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Motor Augment for Automotive Applications

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Abstract

Amidst concerns of climate change, pollution, and a rapid increase in oil prices, hybrid cars have become more favorable than traditional fuel cars. However, purchasing a new hybrid car is an expensive endeavor. The purpose of our project was to design a combination device that can be installed in an old gas car to give it the advantages of a hybrid. Companies such as Toyota and Tesla are using similar technical principles, but the essence of our approach is the development of a device compatible with older vehicles. This allows customers who previously owned the vehicle to enjoy the same performance improvements and fuel economy as an expensive hybrid at a lower price. The core idea of the design is regenerative braking, which recovers the kinetic energy of the kart and stores it in a battery that will power an electric motor. Additionally, gasoline engines expend more energy to accelerate than electric motors, which in turn pollutes the environment and wastes fuel, making the presence of the electric motor all the more valuable. Due to the limited materials in the group as well as space, we will verify the feasibility of our set-up on a go-kart prototype. Requisite steps include refurbishing the entire frame of the car to install the required components such as the engine, motor, and battery pack. We will also conduct a number of tests to verify the improved fuel economy, energy, performance, and torque of the hybrid model. However, due to site and time constraints, we cannot physically perform these experiments, and will instead resort to obtaining data from simulations.

Introduction

This paper will outline the theory that would support the basis of our project along with any learning points in regards to the mockup that we have worked on. Given administrative and policy restrictions, we could not gather results on our build so this paper will delve into simulated results as well as improvements that can be made to the prototype. With an annual economic output of over $1.1 trillion, it's no secret that the automotive industry and its 1.5 billion cars are an indispensable pillar of daily transportation. However, electric cars only account for 1.1% of all those vehicles (roughly 16.5 million). Moreover, the negative environmental impact of internal combustion engine-powered cars is very prominent in the contemporary world. The engine produces a multitude of harmful compounds, including nitrogen dioxide, carbon monoxide, hydrocarbons, benzene, and formaldehyde. Combustion cars also account for roughly 4.6 metric tons of carbon dioxide emissions per year, which is the equivalent of 41% of global emissions. All of this is detrimental to our environment's longevity, but a solution lies in electric cars, which yield significantly less emissions. However, since purchasing entirely new electric or hybrid vehicles is largely infeasible for a majority of the population, our goal is to artificially increase the share of hybrids (by adding tram attributes to previous oil vehicles, such as incorporating a combination of electric motors and regen braking) to simultaneously protect the planet and improve the user experience.

The automotive industry's current battery technology is lithium ion, whose energy density, discharge ability, and relatively low cost are starting to take on larger scale applications in vehicles. Admittedly, lithium ion batteries do not come without their own share of negative environmental impacts, particularly through a large quantity of emissions at their inception. However, enough usage, over time, will eventually create a less significant impact on the environment than standard combustion engines. While companies continue to work towards more environmentally friendly batteries, good battery management practices can ensure that these cells remain stable with lifespans that would exceed warranty times created by automotive companies, thereby outlasting their initial creation costs.

Electric motors, on the other hand, are a longstanding technology, and the complexity of their workings limit the scale of improvements that the industry can make at this time. Our mockup unit utilizes a BLDC (Brushless Direct Current) motor that calls for a diode rectifier in order to produce power from the back emf under braking conditions. It should be noted that the use of regen braking would create additional hurdles when accounting for freewheel situations since the electric motor would end up creating drag in high rpm conditions such as on the highway. Our primary objective is to incorporate this plug-in hybrid device into a variety of fuel vehicles. After the development is mature and the feasibility of the device is verified, different models of the device assembly will be developed according to different fuel vehicles. For the scope of our prototype, however, we will focus on building a go-kart from scratch, and subsequently attaching a battery pack, controller, and electric motor to control the axle via an additional sprocket and provide pseudo-hybrid functionality.

Methodology and Approach

This project was first initiated when we were assigned with the task of designing a product that could produce energy from an everyday task. Amidst a myriad of solar and hydropower enthusiasts, our group formed and identified a common interest in electric vehicles.

In the early stages of the project, we were having a difficult time identifying where the electric motor could be placed on the vehicle. At first, the obvious choice was to have in-wheel hub motors on the car to guarantee a universal fit to nearly any vehicle. But as we looked through the market, it was concluded that in-wheel motors will not be a lasting solution given the amount of stress that the wheel has to endure. Our two remaining approaches were to either integrate the motor next to the engine or apply a single motor along the rear axle/differential. Given our go-kart's design, the best solution was to apply the motor in-line to the gas engine's drivetrain. This application was inspired by the implementation method of the Toyota Prius, which uses an electric motor next to the engine that is engaged through an electromechanical clutch.

In the automotive industry, hybrids are classified as series, parallel, or series/parallel. With proper implementation, our build can implement a series solution where the electric motor engages at low speeds and the gas engine would engage at higher ground speeds. This ensures the highest efficiency under stop-and-go conditions while having the gas engine ready for highway conditions. With battery technology, the most apparent choice was in the usage of a lithium ion battery pack. Common in the market is the Lithium Nickel Manganese Cobalt (Li-NMC) chemistry which is known for its high power density. An alternative to it was Lithium

Iron Phosphate (LiFePO4) which fares better for cyclic lifespan and discharge rate but suffers in power density. Pending development is a Graphene Aluminum composition which is capable of a much greater power density, environmental benefit, discharge, and charge rate with its main drawback of lifespan hindrances preventing its commercialization at this time.

For previous generations of the Toyota Prius, their use of Nickel Metal Hydride (NiMH) batteries might seem counterintuitive given the traditional knowledge of their power density and flaws. But its primary advantage comes from its inherent safety from thermal runaway along with having well known properties that make it more predictable to build around and optimize for automotive applications. More recent models are implementing Lithium-ion packs with NiMH being gradually phased out. Given how more recent models are using this chemistry, our demo unit will use an Li-NMC pack. Thanks to various research articles available on Li-NMC packs, we can optimize the implementation of our battery pack to improve its cyclic life and safety while still delivering the performance needed to drive the motor. For starters, cyclic life can be directly improved by limiting the battery pack to the range of 10% and 90% State of Charge (SoC). Battery charging can implement the CC-CV (Constant Current-Constant Voltage) charging protocol where charging speed is balanced with lifespan preservation. The CC-CV charging protocol uses the battery's voltage level as an indicator to apply a constant current for bulk charging or constant voltage for low current trickle charging. Finally, temperature management such as pack cooling and heating would keep the battery pack in ideal temperature conditions to promote cyclic lifespan.

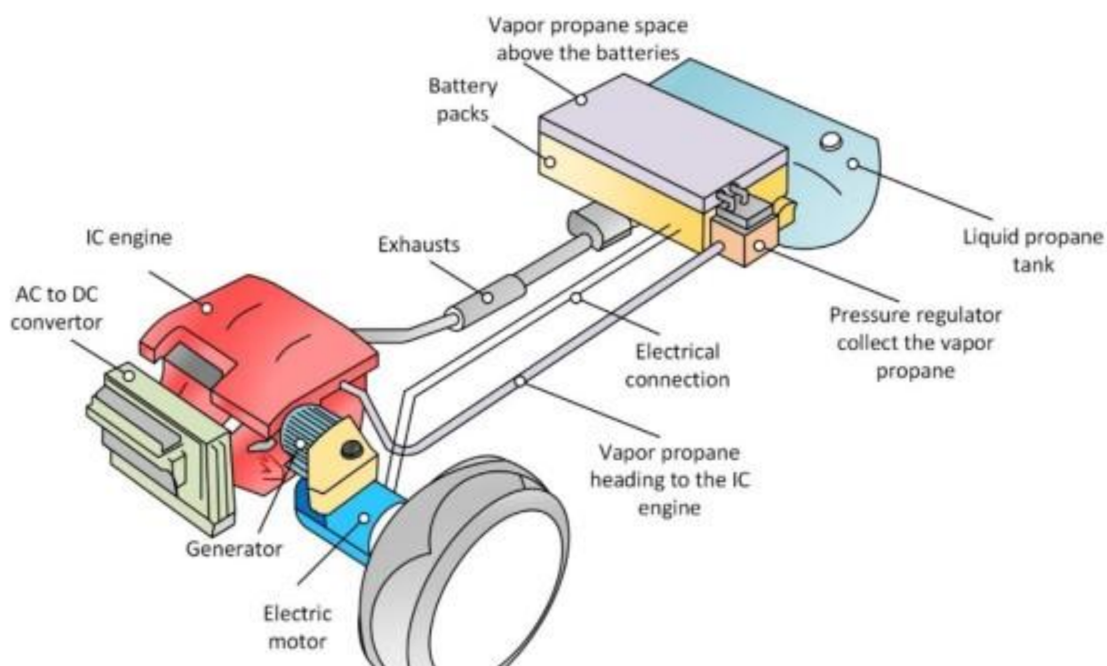

Figure 1: Initial Diagram Brainstorming [1]

From the beginning of this project, our group was extremely ambitious. We wanted to explore the lengths we could take this idea. We brainstormed different strategies for the build of a hybrid. At first, we wanted to convert a car to a hybrid, but we soon realized that this was far beyond the scope of our capabilities. Then, we thought of working on the RC scale, but this idea was also eventually ruled out as RC cars generally don't have combustion engines on them. We then settled on building a prototype at the go-kart scale. To collect data, we were going to take four different tests: a fuel economy test, an energy test, a performance test, and a torque test. Given the difficulties faced with completing a prototype within the provided timeline, this paper will present theoretical data obtained through simulations based on the projected build of the go-kart.

Design Details

We ordered a go-kart frame online and drove to New Hampshire to pick it up, and then cleaned the rust and spray painted it black for visual appeal. After getting the frame, we did some digital design work in order to plan our next steps for both gas and electric integration. First, we measured all the dimensions of the go-kart and drew a 1:1 frame in AutoCAD.

Figure 2a: Go-Kart Frame

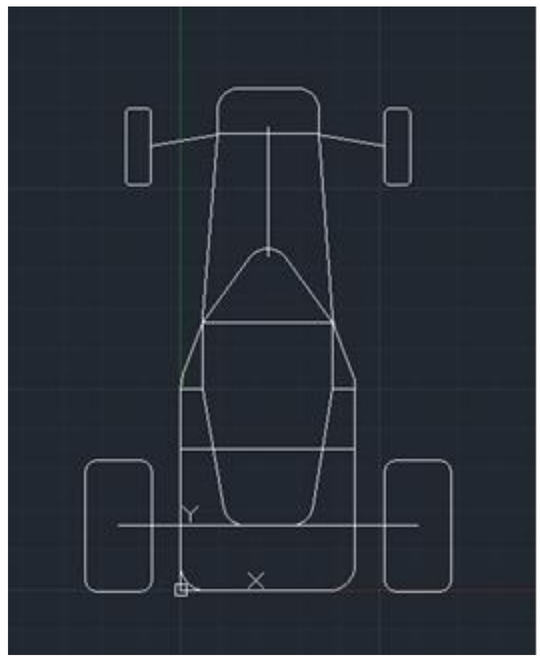

Figure 2b: Frame in AutoCAD

After this, we built separate parts of the car in SolidWorks, including the frame of the go-kart as well as large (rear) and small (front) wheels. We also added boxes representing the gas engine, electric-motor, controller, and battery pack. This helped us determine a relative position to mount those parts.

After getting a rough digital outline, we purchased an engine and mounted it. We were getting closer and closer to a drivable vehicle, but then we hit two roadblocks. First, we were confronted with the fact that we would not be allowed to use gasoline on campus without special approval from the head of engineering, so we planned a meeting to discuss that. Second, we realized that the rear axle would be unable to support our engine, as the sprocket was unmovable due to its rust. We hammered the sprocket to move it until it finally did - because it cracked. We took the rear axle to the university's facilities to see if we could remove the roll pins on either side in order to mount a new sprocket, but after many hours of work with heavy duty tools, we received the news that the axle was no good, and that it would need to be replaced. We ordered an axle, which did not arrive until two weeks later. During that period, we worked on smaller aspects of the car, such as the gas and brake pedals, and well as the seat. After we finally got the new axle, we mounted it, only to receive news that the project was being shut down. From there, our plan was to then mount the necessary electrical components and motor for visual demonstration purposes at a university expo. The final cost of the project was roughly $700, with the hybrid components (electric motor, battery pack, and controller) costing around $200.

Figure 3a: 3D Go-Kart Frame

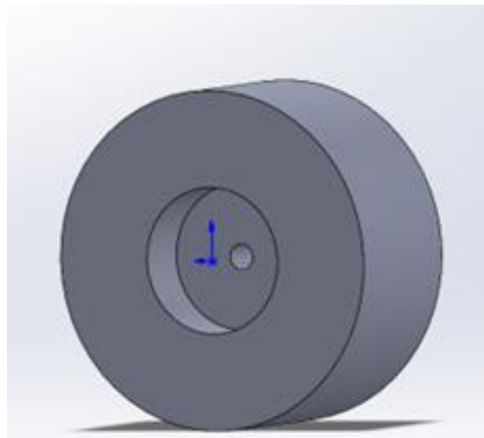

Figure 3b: 3D Big (Rear) Wheels

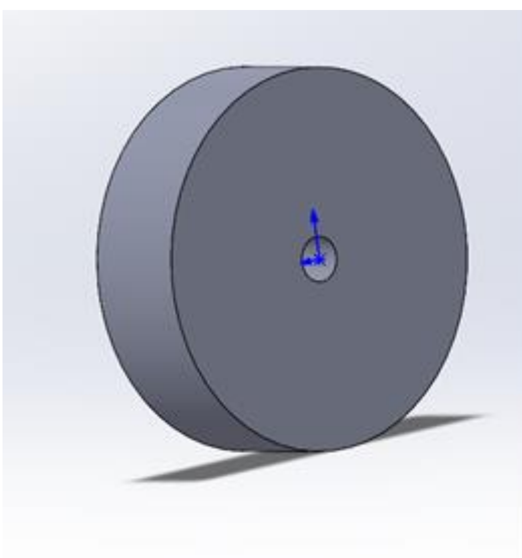

Figure 3c: 3D Small (Front) Wheels

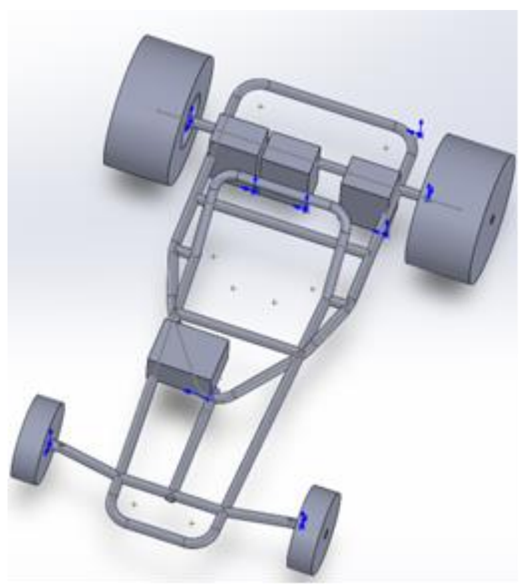

Figure 3d: 3D Go-Kart Assembly

Figure 4a: Go-Kart 3D Assembly - Full

Figure 4b: Go-Kart Assembly - Back

Results and Discussion

Since we were unable to complete the car and obtain permission from the university to test it both on and off campus due to policies concerning gasoline usage, we will be basing our discussion off research and simulated statistics that we would've obtained had we conducted the following hypothetical test procedures and results.

Test 1 - Fuel Economy

Our first test was concerning fuel economy. This test was used to calculate the efficiency of regenerative braking. We would have driven a given distance in the city using solely the gas engine, and then disengaged it and driven using solely the electric motor and the charge recuperated from regenerative braking. The percentage of resources recuperated was calculated by dividing the distance achieved from the charge collected through regenerative braking by the distance driven using gas. Data collected from research is illustrated in the following table and graph.

Initial Distance Driven (mi)	Distance from Regen (mi)	Resources Recuperated (%)
1	0.12	12.00
2	0.26	13.00
3	0.44	14.67
4	0.56	14.00
5	0.71	14.20

Figure 5a: Test 1 Data Table

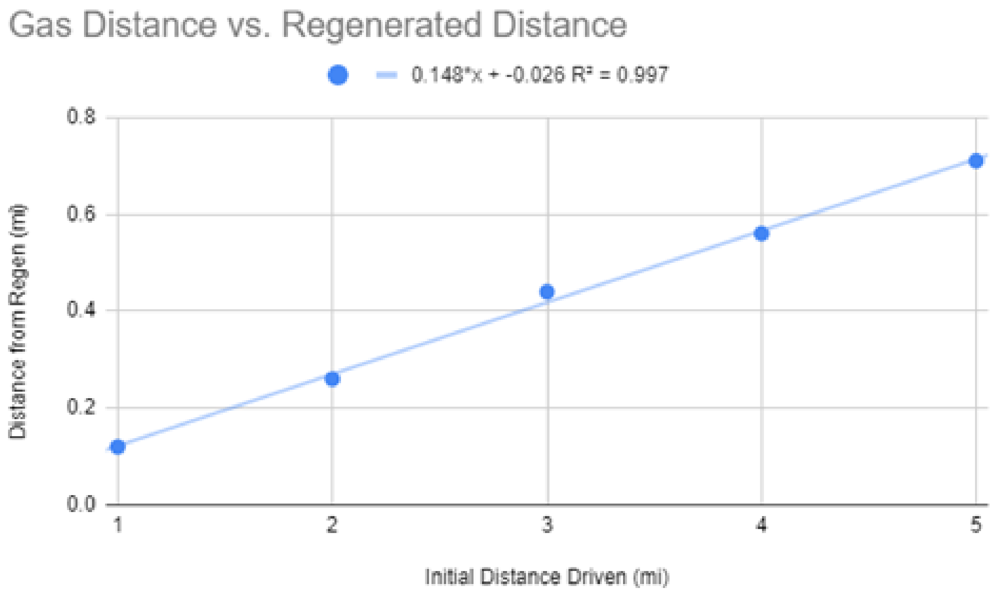

Figure 5b: Test 1 Graph

The slope of the best fit line for the data represents the rough average of the percentage of resources recuperated from regenerative braking, which turns out to be ~14.8% for most hybrid vehicles. It is important to note that normally, the prevalence of stop and go traffic in the city would contribute to higher usage of braking [2].

Test 2 - Energy

Our second test was concerning energy. This test was used to calculate and compare the efficiency of energy expenditure of an electric motor and a gas engine. We would've driven 400 meters (1 lap around a track) using solely the gas engine, and then the same distance using solely the electric motor. We would've then repeated this for three total trials, measuring the quantity of gas in the tank (based on mass of the vehicle) and voltage of the battery (using an ammeter) before and after each usage. For the engine, we can compute the energy expended by converting the change in mass to a quantity of gas used (based on the density of gasoline) and then multiply that by the standard mileage of our engine (which was roughly 40 mph). And for the battery, we can compute the energy expended by multiplying the change in voltage by the capacity (which is 13 Ah). The data collected from research is shown below [3].

Vehicle Mass Change (kg)	Gas Used (gal)	Energy Expended (MJ)
0.00178	0.00625	0.805
0.00175	0.00625	0.805
0.00175	0.00625	0.805

Figure 6a: Test 2 Data Table (Gas)

Voltage Before (V)	Voltage After (V)	Energy Expended (MJ)
53.0	47.0	0.281
53.0	47.0	0.281
53.0	47.1	0.276

Figure 6b: Test 2 Data Table (Electric)

It’s clear that much less electrical energy is expended for the electric motor to drive than combustion energy for the gas engine. This can be explained by the fact that the combustion of gasoline converts much less of its energy into mechanical motion than electricity; the average energy expended for gasoline is 0.805 MJ, while the average energy expended for electricity is 0.279 MJ [4].

Test 3 - Performance

Our third test was concerning performance. We would've accelerated the go-kart from 0-20 mph (and determined speed based on the rpm of the axle, which would be measured by the Arduino RedBoard) using solely the gas engine, and then done the same for solely the electric motor, recording the time needed for each. The table below shows the standard acceleration of gas and electric cars obtained from research [5] [6].

Gas Acceleration Time (s)	Gas Acceleration (mph/s)	Electric Acceleration Time (s)	Electric Acceleration (mph/s)
1.67	11.98	0.88	22.73
1.72	11.63	0.84	23.81
1.60	12.50	0.92	21.74

Figure 7: Test 3 Data Table

The electric motor has a noticeable advantage in acceleration because it is able to produce energy without the need for a transmission (which is needed for gasoline engines). The average acceleration of the gasoline engine is 12.04 mph/s, while the average acceleration of the electric motor is 22.76 mph/s. This translates to an ~89% advantage in performance. It is also worth mentioning that while electric vehicles have lower top speeds than gas cars, acceleration is a more important advantage for driving in the city.

Test 4 - Torque

Our last test was concerning torque. We would've borrowed a dyno from the University’s Electric Racing Team, which we would've then used to observe the go-kart while it was using either solely gas or electricity. Torque graphs of standard gas and electric vehicles collected from research are shown below [7].

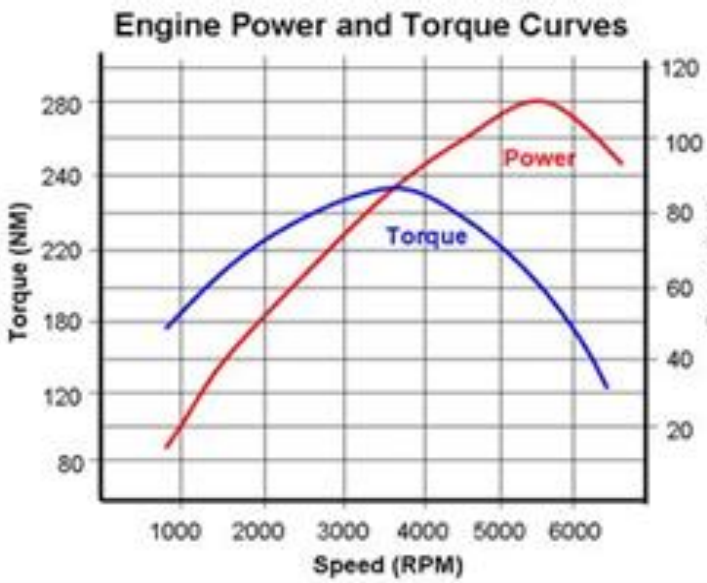

Figure 8a: Test 4 Data Table (Gas) [8]

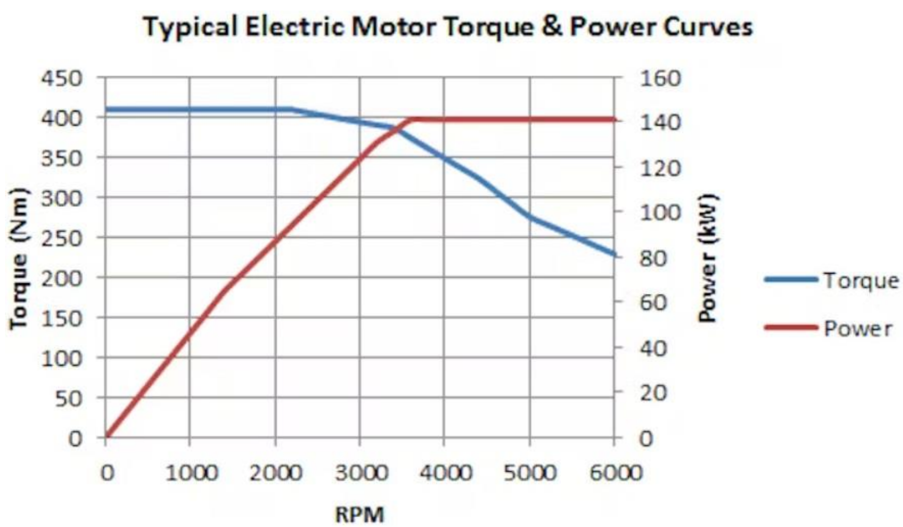

Figure 8b: Test 4 Data Table (Electric) [9]

Based on the graphs, it's clear that the electric motor is much better for acceleration; at low speeds such as 1000 RPM, the electric motor has 400 Nm of torque, while the gas engine only has around 187 Nm.

Conclusion

With a resource recovery rate of 14.8%, a mileage of roughly 40 mpg, and gas prices at roughly $3.60, our hybrid augmentation would theoretically be able to pay for itself by recuperating $200 worth of resources after driving roughly 15000 miles. With the average person driving around 13500 miles per year, this equates to a little more than a year of driving. The additional advantages of the electric motor in acceleration, torque, and energy conversion would also be both environmentally and user friendly as a bonus, especially in cities like Boston.

But in truth, our project isn’t completed, and we are still unsure of its potential. It’s truly a shame that we were forced to abandon this, but that’s just how things were meant to be. Looking back, we are so proud of how far we’ve come together. We are flattered by the academic encouragement and freedom that we as newfound college students have received in designing and building whatever we could dream of. Moreover, we are impressed by the myriad of knowledge and skills that each of us, coming from very different backgrounds, has had the privilege of contributing to this project.

Since the end of the first semester, we have had the opportunity to work on the go-kart outside of the bounds of the university, and have managed to achieve a driving prototype. Though the electric motor and regenerative braking aspects have not yet been incorporated, we are now one step closer to fulfilling our dream of a hybrid augmented system. Even if the final product isn’t perfect, we have all learned so much about engineering - both the people and the process - and our eyes have been opened to pursue even greater endeavors in the future.

References

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Appendix 1: Data Collection and Analysis [4]

```
//code to measure rpm for performance test
int sen = A0;
const float wid = 0.012;   //width of the fan blade
const float rad = 0.045;   //radius of the point of detection in the fc
const float pi = 3.1415;  //constant for pi
float t1;
float t2;
float vel;
float diff;
float tnet;
float rpm;

void setup()
{
  Serial.begin(9600);
  pinMode(sen,INPUT);
  Serial.print(" \n please start the motor at least 3 seconds prior.\n'
  delay(3000);
}

void loop()
{
  if(analogRead(sen)<950)
  {
    t1 = millis();
    delay(30);
  }
  if(analogRead(sen)>950)
  {
    t2 = millis();
    diff = (t2-t1);
    vel = wid/diff;            //rotation velocity
    tnet = (2*pi*rad)/vel;  //time = (2*pi*radius)/velocity.
    rpm = (60000)/tnet;     //convert to rpm
  }
Serial.print("\n The rpm is : ");
Serial.println( rpm );
}
```