voltage (V)	0.25	0.20	0.18	0.10	0.09	0.05	0.04

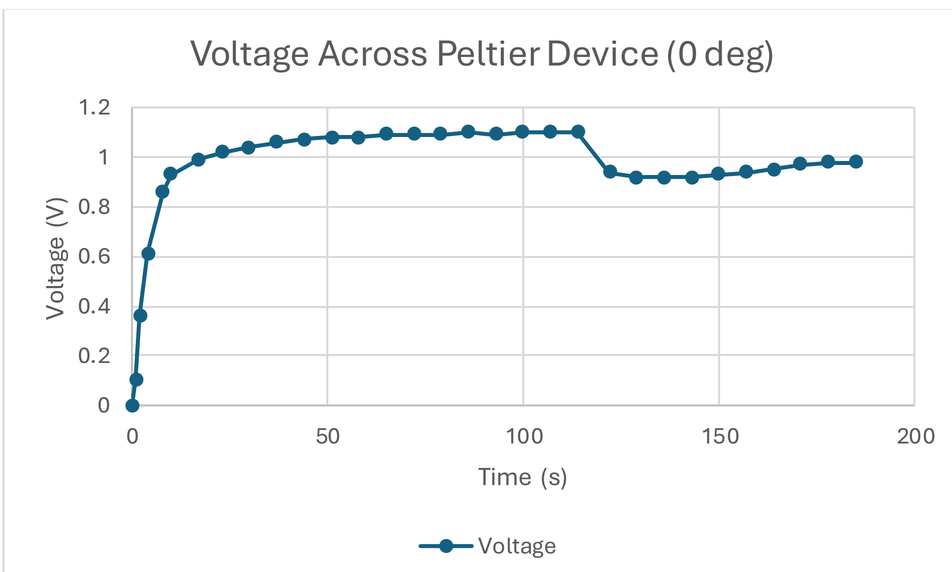


Graph 1: Voltage change with one sided heat application.

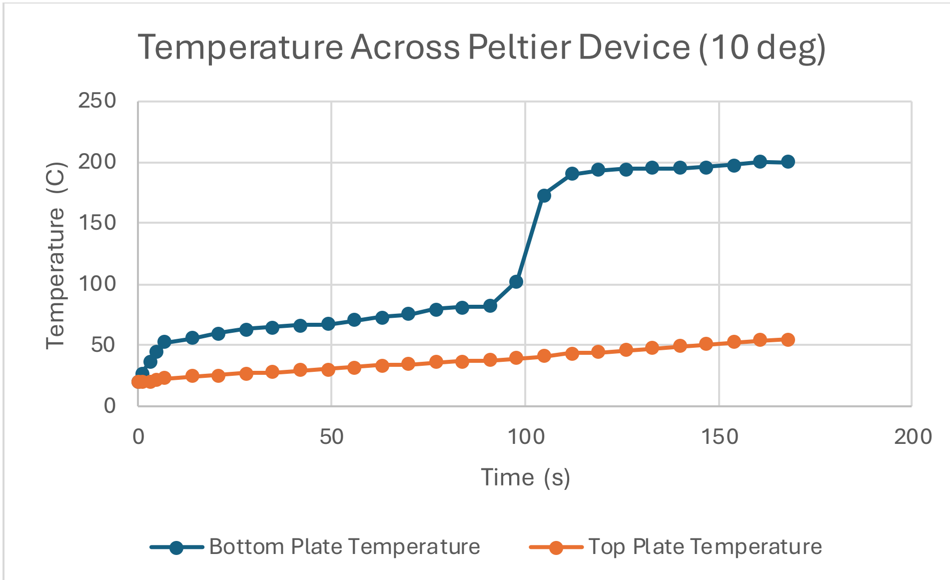
Apx. 3. Test 3 Results



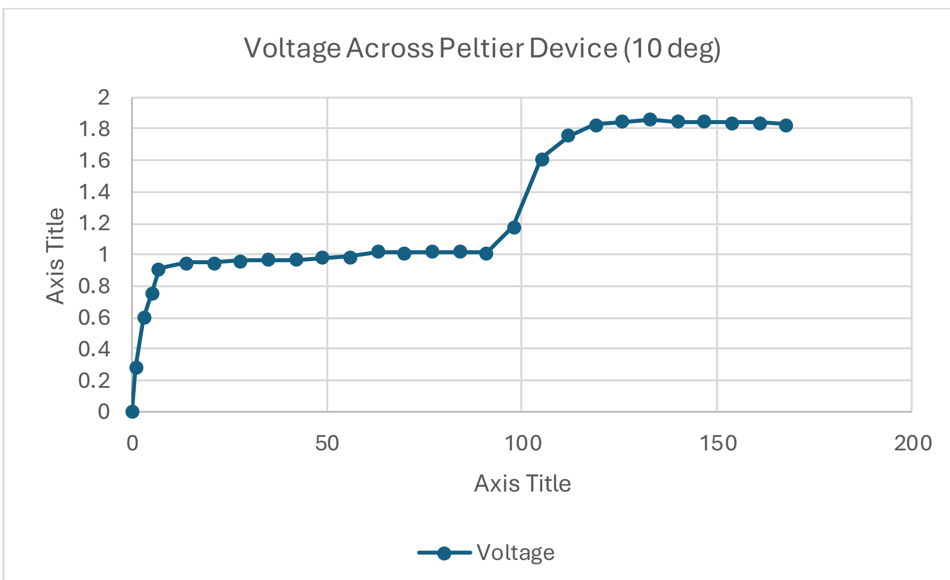
Graph 2: Temperature change at 0 degrees from horizontal



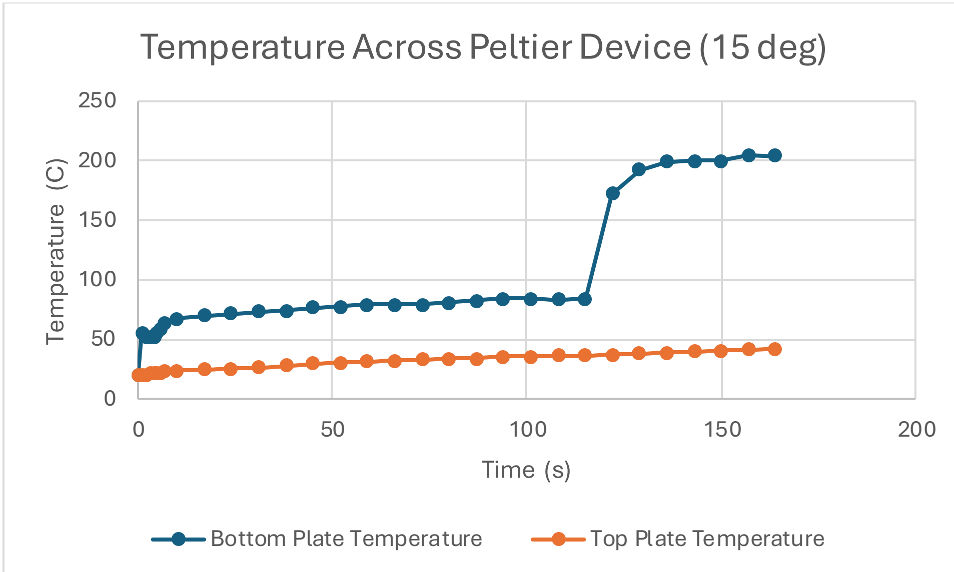
Graph 3: Voltage change at 0 degrees from horizontal



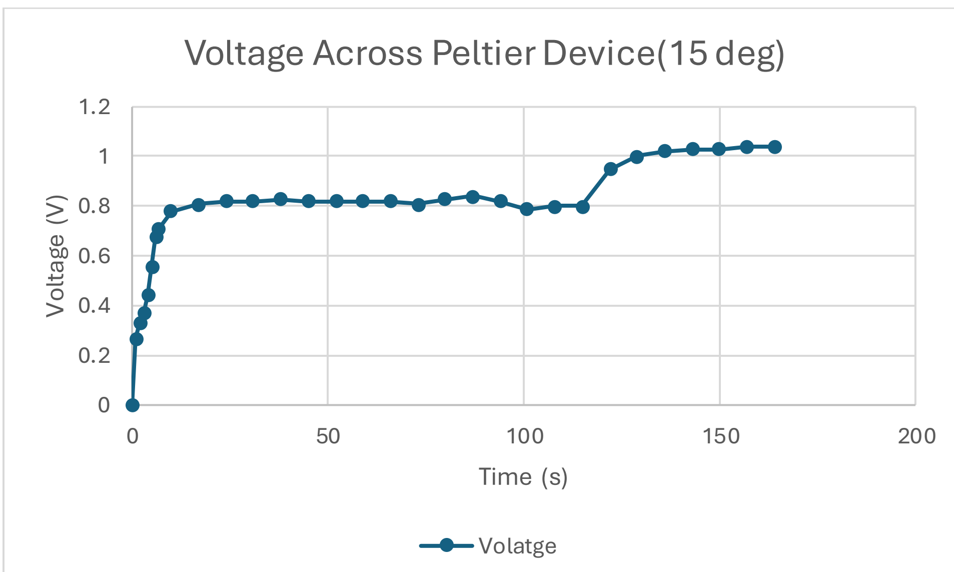
Graph 4: Temperature change at 10 degrees from horizontal



Graph 5: Voltage change at 10 degrees from horizontal



Graph 6: Temperature change at 15 degrees from horizontal



Graph 7: Voltage changes at 15 degrees from horizontal

Table 3: Amperage readings of 10-degree inclined car

	On Horizontal	**On 20-degree ramp**
Amperage reading	29.1 mA	32.2 mA

Apx. 4. Final Car Design

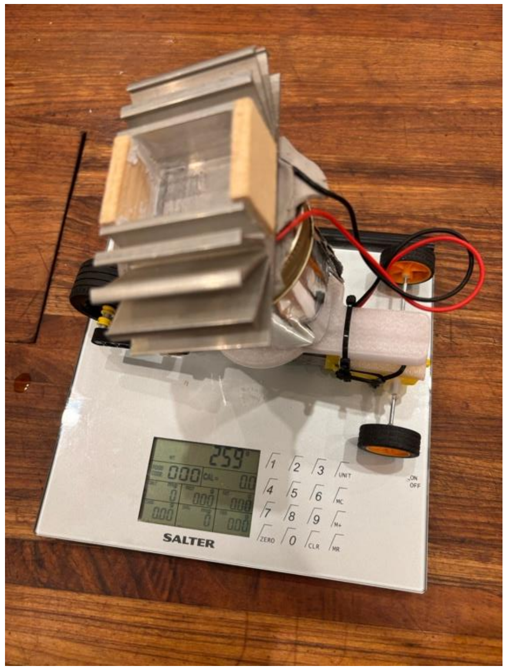


Figure 5: Mass Reading of Final Car Design

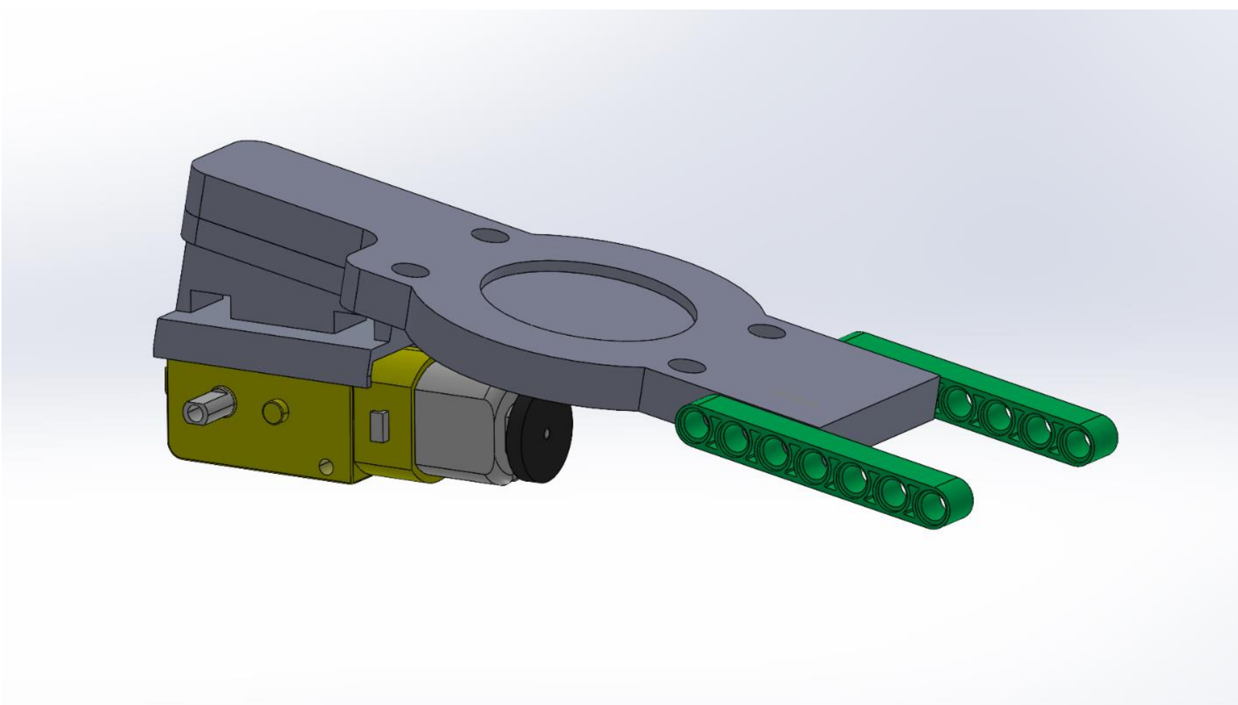


Figure 6: CAD Assembly ISO View

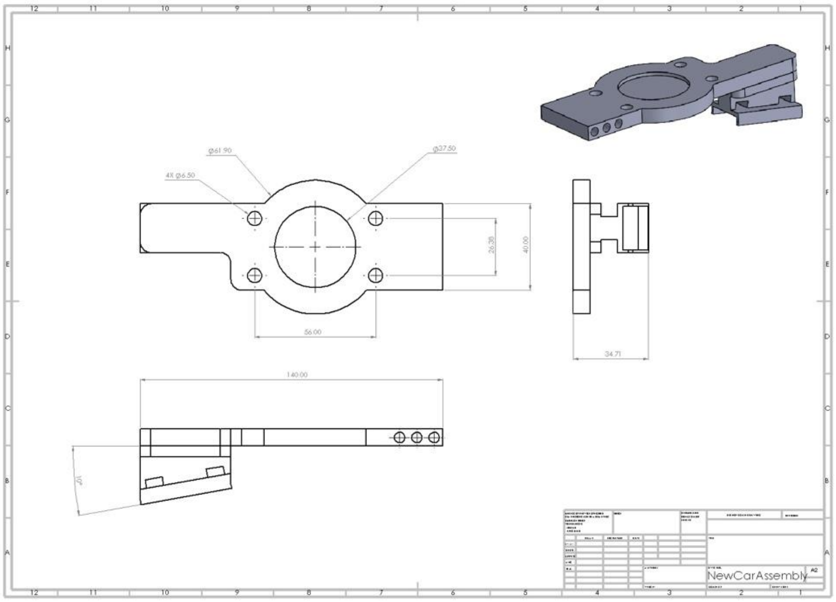


Figure 7: CAD Drawing of Chassis

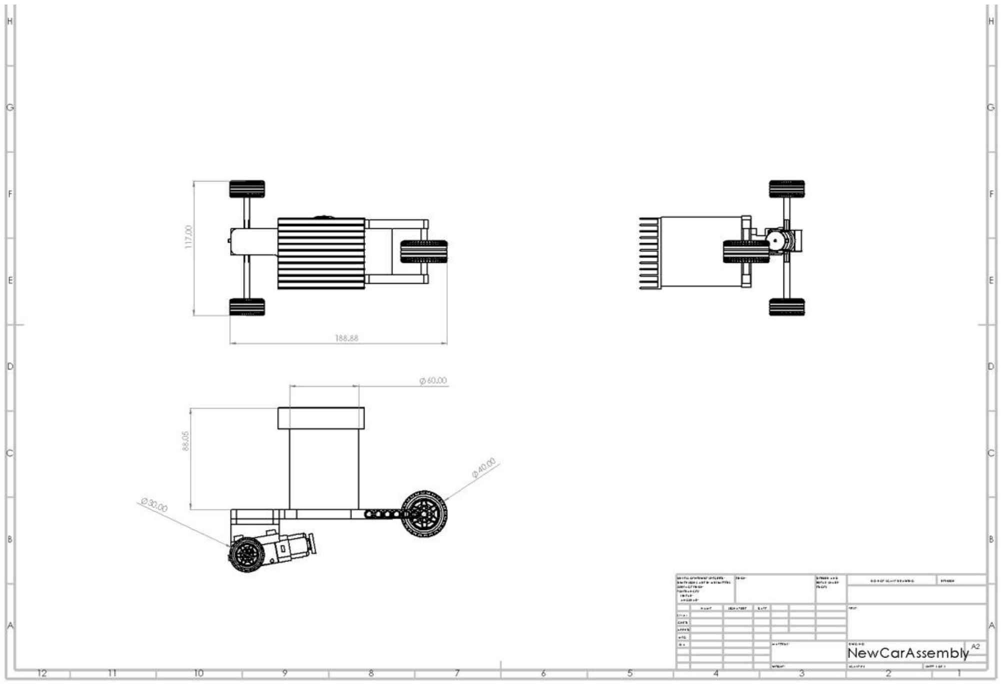


Figure 8: CAD Assembly Drawing

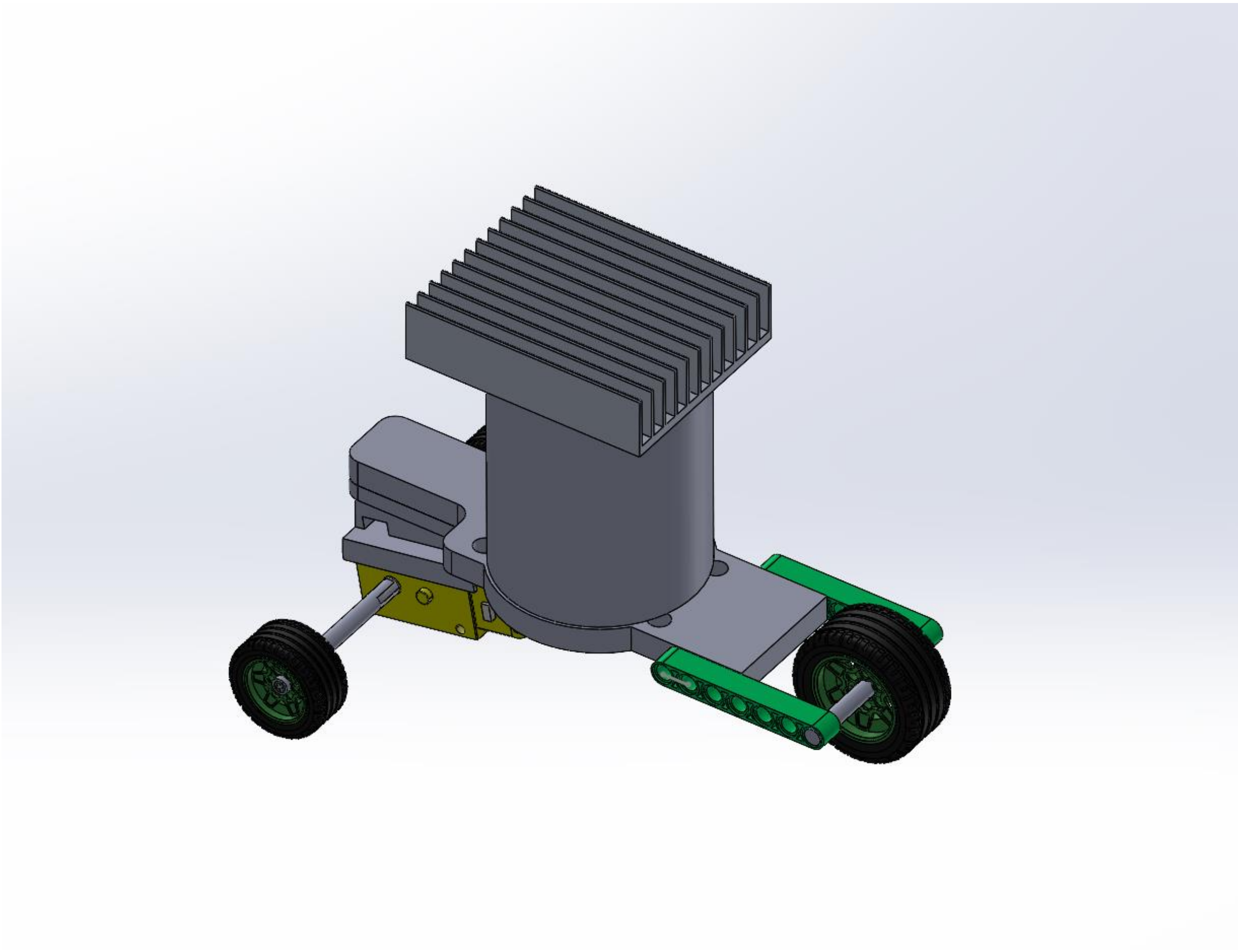


Figure 9: ISO View of CAD Assembly