FLORIDA INTERNATIONAL UNIVERSITY

EML 4905 Senior Design Project

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REQUIREMENT FOR THE DEGREE OF
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MECHANICAL ENGINEERING

SHELL ECO-MARATHON
100 % of Final Report

Bryand Acosta
Marco Betancourt
Fernando Pinheiro

Advisor: Professor Igor Tsukanov

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This B.S. thesis is written in partial fulfillment of the requirements in EML 4905. The contents represent the opinion of the authors and not the Department of Mechanical and Materials Engineering.

Ethics Statement and Signatures

The work submitted in this B.S. thesis is solely prepared by a team consisting of Marco Betancourt, Bryand Acosta, and Fernando Pinheiro and it is original. Excerpts from others' work have been clearly identified, their work acknowledged within the text and listed in the list of references. All of the engineering drawings, computer programs, formulations, design work, prototype development and testing reported in this document are also original and prepared by the same team of students.

Marco Betancourt	Bryand Acosta	Fernando Pinheiro
Team Leader	Team Member	Team Member

Dr. Igor Tsukanov
Faculty Advisor

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Abstract

The main objective of this project is to design a fuel-efficient car prototype moved by an internal combustion engine to participate in the 2013 Shell Eco Marathon in Houston, Texas during the dates of March 29th- April 1st. “Panther Killer” used Panther Rage G2 and Panther Rage cars as reference but a new car was build from scratch envisioning an efficient transition to the internal combustion category of the competition. Abiding by the extensive rules and regulations of the competition, our group modeled, manufactured and tested a vehicle with optimum aerodynamics, minimum weight and reasonable budget that fit the realistic guidelines of the project.

1 Introduction

1.1 Problem Statement

One of the main concerns of our generation is the gradual increase of the earth's temperature, in other words, the phenomenon called Global Warming. This constant elevation of the earth's thermometers could lead to catastrophic results in a matter of decades, such as the melting of the poles, disappearing of islands and extinction of races. The biggest catalyst to this phenomenon is the emission of greenhouse gases. Greenhouse gases, such as carbon dioxide and methane, are mainly generated due to the combustion of fossil fuels, one of them being oil that moves our cars. The accumulation of those gases in the layers of the atmosphere is called the greenhouse effect.

Keeping in mind the threats our environment is currently under, Shell created a few decades ago the Shell Eco-Marathon competition, challenging students to not only look for other alternatives of energy but also, to improve and optimize the ones that can be found today. Even though our government invests over $51 billion dollars per year in renewable energies[i], over 80% of the energy we use in the world today, still comes from fossil fuels against 9% from renewable sources. Therefore, keeping in mind oil will still be the main source of energy for our cars in the near future; the Shell Eco-Marathon has helped students to explore ways to improve mileage per gallon in such vehicles. [ii]

1.2 Motivation

The project was first introduced to the group by one of the team's members, Bryand Acosta. Bryand, who had contacted members that were part of Panther Rage G2 team in the previous year, saw a great opportunity in this project to keep the tradition at Florida International University (FIU) of participating and representing the school in this internationally recognized competition. Last year's team had nothing but great feedback to give to "Panther Killer", and after surpassing their own expectations in the competition, they highly recommended the experience for the present team.

Made up of members that had previously few or no "hands on" experience with the concepts learned throughout our engineering courses at FIU, our team was immediately attracted by the chance of building a car prototype. This project involves basic concepts of real sized cars such as design of a chassis, a body, steering and braking systems and most importantly putting it all to work with an engine. Combining these elements with the challenges of reducing weight, increasing aerodynamics and respecting the rules of the competition, this year's team saw in the Eco Shell Marathon the perfect components to fulfill the requirements of Senior Design Project.

Panther Killer has utilized concepts learned not only in the classroom but also in computer programs, such as Solid Works and CAD, which were essential in order to make some of the simulations of the car.

Last, the team that is representing FIU this time around, is looking forward to travel to a different state and network with students from different countries and exchanging ideas and different concepts that are utilized in the engineering world. The team sees the competition as a rewarding experience for all the months of hard work put into it.

1.3 Literature Survey

This survey has the purpose of letting the team members become informed on the theory behind the basic functionality and operation of the different components and systems that come together to make an automobile. Furthermore this survey will extend into assessing the technologies used by the top ranking competitors in the Shell Eco-Marathon over the years.

1.3.1 Regulation Requirements

Shell provides access to a comprehensive publication of all the rules and regulations of each year's competition, the team will have to constantly reference this book to make sure every design requirement is met before manufacturing can take place. A copy of this rulebook is not provided within the body of this document so as not to dilute its content, but is available in appendix A.

1.3.2 Competitor Assessment

To assess the competition, the team gathered the results of the Shell Eco-Marathon, Houston 2012, in the gasoline combustion fueled engine category, and took a further look into winning teams from Europe and East Asia. Unfortunately some teams do not publish their research on the Internet and because of this fact it was not possible to research some of the most important competitors

Evolution Supermileage team

EVO 4 vehicle

Figure 1 - Evo Supermileage

Results:

673km/L

Body:

Monocoque carbon fiber, with 3 wheels

Engine:

modified briggs &Stratton engine with custom overhead cams and valves, 47cc of displacement, 13.7:1 compression ratio, sequential electronic fuel injection with programmable ECU and electric starter.

Transmission:

Centrifugal clutch, single gear ratio 10:1, with replaceable gears to vary from 9:1 to 13:1

Vehicle Weight:

47kg

Cost:

50000$ Canadian dollars and 8000 hours of fabrication

Alerion Supermileage

Figure 2 - Alerion Supermileage

Results:

1347km/L

Body:

Monocoque carbon fiber, with 3 wheels

Vehicle Weight:

94lb

Project Infinity

Figure 3 - Project Infinity

Results:

1347km/L

Body:

Monocoque carbon fiber, with 3 wheels

Wheels:

Michelin 44-406

University of Science of Malaysia

Figure 4 - Univ of Malaysia

Body:

Aluminum frame on composite honeycomb sandwich for the floor pan

Wheels:

Custom made hubs for ceramic angular contact bearings, as replacement for OEM wheel hub

Results:

Could not finish race because the car could not travel up a steep slope for lack of a lower gear ratio

Eco Illini

Figure 5 - Eco Illini

Body:

Monocoque carbon fiber, with 3 wheels

Engine:

Saito 57cc 2 cylinder boxer engine for hobby aircraft, with custom throttle body for electronic fuel injection, with Megasquirt 3 ECU, and electric start

Transmission:

Single reduction transmission with a 451c wheel size sprocket

Team Green

Figure 6 - Team Green

Results:

6603 mpg

Body:

Monocoque carbon fiber, with 3 wheels

Engine:

34cc single cylinder engine customized with 2 sparkplugs, variable inlet valve timing and fuel injection with an engine management system provided by General Engine Management Systems Ltd

Transmission:

Centrifugal Clutch

Wheels:

20in modified BMX style bicycle wheels with Michelin low rolling resistance tires, and custom hubs.

Weight:

42kg

Ecolancers

Figure 7 - Ecolancers

Results:

318 mpg

Body:

Aluminum structure with sheet metal body and 3 wheels

Engine:

GXH Honda 49cc single cylinder engine with fuel delivery via carburetor

Transmission:

Extreme Duty Centrifugal Clutch coupled with a single gear 12:1 reduction as large as the wheel itself

Wheels:

Bicycle wheels with Michelin low rolling resistance tires.

Weight:

42kg

1.3.3 Background Theory

Engine Efficiency

Competition guidelines state that every internal combustion engine used to compete must use a four-stroke cycle to produce power.

In theory the internal combustion engine efficiency is limited to that of the Carnot-cycle

The efficiency for a Thermodynamically reversible Carnot cycle engine is given by the equation:

$$\eta = 1 - \frac{T_C}{T_H}$$

where: η is the efficiency

T_C is the absolute temperature in the cold heat reservoir

T_H is the absolute temperature in the hot heat reservoir

The Carnot Cycle theorem states that:

"An engine operating between two heat reservoirs can not be more efficient than a Carnot engine operating between these same reservoirs."[iii]

The temperature of the cold reservoir is given by the ambient temperature outside the engine, which should be between 15°C and 25°C during the month of April in Houston, Texas.[iv] On the other hand the maximum temperature that could be achieved would be limited by the metallurgic properties of the engine and this temperature is also referred to as the adiabatic flame temperature, which is itself a function of the products of combustion used. The adiabatic flame temperature is both difficult to quantify in practice and theoretically due to hysteresis in temperature sensors and due to the fact that incomplete combustion will change the molar ratio of products of combustion being produced.

Furthermore the engine of choice for this competition has to be a four stroke, which makes it an Otto cycle engine for which the efficiency equation is given by

$$\eta_{TH} = 1 - \frac{1}{r^{(\gamma-1)}}$$

where: r is the compression ratio

γ is the specific heat ratio

The compression ratio is specific to the engine design and higher values increase the engine efficiency, yet it is limited by the fact that higher ratios may cause the combustion in the cylinder to occur prematurely, this is a phenomenon called engine knock and it will adversely affect engine efficiency and life expectancy. Engine efficiency is in most part a function of this value since for air/fuel mixtures γ is usually taken to be 1.4, but it is important to note that this value rises with increasing temperature.[v] This equation gives the thermal efficiency of the engine, which is the heat energy it can actually extract from the products of combustion to transform into mechanical work.

Non the less the efficiencies that can be derived from the above equations far exceed the real world efficiency measured from a real world engine which initially has an inefficient combustion, and then has to overcome friction, aerodynamic drag of gases inside the engine, parasitic losses from accessories, alternators and pumps, poor valve timing causing vacuums during the intake stroke or pressure loss during compression and expansion, all this while loosing heat through the cylinder walls. This real world efficiency is termed the brake specific fuel consumption and is the ratio between the fuel consumed and power produced, and it is measured in $\frac{grams}{kW \times h}$

$$BSFC = \frac{r}{\mathrm{T}\omega}$$

Where: r is the rate of fuel consumed in g/s

T is the torque produced by the engine in Newton•Meters

ω is the engine speed in radians/second

Note that by knowing the energy density of the fuel in terms of its mass it is possible to calculate how much energy is actually stored in that fuel in order to get a number in terms of strict energy efficiency.

Vehicle Efficiency

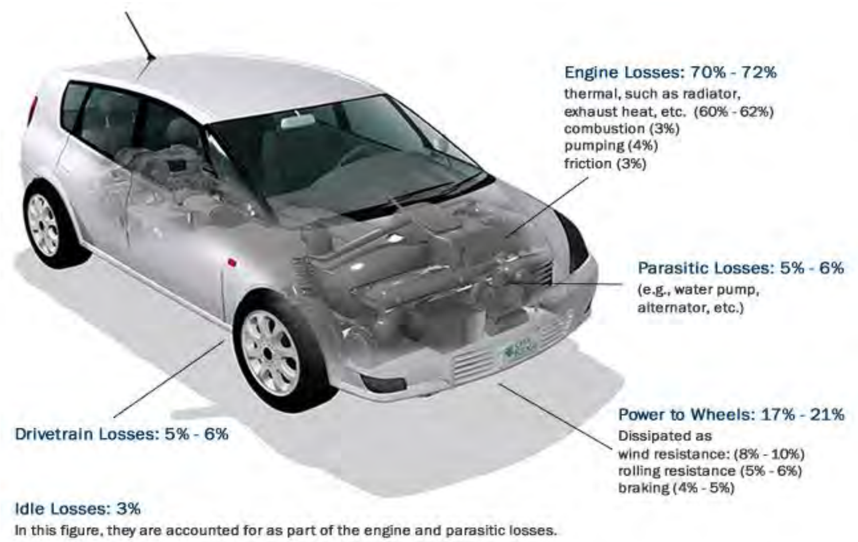


Figure 8 – Distribution of energy in a vehicle

The energy that the engine can convert to mechanical work is limited by its thermal efficiency and the mechanical losses inside the engine, but not all the energy produced by the engine is available to energize the transmission, there are also parasitic losses that arise from using energy from the engine to pump fluids throughout the vehicle and create electricity in order to power the car's electrical system.

The powertrain efficiency is given by the product of the efficiencies of all mechanical components starting at the engine and ending at the wheels axle. For our design this includes the engine's thermodynamic efficiency, its mechanical efficiency, and that of the transmission plus the parasitic losses. It can also be calculated as the ratio between the powertrain output, and the power associated with the fuel consumption rate.

$$\eta_{PT} = \eta_{TH}\eta_{M}\eta_{T} = \frac{P}{P_{Fuel}}$$

After all this losses the power that is available at the wheels also has to overcome aerodynamic drag, rolling resistance forces, and the weight of the vehicle unless the surface is perfectly flat, together this make up the forces required for the vehicle to maintain a given speed, any power available at the wheels, in excess of this will be available for acceleration

Steering System

Defining the steering of our car was a challenging task and one that required plenty of time and attention since this component is so crucial to the performance of any fuel-efficient vehicle. The steering is a key component for a few different reasons. First, it places the wheels in a manner that will reduce the rolling resistance force of the overall car. Also, this is the most important component of driver interface and must allow the pilot to perform the task in an efficient manner and most importantly, having a reliable steering will play a major role in the drivers safety.

The first question that our group asked was weather we would opt for front wheel or back wheel steering. Since our engine is directly connected to the back tire, which is heavier and thicker for being an original scooter slick tire, we immediately discarded the option of rear steering. Once we had decided the steering would go on the front two wheels, we still had to analyze several different options available in the marker in order to find the most cost efficient one.

Immediately after starting our literature survey, we considered having a hydraulic breaking system (mainly because it is the one recommended by the organizers of the competition). The hydraulic was certainly a reliable one, however, our team did not find this option cost/weight efficient since it would require an extra system to pump the liquid necessary to make the calipers function. Therefore, we withdrew this option as well. The following steering option that caught our attention was steering by wire. This is by far the most weight efficient technique since steering mechanism is replaced by electronic control. At first, this sounded like a great option since removing all the usual components of a mechanical system would reduce the vehicle's weight. Unfortunately, this method also had its downsides. First the amount of electricity to be provided by a battery to make the system work would require a battery that physically did not fit our car. Second, previous groups that performed tests with this kind of system proved a slow response to the driver's commands and it was unreliable. Since we did not have the resources to buy the system and test it ourselves, we trusted previous competitors assessments and opted for something more efficient. Our last frustrated attempt was to make a custom made system similar to last years, which resembled a pulley system to turn the spindles. Since our teams concept design envisions to provide steering in only one hand, rather than both, this option was forgotten.

Finally, our group opted for a mechanical system. We evaluated different designs that were inspired in go-karts. The problem we encountered in this case was the availability of products that could be purchased online to match wheels. Most specifically, the diameter of the spindle axles were too thick to fit in any bicycle wheels that we could purchase. We had the option of manufacturing our own parts but that would require time and some resources that were not easily available to us. Therefore, we finally found something that would be perfect to our design; we decided to go with a steering system extremely similar to recumbent bikes and tadpole trikes. All the details about the selected steering will be explained on the proposed design section of the report.

Wheels

Wheel selection to our car came almost simultaneously with the steering system since we needed to find a hub that would comply with the diameter of the spindle axle. As briefly mentioned above, our team spent countless hours looking for the perfect combination of wheels and bearings to our car. In order to find that, the following parameters were taken into account:

- The wheel must have optimal aerodynamics to minimize energy loss
- It had to fit our Michelin ultra low resistance tires (20'' x 1.75'')
- Made of lightweight material
- Strong enough to sustain loads and keep the tires in the correct place

First we had to consider the option of having wheels with spokes against disk wheels. Unfortunately, due to the limited resources available to our team, manufacturing our own disk wheels had to be taken out of question, so we agreed on purchasing a pair of wheels already available in the market. It is important to remember that the back tire wheel was part of a "package" that was purchased with the engine and therefore, those decisions would only affect the front two. The previous two teams at FIU had used bicycle wheels, which are a viable option for the job especially cost-wise. Our team could not proceed with the same choice since the diameter of the axle of bicycle wheels was extremely small for our steering ideas. It was possible to get those custom made; however the price and the difficulty of incorporating a braking system to it forced our team to move on to a different option. Finally, we found the option of recumbent bikes and tadpole trikes, which use a wheel with the specifications, that we needed and meets all the criteria described in the bullet points above.

Another important decision relating to the wheels used in the car were the wheel bearings. Even though the drag produced by those is relatively small when compared to the ones produced by the tires, it helps to select the correct bearings in order to optimize your vehicle's result. Since the vehicle will run at low speed and will yield a relatively low amount of loads, ball bearings seem to be the most viable option due to smaller frictional moment. Also, using ceramic bearings rather than steel would be beneficial since it reduces the overall weight and friction.

Improving Vehicle Efficiency

Since the thermodynamic efficiency is dictated by the engines compression ratio it is ideal to have higher values of such, but for any given fuel there exists a limit to which this compression can be achieved without self-igniting the air/fuel mix prematurely, which is known as engine knock, different types and grades of fuel have distinct anti-knock characteristics.

It is important to also note that internal combustion engines are most efficient at a certain operational speed that is particular to each engine, with small engines having particularly high values for such ranging around 5000RPM to 7000RPM. Furthermore, the relationship between the engine's operating RPM and the power/torque output is not linear, and there exists a point where the engine operates at maximum efficiency.

Keeping the engine operating at this speed thus provides better power output characteristics.

Being able to control how much fuel is fed to the engine for each combustion cycle will directly contribute to fuel economy by being able to provide the exact amount of fuel to keep combustion occurring at the proper stoichiometric ratio or in a lean-burn regime where there is a slight excess of air over which is required to maintain stoichiometry. This fine degree of control can be achieved by implementing fuel injection controlled by an onboard computer for the engine named an electronic control unit, or ECU, that makes decisions based on its programming and input from different sensors that relay information about the engine timing, and the oxygen content of the intake and exhaust.

Further efficiency can be gained by the use of bearings that produce less friction within the engine and in the hubs of free rolling wheels. Reducing or eliminating the electrical and fluid pumping loads on the engine can further cut parasitic losses. Reducing the mass of the vehicle offers a great advantage not only because it lowers the kinetic energy of the vehicle at any given speed and it offers an especially significant advantage when driving on an incline. Minimizing the effects of wind resistance, using low rolling resistance tires and avoiding drag due to the vehicle’s braking systems, can further reduce the drag forces acting against the vehicle’s motion.

Finally it is crucial to understand that it is the driver and the driving style implemented that ultimately define the fuel economy that the vehicle will actually achieve, and it is important to train the driver in the implementation of highly efficient driving methods. The most common method implemented in the competition is the drive-and-glide method where the driver accelerates the car to 20MPH, he then shuts off the engine, and allows the car to coast down to a speed of 10MPH, at which point the engine is restarted and accelerated again, this is all keeping in mind that the average velocity during the competition must remain above 15MPH.

1.4 Global Learning

This project would not have been possible without the team's effort to engineer solutions (or procure them) based on concepts, ideas, and applications that we were not familiar with when we chose to begin this endeavor; our technical knowledge about vehicle systems was very limited, as well as our experience in manufacturing and fabrication.

During the project conception our ideas had to undergo constant revision based on newly acquired knowledge, and this trend continued throughout manufacturing as we noticed that some of our ideas could interfere with others. Looking for ideas in the world around us, and thanks to the Internet, we were able to expedite this process and arrive to sound designs.

It was a very interesting exercise to learn about new parts, tools, and techniques we were not familiar with. Sometimes we can understand that we need something in order to develop a function, but closer inspection reveals that those "specialized" parts, and tools actually have a name, and you can find them somewhere probably for less expense that it would have taken the team to develop it. This was very important because we made it a point to try to build the vehicle from as many standardized parts as we could possibly find.

This project taught us that the devil is in the details in a project of this scale. Since several systems had to come together and work in unison, they first must also work perfectly by themselves, and accomplishing this is not always as straightforward as once imagined by the engineer, the devil truly is in the details.

Becoming acquainted with existing applications was also a godsend, especially when we became familiar with the concept of recumbent tricycles, since this helped the team develop the steering system in a much more effective way that we would have been able to engineer otherwise, based on the temporal constraints imposed.

Learning about engines outside of the textbook was truly challenging, specifically with a Chinese scooter engine like the one we had, and the way they are supposed to be wired which seems to be an internet-mystery of its own, since there barely are any diagrams to accompany them; adding a fuel injection system just kept adding to the complexity

Designing the body was a daunting task on its own, trying to figure out what its dimensions had to be without having finished versions of the components in its interior was nearly impossible without risking having clearances ending up too low, specially since downsizing was always a goal in the design process, even if we had full understanding of what the vehicle aerodynamics should be like.

Furthermore choosing and implementing the ideal manufacturing methods to keep costs low while maximizing material properties and appearance appeal meant we had to become acquainted with advanced composite manufacturing techniques, and choose the ideal materials that would facilitate this process.

This project has achieved the goal of granting our team a global learning experience, that made us implement many of the skills we have been exposed to as engineering students, while forcing us to go beyond the classroom's scope and into real life applications, which not only include engineering development, and part sourcing, but also extend to financing, time management, and personal interactions with suppliers, superiors, and team members, to name a few.

2. Design Alternatives

2.1 Overview of conceptual design

Weight:

The target weight of our vehicle is less than 100 lbs, with a 150lb being a worst possible case scenario

Body:

The body and frame should combine to make a sturdy and structurally safe aerodynamic shell. Its construction must consist of a mixture of lightweight materials that can be shaped into complex parts: plastic sheets, aluminum, carbon, and glass-reinforced plastics are being considered. Rigidity and strength would be achieved by using honeycomb cores or tubular frame structures.

Engine:

Must be a small and fuel efficient engine under 50cc

Fuel Delivery System:

Electronic fuel injection is preferred over carburetion to achieve stoichiometric combustion, since Maximum flame temperature occurs at the 14.7:1 air/fuel mixture combustion ratio[vi]

Transmission:

Must allow for the engine to be started under unloaded conditions even if the vehicle is in movement, and should at least provide one reduction gear to have the engine operating in the most efficient range of its power band while making the vehicle drivable in the speed range of 0-20 MPH

Starter

The starter must allow for a single person inside the cabin to turn the engine on without taking their hands of the steering wheel.

Wheels and tires:

Michelin designs and manufactures ultra low rolling resistance tires specifically for this competition, these are meant to fit over standard bicycle wheels, outfitting such wheel with ultra low friction bearings and making this whole assembly as light as possible would be ideal for the design.

2.2 Proposed Design Alternatives

2.2.1 Engine

In order to select the engine it is necessary to first examine the power requirements to move our vehicle at the speed required by the competition. For the preliminary analysis there will be several assumptions made, and these will be clearly stated. The power requirements of our vehicle for any given speed are given by the product of the sum of the forces acting against our vehicle's motion and the vehicle's velocity and acceleration; therefore the power calculations were made using the following parameters:

Table 1 - List of parameters

FrontalAreaOfCar	0.42
PercentGrade	2
VehicleMass	136.36
Drivetrain efficiency	0.8
Tire rolling resistance coefficient	0.0025
Brake and Steering Resistance	0.003
DragCoefficient	0.15
AirDensity	1.225
Wheel Radius	0.254

It was assumed that the total mass for the car, and a driver with an average mass of 150lbs, will be a maximum of approximately 300 lbs, or its equivalent value of 136.6 kg. C_{RR} is found from the Michelin specifications for the ultra low resistance tire that will be used in the car. The density of 1.225 for air is using standard temperature and pressure (STP) guidelines. C_D, the coefficient of drag, was selected as 0.15 considering a worst-case scenario of an aerodynamic body design, based on previous competitors with similar body shapes that have tested their cars and calculated this value. The area used of 0.42 m^2 is an approximation of the frontal area of the car, according to preliminary solid works models of possible designs of our car. Furthermore, R is the outer radius of the Michelin tire that will be used in the car. Also, an assumed drivetrain efficiency of 80%, was again chosen assuming a relatively inefficient transmission for the vehicle to err on the high range of our numbers, and prevent an underpowered vehicle. The brake and steering resistance coefficient was estimated after doing extensive research on previous competitors cars.

The next step in the analysis is to calculate the forces acting on the prototype according to the speed of the same. Keeping in mind the rules of the competition that require an average speed of 15 mph, increments of 2 mph were used to calculate the three component of total force:

$$
\begin{gathered}
F_{air} = 0.5 \times C_D \times A \times \rho \times V^2 \\
F_{RR} = m \times g \times (C_{RR} + C_{BSR}) \\
F_{incline} = m \times g \times P_G \\
F_{drag} = \sum F
\end{gathered}
$$

As shown above, the force (F_{drag}) that acts against the vehicle can be divided in several different components. First F_{RR}, or force due to rolling resistance, which is represented as the sum in between tire, steering and brake resistances. Also, another force that acts against the car at all times is the force due to air friction, F_{air}. Last, we have $F_{incline}$ which is due to the weight of the car parallel to the the road's incline, since there is no information about the topography of the track, a small assumption must be made considering that the competition is takingn place in a track built in the urban setting of a Downtown Houston park.

After calculating all the forces that act against the car, it is possible to begin the calculations for the power required to move the vehicle. The power required to maintain the car at this constant speed was found using the following formula:

$$P_{const} = \frac{F_{drag} \times V}{e} \text{ (W)}$$

Once the power to keep the car moving at a constant speed has been calculated both in Watts and horsepower (diving the above formula by a conversion factor), It is possible to continue with the calculations of the kinetic energy and power required to accelerate the vehicle. After researching average acceleration times for the same engine in similarly sized vehicles and learning that it usually takes it 8s to get from zero to 20MPH, under full throttle, we decided to use this time to do the following calculations:

$$E = \frac{(\frac{1}{2} m V^2)}{e} \text{ (J)}$$

$$P_{accel} = \frac{E}{t} \text{ (W)}$$

Finally, we can use these values to calculate the total power required by the car in Watts and in Horsepower. With this information, we are able to select a properly sized engine that we will try to make as efficient as possible to fit the needs of the competition.

Table 2 - Energy and power calculations

V (mph)	**2**	**4**	**6**	**8**	**10**	**12**	**14**	**16**	**18**	**20**	**22**
F_{drag} (N)	34.11	34.21	34.3	34.58	34.85	35.19	35.59	36.06	36.5	37.17	37.81
P_{const} (W)	38	76	115	155	195	236	278	322	368	415	465
P_{const} (hp)	0.1	0.1	0.2	0.2	0.3	0.3	0.4	0.4	0.5	0.6	0.6
E(J)	68	272	613	1090	1702	2452	3337	4358	5516	6810	8240
P_{accel} (W)	97	195	292	389	486	584	681	778	876	973	1070
P_{accel} (hp)	0.13	0.26	0.39	0.52	0.65	0.78	0.91	1.04	1.17	1.30	1.44
Total Power Required	135	271	407	544	681	820	959	1101	1243	1388	1535
Total Required	0.18	0.36	0.55	0.73	0.91	1.10	1.29	1.48	1.67	1.86	2.06

Using the numbers above, it is possible to plot graphs of the numbers found to better understand the relationships between the velocity of the car and the demand for power and energy.

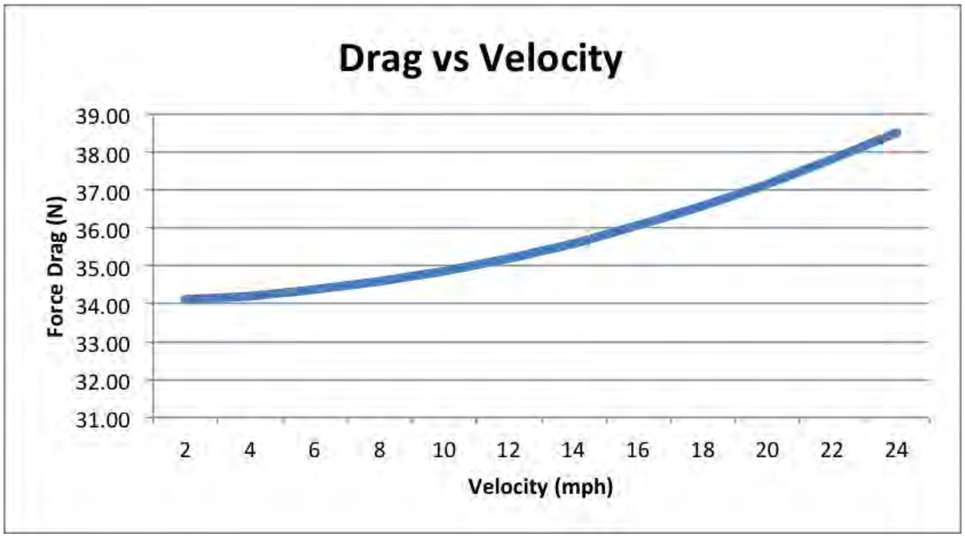


Figure 9 - Drag vs Velocity

From the graph shown above, it is possible to analyze the main sources of resistance towards the movement of the car. From Figure (3), the drag force will increase with an increase in velocity. However, it is important to note that this increase is relatively small. An increase of 4 N in between the velocities of 2 mph to 24 mph makes it clear that the main source of force resisting vehicular movement does not come from aerodynamic drag. Furthermore, the components of F_{drag}, which are show in Appendix A, show that $F_{incline}$ is responsible for about 70% of the total force. Since we can not control the tracks topography, we can say that the total weight of the car is the major component causing inefficiency on a vehicle that is not traveling on a level surface.

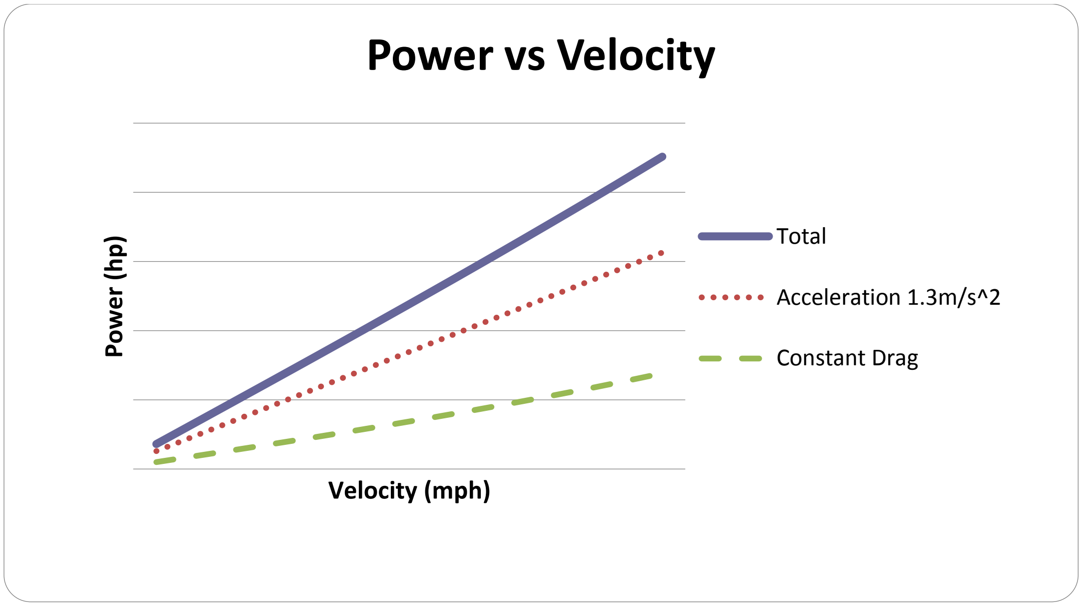


Figure 10 - Power vs Velocity

The most conclusive information from the calculations can be taken from Figure (4) and (5), where we see that the engine must be able to produce about 1,400 W, or about 1.9 horsepower.[2]

Table 3 - Engine selection

Engine model	Size	CR	Power Output	Torque	Fuel Consumption	Price
GY6-139QMB short	49cc	10.5:1	2.82HP (2.1kW) @6500Rpm	2.3lb-ft (3.1N.m) @5500rpm	9.65oz/HP.h (367g/Kw.h) 1.04 L/hr @ 6500 rpm	$359.99
Honda GX25	25cc	8.0:1	1HP (0.72kW) @7000rpm	0.74lb-ft (1.0Nm) @5000rpm	0.54 L/hr - 7000 rpm	$225.00
Honda GX35	35.8cc	8.0:1	1.3HP (1.0kW) @7000rpm	1.3lb-ft (1.6Nm) @7000rpm	0.71 L/hr - 7000 rpm	$245.00
Honda GXH50	49.4cc	8.0:1	2.1HP(1.6kW) @7000rpm	2.0lb-ft(2.7Nm) @5000rpm	0.91 L/hr - 7000 rpm	$325.00

The engines under consideration are all four-stroke engines below 50cc, and there are two main families of engines being considered:

The GY6 style engines are popular in the small scooter, ATV and Go-kart markets. There are various performance upgrade parts and documented modifications for this type of engines available, including fuel injection conversions. This engine has a higher compression ratio, which is something desired for higher thermodynamic efficiency. The power rating and maximum torque are also the highest in the list with almost a 33% advantage over the comparable Honda GXH50. On the downside; its fuel consumption is about 10% higher. This engine is sold ready for a drum brake setup, and comes equipped with an electric starter, and a continuously variable transmission (CVT).

The Honda engines are made in different sizes from 25cc to 50cc, and include a recoil starter, and a centrifugal clutch. For the competition's purposes this starter would have to be changed to an electric type in order to make it possible for the driver to turn the engine on and off from the cockpit while the vehicle is in motion. On the other hand the centrifugal clutch might come in useful for the development of a discrete reduction gearing system with automatic engagement. Nonetheless the amount of support material and documented modifications for this type of engines is also scarce, and the nonexistence of an aftermarket part market means that tuning and performance part upgrades would require more development and custom manufacturing.

Taking these factors into account and the expected power requirements of our vehicle, the team has decided to opt for the GY6 engine.

Figure 11 - Engine Top View

Figure 12 - Engine side view

- Accommodates 10 inch wheel
- Set up for drum brake

The engine was procured off a new scooter along with the stock wiring harness so as to minimize any electrical issues that the team might encounter during manufacturing, a stand was then built in order to hoist the engine in a fashion similar to its final operational condition, so that it can be outfitted with all the peripherals and prepared for testing. The pictures below show the actual state of the engine, the missing parts should arrive in the next couple of days and it will be prepared to run by the first weekend of February. The team is currently searching for a dynamometer on which to properly break-in and test our engine, and it is not intended for it to be run for extended periods of time until this is possible because research shows that a proper break has a positive effect on an engines performance.

Figure 13 - Engine on Stand

2.2.2 Clutch and Transmission

The GY6 engine comes with a proprietary centrifugal clutch and a continuously variable transmission, or CVT. This transmission consists of a pulley on the engine shaft, and another on the output shaft with a belt transmitting power between them. The way different gear ratios are achieved is by having the pulleys be made of independent conical halves (sheaves) that can move relative to each other increasing or decreasing the gap between them so that the belt sits at different pitch circles, the ratio between the two pitch circles would give us the gear ratio for that specific configuration, to obtain higher understanding of the device is an exploded view in the diagram below:

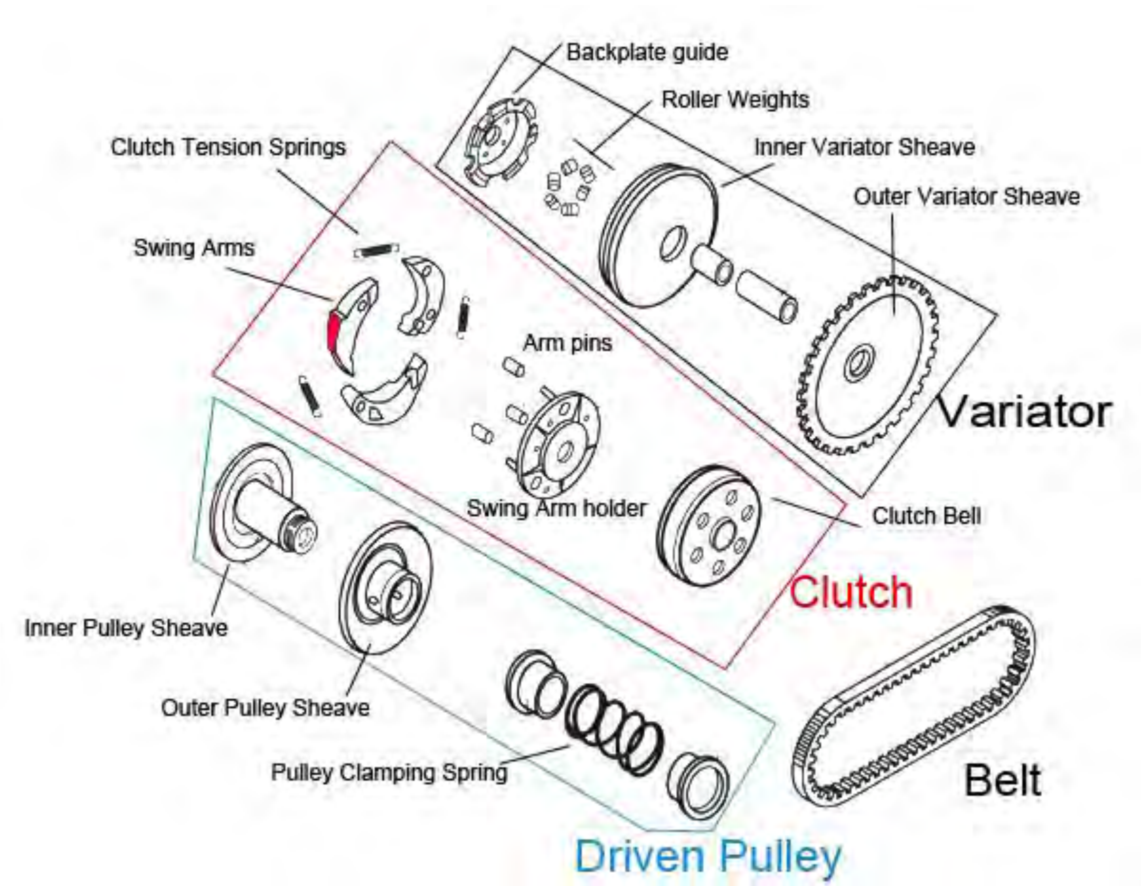


Figure 14 - Parts Breakdown

The process to arrive to those two pitch circles is governed by centrifugal, spring, and frictional forces. Power from the engine is originally transmitted to the variator, from a splined engine output shaft, as the assembly rotates the massed rollers start pushing outward, and against ramp-like guides in the variator's back-plate, pushing these two apart and reducing the gap between the two halves of the variator. As this happens the belt is driven outward in the variator while being driven inward in the output pulley, a motion that is opposed by the clamping spring.

Changing the weight of the rollers, and the stiffness of the clamping spring can control the rate at which the changes occur. This is unfortunately something that we cannot model mathematically unless we know several dimensions, and material properties about the transmission that are currently not available. Most of the data that will help us optimize this transmission will come from obtaining direct measurements through experimentation and what is referred to as tuning in the racing world.

The final drive ratio is the product of this reduction and two more that occur inside a gearbox after the CVT, the stock gear ratios for these are in the table below and the overall gear ratio describes the overall range:

Table 3 – Transmission gearing range

CVT Drive Ratio	0.8-2.0
First Gear Box Reduction	3.4
Second Gear Box Reduction	3.25
Overall Gear Ratio	8.84-26.1

The centrifugal clutch consists of two main parts; the clutch swing arm assembly, which rotates with the driven pulley, as the angular speed increases the arms swing outward due to the centrifugal force and ultimately engage with the clutch bell. The clutch bell being linked to the CVTs output shaft delivers the power to the gearbox and after the compound reduction; it delivers it to the wheel. This clutch is extremely important and needs to be tuned to achieve the following goals:

1. The clutch must be disengaged when the engine is idling, to comply with the competitions guidelines
2. The clutch must engage quickly as the engine is throttled and must disengage instantly when the engine is turned off. These two things are extremely important for transmission efficiency and to enable the vehicle to coast freely without being

subjected to braking forces due to compression in the engine piston when the engine is off.

To achieve this goal it is necessary to try different clutch springs in order to find the appropriate stiffness for the ones that will satisfy the design.

Unfortunately while a CVT offers very simple operation with virtually no driver interaction, it is important to note that these transmissions can be very inefficient, with values as low as 75%, mainly due to belt slippage, other sources that contribute to this inefficiencies are friction at surface contacts of bushings and bearings, which the team will attempt to reduce once the engine is physically dissected, and the parts measured, in order to assess if suitable replacements can be found

2.2.3 Fuel Delivery System

The engines above come carbureted and the team is considering having a fuel-injected design that would be satisfied by implementing small engine fuel injection and ECU kits sold by Ecotrons or MBE Motorsports.

Figure 15 - Fuel Injection Kit

The kits sold by both companies come equipped with an electric fuel pump to pressurize the fuel before it reaches the injector, but using this pump goes against the rules and regulations of the competition and a pre-pressurized fuel delivery system must be implemented instead.

The guidelines stipulate that the maximum pressure this system can have is 5bar or 72.5psi, furthermore the pressurized air must be stored in a clear container, and be filled through a Schrader valve, the system must include safety valves, shutoff valves, regulator, and gages, and everything must be easily drained, and removed from the vehicle for inspection purposes.

The vehicle's system will use a regular soda bottle outfitted with a Schrader valve to accumulate air at up to 70psi, a safety relief valve will be set to release any excess pressure, and a shutoff valve will be placed inline, as per competition guidelines. This pressure will then be reduced to 36psi with a regulator, to satisfy the operational pressure requirements of the injector, and will then be routed to the competition-sanctioned fuel tank. The pressurized fuel then travels through a line equipped with a shutoff valve, and fuel-filter, before reaching the injector. A diagram of this system must be supplied to Shell for the competition and can be seen below.

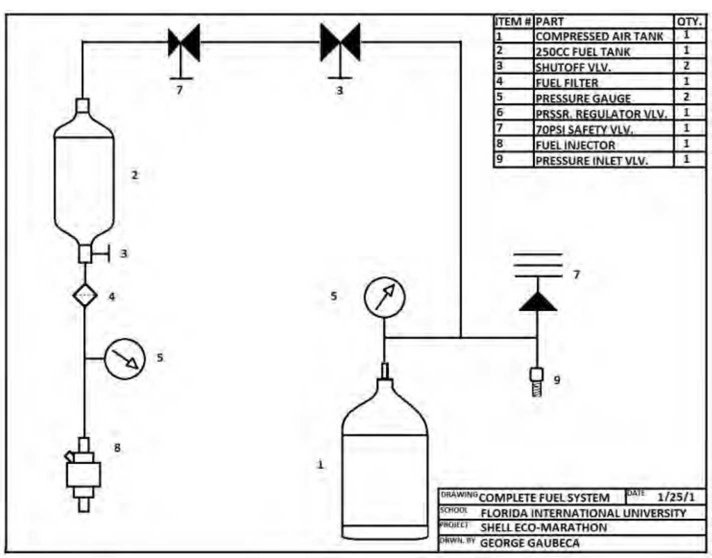


Figure 16 - Complete Fuel Delivery System Diagram

The assembled fuel system seems to have some pressure leak we have yet to detect, and the volume of air in the pressurized 16oz soda bottle proved to be insufficient to maintain acceptable pressure downstream once the valve was open. The air tank will be exchanged for a 2 Liter bottle in order to compensate for the leaks and the volumetric expansion of the gas downstream.

Figure 17- Functional fuel system

2.2.4 Fuel

Two types of liquid fuel are available for spark-ignited engines, and the engine and fuel injection kit can handle both types of fuel, these are 87-octane regular gasoline and pure ethanol (E100).

Regular gasoline has an octane rating of 87 while pure ethanol has an equivalent slightly over 115. The higher the octane rating, the higher compression the engine can achieve before the air/fuel mix self-ignites creating engine knock which will hinder performance and create more wear on the engine. On the other hand gasoline has a higher energy density when compared to E100.

The team will choose to run 87-octane regular gasoline in our vehicle because although it is recommended to modify the engine to achieve higher compression it is not expected that this will happen due to time constraints, therefore we choose gasoline due to its effectiveness and higher energy density that ethanol. Note that to this date the team has not been able to find tables or equations that can help predict how much compression an engine can achieve before inducing knock when using fuel with a given octane rating.

2.2.5 Starter

The engine considered comes with an electric starter, which is needed so that the driver and/or computer can control when the engine turns on and off, allowing the car to cruise with the engine off and then be started from within the cockpit when the speed falls below a predetermined level.

2.2.6 Electrical System

The Vehicle's electrical system consists of a 12v charging system comprised of a battery and the AC magneto/stator integrated in the engine. The battery selected is the smallest Lithium Ion battery manufactured for motosports and weights 0.5lbs at a cost of 50$, while an equivalent Lead/acid battery would have costed $30 but would have weighted 3lbs.

The wiring harness was obtained from the same scooter that the engine was pulled from, and was later simplified, spliced, and readapted to our vehicle's needs. The diagram below accurately represents the final product, and it is ready to be submitted to the competition's authorities for review. The team made sure to include kill switches for the engine accessible from the cockpit and from the vehicles exterior, plus a dedicated toggle switch for the ECU, buttons were also included to spool the starter engine while illuminating the starter signal light, and another one to sound the horn.

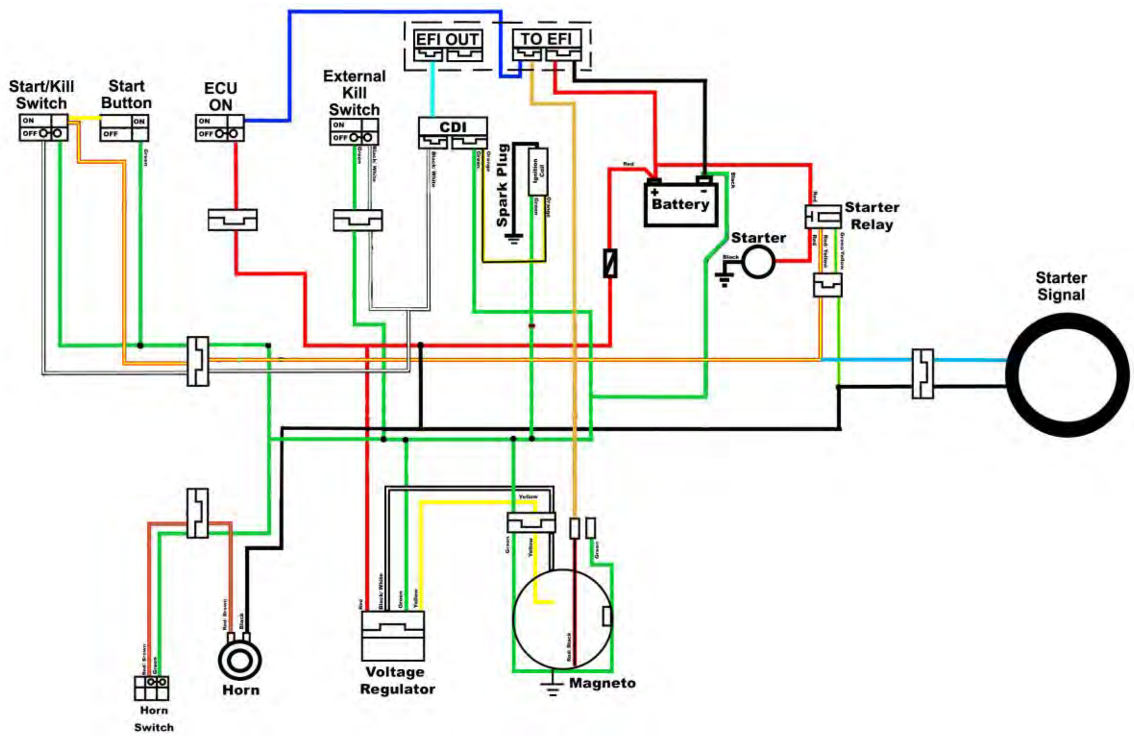


Figure 18 - Vehicle Wiring diagram

Note that the Electronic Fuel Injection system comes with an extensive and complex harness of its own, but the connections shown accurately picture how both harnesses interact with each other.

2.2.7 Tires

As for the rear tire the GY6 engine under consideration uses a distinct type of tires that is designed for scooters, and compatible wheels include a hub for an expanding internal drum brake that is built into the engine, these must also have a distinct spline pattern that must match the one on the engine's output shaft, and these two patterns are not consistent between all 139QMB engines or the wheels that are advertised as compatible, which complicates the issue of finding correct matches.

The options to reduce rolling resistance in the rear tire would be to procure a high pressure slick racing tire meant for scooters, for which there are only two manufacturers worldwide, Savatech and Heideneau, and which would also produce a heavier assembly which would not be as efficient as the one achieved with the Michelin tires, but to be able to put this type of tire on the engine the team would have to be willing to invest time and money in manufacturing it. So far the team has opted to procure the scooter racing Heideneu tire and the wheel was inexpensively purchased along with the engine to guarantee a proper mate, but it was later realized that it is made of iron, so finding a cast aluminum one would be the a viable improvement in weight reduction. Below is an image of the slick tire mounted on the engine:

Figure 19 - Engine with Wheel and Tire

2.2.8 Frame

The design and manufacturing of the frame was undoubtedly as extensive as it was challenging. Nonetheless, it was imperative that much effort went into this part of the project due to its importance. It was clear that the frame of the car would be the root of the car, as all the other components would be attached to the frame. Furthermore, the frame would give the car its structural integrity and keep the driver safe in the case of an accident.

Keeping in mind that because this is a super mileage competition, the car had to be as light as possible while also being safe. The first step in designing the car was to acknowledge the competition requirements for the chassis, and design around them. Fortunately, the competition's only requirements for the chassis were that the roll bar extend 5cm around the driver's helmet, and be large enough to protect the driver in the case of a collision. With so few design requirements, there was plenty of freedom to design the frame, or so the team thought. Throughout the design and manufacturing process many constrictions were found that reduced the team's choices for the design of the frame. These constraints will be mentioned all throughout the explanation of the design process.

Once the requirements were known, initial designs began. The first consideration was to follow in the previous team's footsteps and build a chassis out of aluminum and weld the tubes together. In the interest of exceling the previous team, further research was made that lead to considerations of carbon fiber tubing while using carbon fiber plates with composites in between (figure ??) as the base of the chassis. For the composite, many choices were considered including balsa, birch, honeycomb nomex, and foam. The amount of materials allowed for many options that varied in price, weight, and strength. Ultimately, because the team was unable to find a plate and composite combination priced under $1000 that satisfied their desired parameters, the choice was made to build the frame out of carbon fiber tubing. This lead to concern as welding was no longer an option as it is impossible to weld carbon fiber. Fortunately, research unveiled a very unique and innovate method to join any type or size of tubing. Patent 8266788, invented by Krysztof Kotlinski, consisted in creating custom u-shaped joints that would contour to the circular shape of tubes. More specifically the method involves taking carbon fiber tow and wrapping it around mandrels, mixing the tow with resin, and allowing it to cure in order to obtain a somewhat oval shape that would be cut into two different u-joints. These u joints would then be reinforced with more tow at the end opposite to the side where the tube is inserted. The tube and u joint would then be further reinforced together. Lastly, the tubes would be tied together with more tow. This method will be further depicted in the manufacturing section.

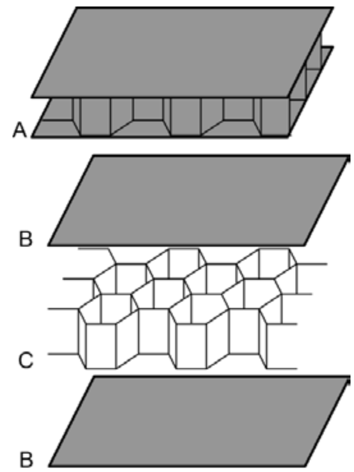


Figure 20 - Honeycomb Structure

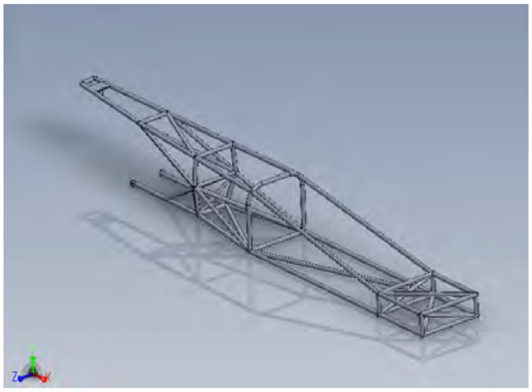


Figure 21 - First Frame Design

The process of designing the car was one of much trial and error. Several designs for the car were made until a final design was chosen. Even then, it was decided that the at-time final design required additional supports. The very first design can be seen in figure ??. This design served as a starting point for future designs, but was nonetheless discarded as the team felt that a functional frame could be achieved with more simplistic configurations and less materials. From there, a second design was made and can be seen in figure ??. As evidenced by the figure, after the initial design, more simplistic designs were sought. This design features two front diagonals that connect at the front vertices and the top vertices of the roll bar. Furthermore, a quadrilateral roll bar was designed since carbon fiber tubers would be used and those cannot be molded into a circular shape. Because the engine had already been selected at this point, the connecting points were known, and were considered when used for this design. The two diagonal lower tubes than can be seen in a cantilever state would serve as the lower mounting points for the engine. Likewise, the horizontal tube located at the far back of the frame would serve as the upper mounting point for the engine. This mounting point would be to the tire's shock absorber. As pointed out in the description of the engine, this connection is not in the center plane of the motor and tire configuration. The decision was then made to proceed and purchase 36 feet of carbon fiber tubing. The purchase was made for 6 tubes of 6 feet, each tube costing just about $100, for a total of just under $600.

The following figures show some of the preliminary simulations performed. This figures show some analysis results that show factor of safety, total displacement, and stresses.

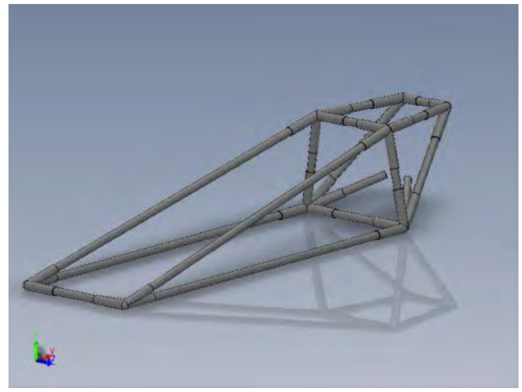


Figure 22 - Second Frame Design

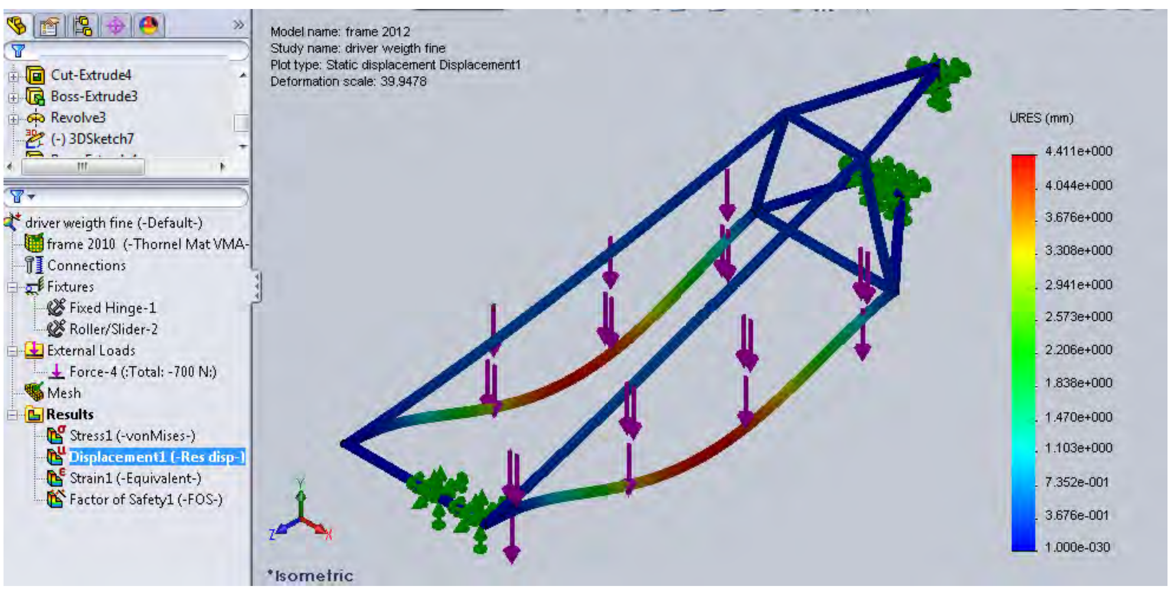


Figure 23 Analysis (1)

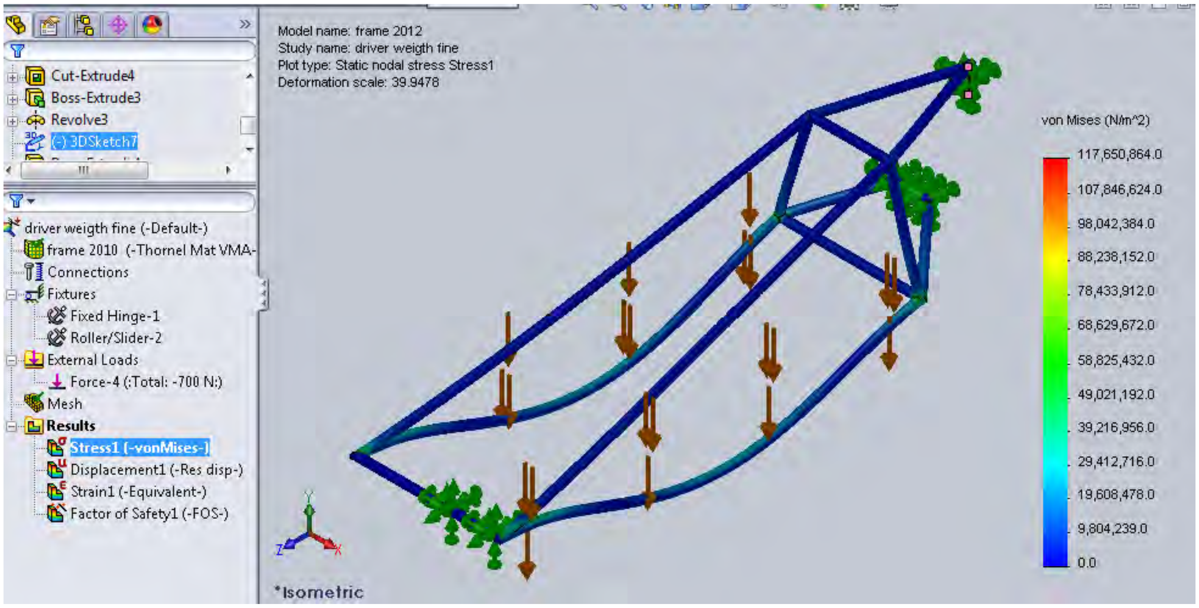


Figure 24 Analysis (2)

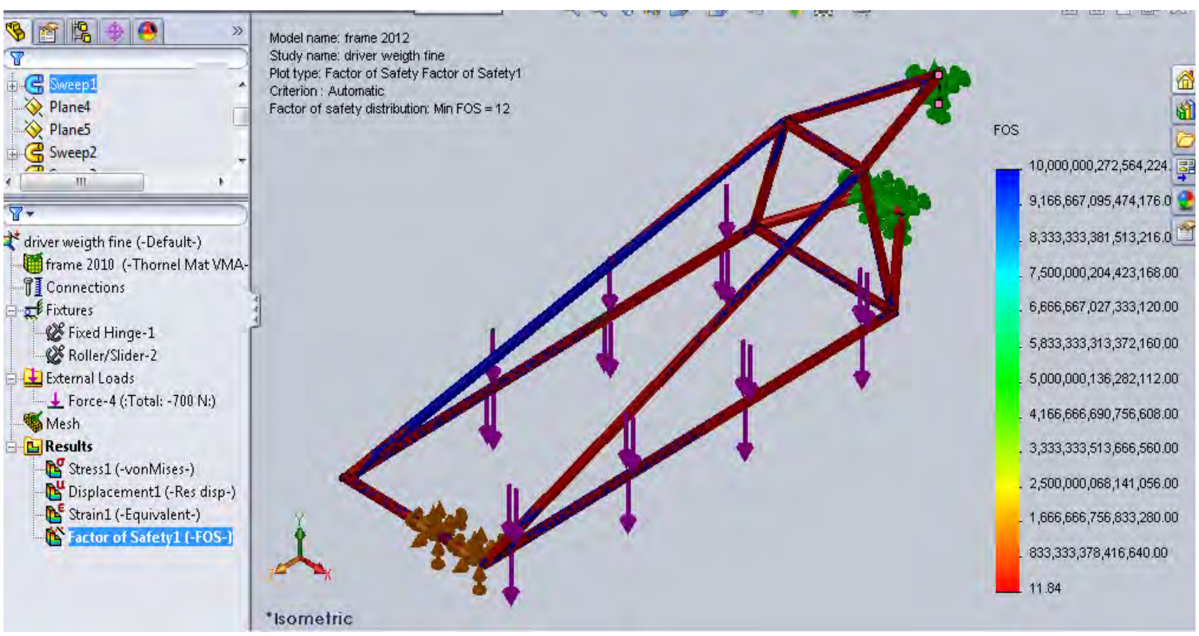


Figure 25 Analysis (3)

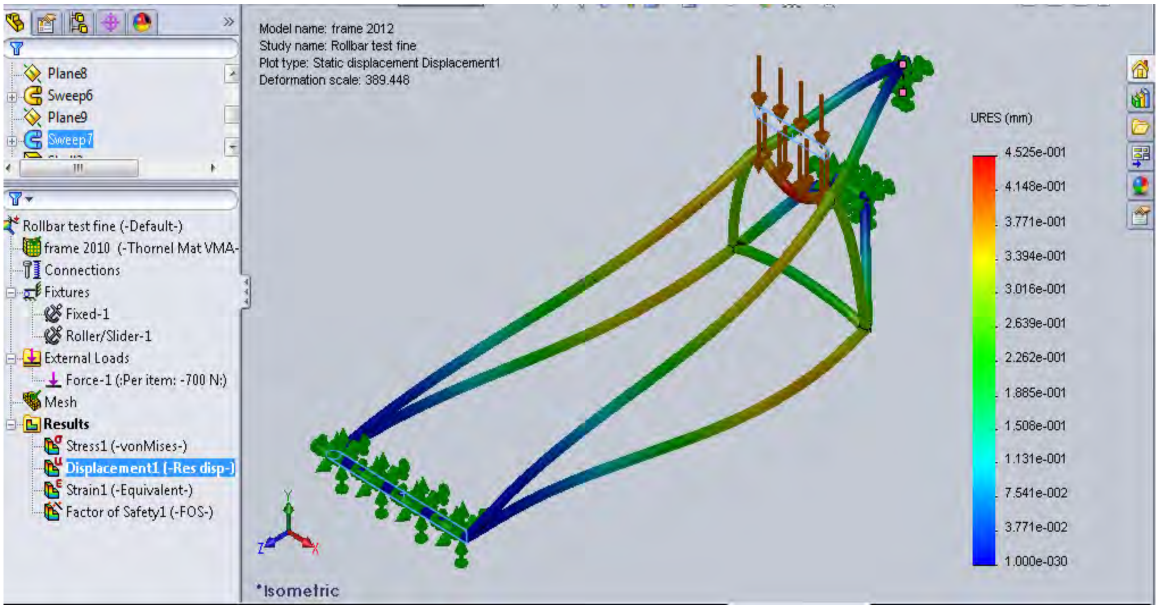


Figure 26 Analysis (4)

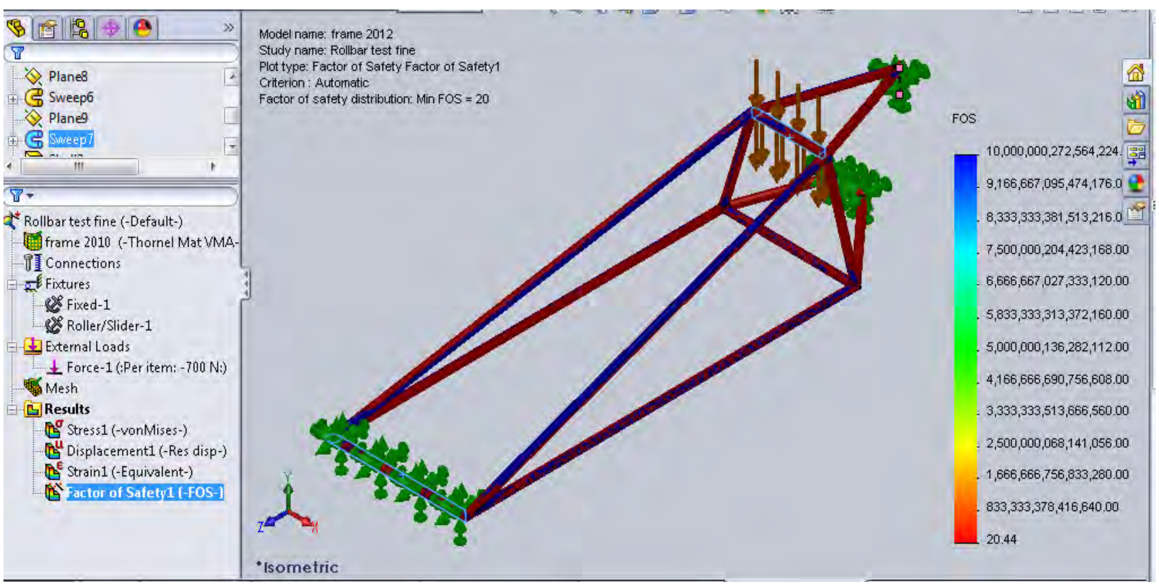


Figure 27 Analysis (5)

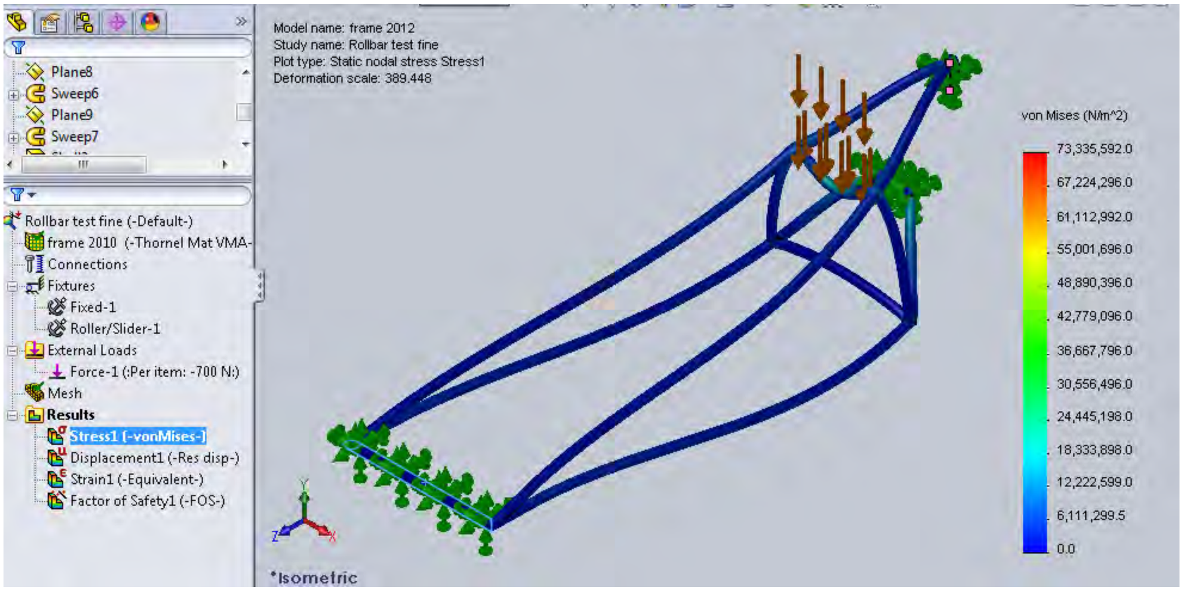


Figure 28 Analysis (6)

According to this analysis, the tentative dimensions of the carbon fiber tubes showed that the structure would be quite overbuilt, and choosing a smaller pipe diameter might have been a good option to reduce size, weight, and cost. Nonetheless the team decided against this in order to be conservative, since we knew that our simulations did not accurately represent the anisotropic nature of the material or the joining method to be used.

Once this design was made, and the tubes had arrived, the team called the driver and began testing the current assumed dimensions and frame configuration, as depicted in the figure. Doing this proved to be the correct choice as testing this configuration with the actual driver revealed several changes needed to be made. Firstly, the upper horizontal tube used for the roll bar proved to be too small. This caused the diagonals that connect to the upper vertices of the roll bar to collide with the driver's helmet and thus

Figure 29 - Using Driver to Extract Dimensions

not allowing the helmet to fit. Secondly, the height of the roll bar also proved to be insufficient, as it did not provide the clearance from the helmet required by the competition. Moreover, the initial allocated length for the driver's compartment of 5 feet 6 inches proved to be unnecessarily long. Since the driver is 5 feet tall and capable of bending her knees allowing the compartment to be even shorter, the initial allocated length was reduced.

With all these observations, a new chassis was designed. Later on this new design would be designated the final design. This new design consisted in changing the connection of the front diagonals to the horizontal tube beneath, rather than the corner. This was done because it allowed for less material to be used as the required tubes would be shorter and also because this new configuration would actually widen the distance from the diagonal tubes and thus allowing more room for the helmet to fit. By doing this and widening the front of the frame by merely 2 inches proved to be more than enough for the helmet to fit. Also, as can be seen in the figure, the length of the driver compartment was reduced to 54 inches, less than the driver's height of 5 feet. The driver would bend her knees and fit, nonetheless. This allowed the car to be shorter which allowed for better aerodynamics, less material for the body and frame, and less chances for the team to exceed the competition requirements of a maximum length. Lastly, at this point the rear diagonals had to be removed as it was discovered that they collided with the engine. This was a tremendous oversight by the team which meant that without those supports, the tubes that connect directly to the engine would be in full cantilever statues. This caused the team to fear that the torque would be enough to cause enough of a shear to make the epoxy resin that held the parts together fail. This was later addressed by having these diagonals connect at the middle of the roll bar rather than the lower vertices. This last minute reinforcement can be seen clearly in the following figure.

Figure 30 - Engine Reinforcements

2.2.9 Steering system

While researching and designing the steering system, the team took into consideration the radius of turning and how it would impact the size and design of the frame and body of the car. When considering the steering system, the group took into consideration Ackermann turning where the larger the distance between the front and back wheels of the car, the larger the radius of turning is. This goes against the team's goal as they strive for the lowest turning radius for highest efficiency. Also, having a lower turning radius means the wheels need to turn more in order to compensate, and this in turn forces the car design to be wider in order to allow for the extra space needed for the wheels to turn.

2.2.10 Body

Just like the frame, the body was a very complicated aspect of the car. Much energy is lost to friction with the air, making it imperative that the difficulties be overcome with the best results possible. Nonetheless, it is imperative to say the team was pressed on time and that did not allow the team to design the body as extensive and thoroughly as originally intended. Original plans included running drag simulations on Ansys software in order to find the coefficient of drag, and running wind tunnel simulations on a scaled model in order to compare the practical results with the ones from the simulations. Furthermore, the panther rage G2 team suggested to team phantom to begin and complete the design of the chassis before they began designing the body of the car. This recommendation was put to practice and it was the right choice. Designing the body of the car before designing the interior would have been a huge mistake that inevitably would have lead to the body colliding with the one of the many interior components. Although doing the frame first was considered the best idea, this resulted in pushing back all the work on the body until the frame was completed. Because the competition was to be held the first week of April, the car had to be shipped by the last week of March, and the frame was not completed until early March, this resulted in a small window of only a few weeks to completely design and manufacture the body from scratch.

Even though the team did not expect to make a final decision on the body of the car until the frame was complete, many different body designs were made with the intention of testing them and determining which had the best aerodynamics. By doing this, the process of designing and manufacturing could be expedited. Furthermore, by designing this early in the competition, much experience would be gained in the process of designing complex shapes. This proved to be the case. Although the initial designs were not picked, the official design was made possible because of the experience and practice from the earlier models.

Initially, three different models were made. These three models, as can be seen in the next figure, are all made with all three wheels inside the body. The main difference between the three is how the rears end. Research revealed that the trailing edge of a object can have as much influence on its aerodynamics as the front of the object. Furthermore, another difference is the position of the wheels relative to the body. In the top right model, it can be seen that the body completely covers the top half of the wheel, allowing for a continuous and flowing surface. Whereas, in the other two figures, the wheels protrude from the surface of the body thus causing somewhat of a discontinuity that threatens the desired raindrop-like shape.

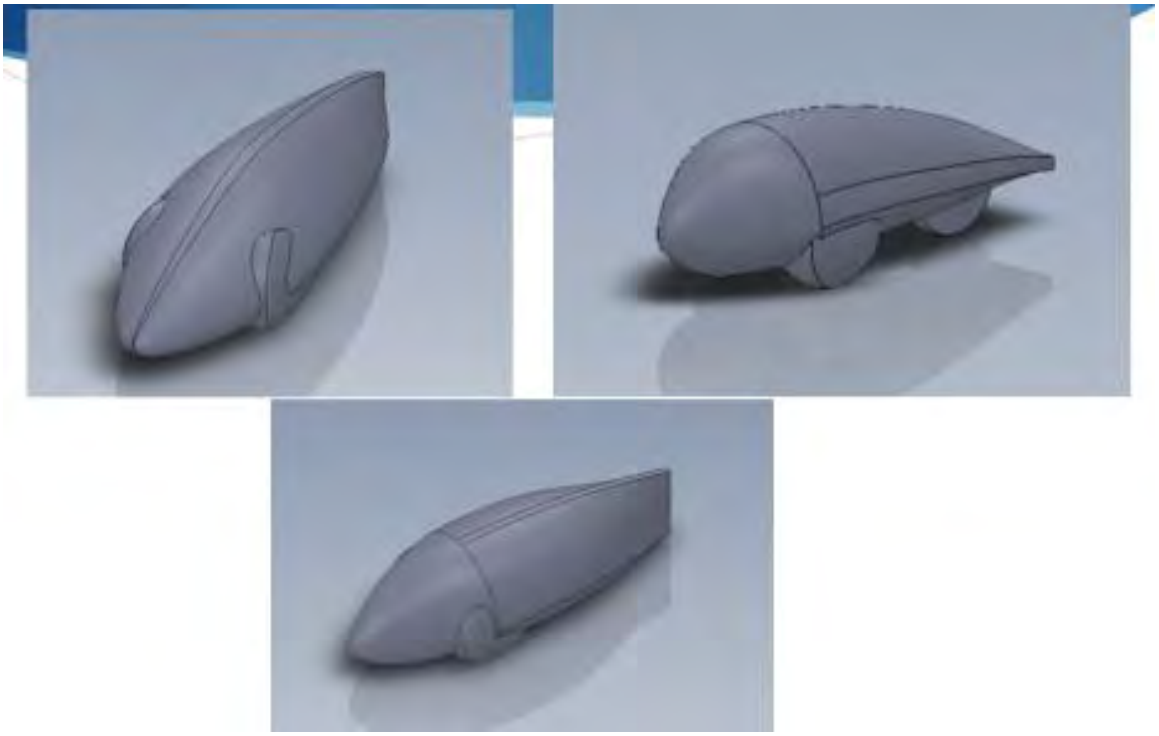


Figure 31 - First Three Body Designs

As mentioned before, these were only preliminary designs. Once the frame began to take shape a more concrete idea was formed but still insufficient to make a final design. Regardless, a new body as seen in the next figure was designed. At the time of completion, this new designed was expected to be final, or at the very least very close to the final product. However, it is imperative to say that once this most recent model was finished, and 4 different options were available to test, the decision was made to avoid running simulations for drag coefficients. Although unorthodox, the team believed that it would be better to wait until a final frame and an incorporated steering system with the wheel were designed in order to begin simulations. At the time, it seemed unintuitive to run simulations on different bodies that potentially would be impossible to incorporate with the other components of the car. With the car completed, it can now be said that it was clearly the right decision, as none of the four initial drafts were used. This will be explained further.

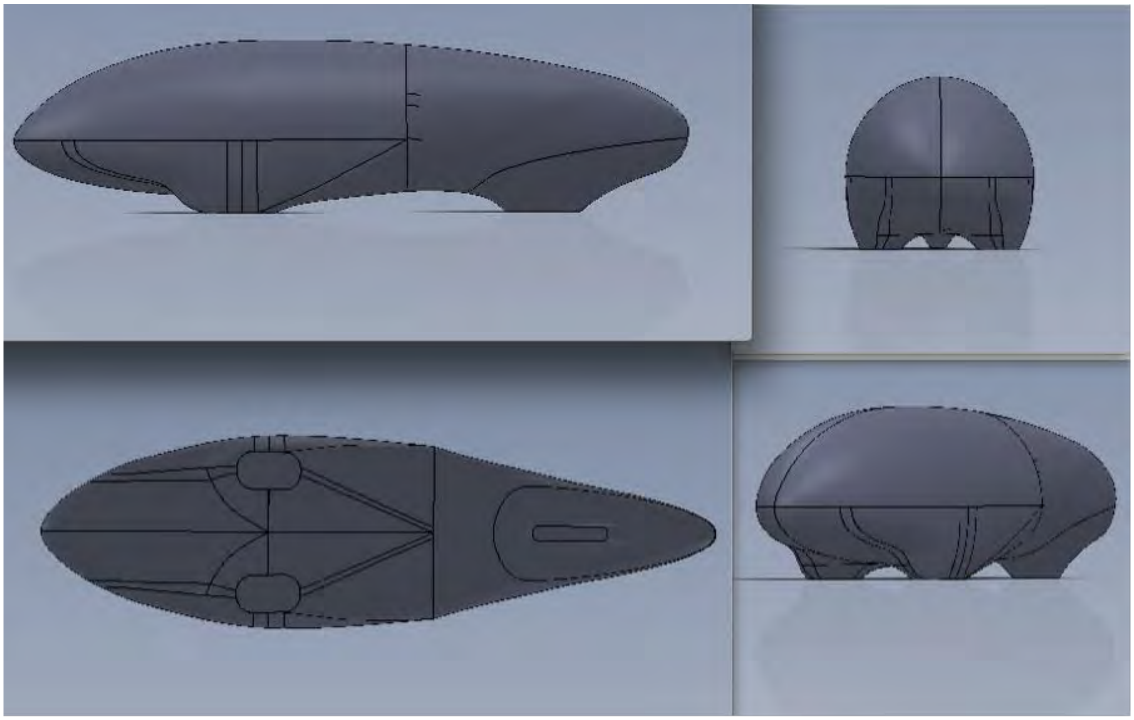


Figure 32 - Fourth and Expected Design

3. Proposed Design

3.1 Brakes selection

One of the most important things to keep in mind when defining the brakes of the car was the overall usage of the same. During a fuel-efficient race, since the cars run at very low speed, there are only two times when the brakes are mainly used. First, hours before the race where you need to pass the inspection, which in the case of Shell Eco Marathon is to make sure the system will support your car on a 20 degree slope, and second, to keep your car stopped before the begin of a trial. Other than that, the brakes are rarely used and therefore must be as weight and cost efficient as possible. As mentioned above, the back tire comes with a drum breaking system already mounted, which for convenience and cost purposes, did not have to be touched. For the two front wheels, since we were using a model inspired in a tricycle, our team was able to incorporate two low cost efficient disk braking systems alongside with the wheels provided by the manufacturer, who also provided us with the necessary cables and brake levers, in order to connect the system to the driver's hand. A picture very similar to the braking system used in the car is shown below:

Figure 33 - Braking system

3.2 Wheels, Tires, and Hubs:

There are three wheels to be used in our vehicle's design. One of this wheels, the rear one, is to be the powered wheel and two other wheels in the front will be used to steer the car and will be free rolling.

The tires should cause the least rolling resistance possible and the Michelin ultra low rolling resistance 44-406 tires are the best in its class for this application. Shell has a partnership with Michelin to offer these to the participating teams for purchase at $78 per tire. Our group was fortunate enough to be able to borrow last year's Michelin two front tires for our car. Some important characteristics of these tires are[vii]:

- Rolling resistance: 2 kg/t (kilogram/ton)
- Suitable pressure: 50PSI
- Weight: About 150 grams
- Suitable crochet-type rim reference: 20''x1.75''
- Section Width: 45 mm
- Overall diameter: 500 mm

Figure 34 - Michelin 44-406

Taking into account the tire's requirements, we solidified our choices for the two front wheels. Inspired on a tadpole tricycle, two 20", non-machined rim wheels with 20mm trike hubs were purchased from PowerOnCycling to go in the front. In order to optimize the design, we decided to customize with ceramic bearings, which also minimizes dissipation[viii]. Together with the wheels, the same manufacturer was able to provide us the hub mounts that will fit perfectly the diameter of wheel axle, which is ideal for our steering system. It is important to remember that the back wheel and the back tire have been purchased as package with the engine as explained in its designated section.

Figure 35 - Wheel

Figure 36 - Hub Mount

3.3 Steering System

The steering system designed a few weeks before the competition was inspired in recumbent trikes and go karts. Since the acceleration of the car was done in one of the hands, the absence of pedals challenged our team to create a system that would turn both of the wheels with the motion with one hand only. The concept used can be somewhat related with the picture below:

Figure 37 - Go-kart steering

On the left side of the prototype, attached to the frame, an aluminum tube was put together perpendicularly to a carbon fiber tube (same one used in the frame) using carbon fiber tow and epoxy. On the other side of that tube, a metal strip was welded to another side of the aluminum tube in order to be connected to one of the tie rods. The picture below can be used as an illustration of the system.

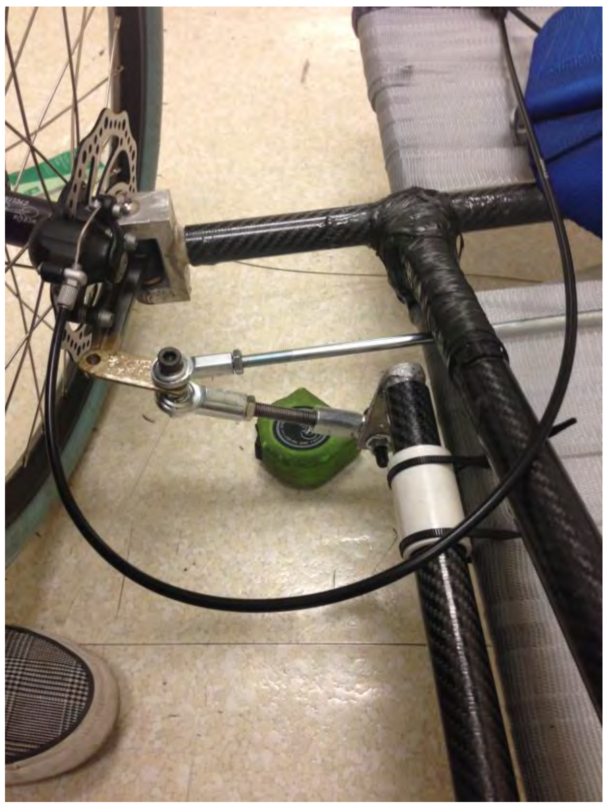


Figure 38 - Steering connections

This tie rod, which is approximately 4 inches long, was connected to a bolt on its other end. This bolt goes through another metal plate, which itself was welded into the hub. This offset from the hubs is responsible for the Ackermann turning on the vehicle. This bolt, which can be seen above also goes through a 24 inches trimmable tubular tie rod, which connects both hubs therefore, giving the turning motion of the car with one movement.

The way this system connects to the frame is very similar to the technique used to construct the body. A carbon fiber tube, length of approximately 26 inches was linked to aluminum 6061 C-Clamps (more details on the manufacturing section of the report). These C-Clamps are then connected to the hubs through the king pin shown in the hub mount.

Figure 39 - Welded hubs

However, after getting to Houston, on the first night of the competition, our group mounted the top part of the body to the bottom, leaving little room for the steering control, which had been designed for a body that would have stayed on the outside of the wheels. Facing this adversity, we had to improvise. During the competition, we came up with a simple pulley system, which would rotate both wheels with a forward and backwards motion (rather than left and right which was limited due to the body shape).

After rushing to home depot and buying the parts, a system with four pulleys and a wire was built. As we had expected, the new system worked fantastically during the weekend.

Figure 40 – Pulley

3.4 Body

As mentioned before, the design of the frame was very complicated and full of trial and error. The tremendous amount of changes to the frame made it so that the expected design for the body became rendered undesirable. More specifically, the original intention of having the wheels inside of the car became unlikely as calculations revealed that having the wheels on the inside of the body would lead to the steering forcing the body to be over 33 inches wide. Although castor angles were added in an effort to reduce the outer deflection of the wheel as it turned, it proved that although the efforts did make the deflection lesser, it was not sufficient to allow the body to be less that 30 inches wide. Because of this, the team felt very obligated to make a last minute change to the car and have the wheels on the outside of the body. This was a huge decision, and one that was made with not much time to spare. By the time the decision to leave the wheels outside of the body was made, there was just under a month until the team has to ship their car. Within this one-month time frame, an entirely new body had to be designed and manufactured.

It cannot be overstated how challenging this was because of the time constrictions. This was further challenging thanks to the obstacles that had to be overcome, namely conforming to the other components of the car. Although having the wheels on the outside of the body did not entail many changes towards the rear of the car, it meant a substantial amount of challenges and changes towards the front of the car. More specifically, the new body had to be designed so that it would not collide with the wheels during steering, yet be big enough to fit the wide roll bar and have extra space to place the steering and accelerating systems for the car. The obstacle here lies in making the car be shaped like a raindrop, as was desired by the designer. Having the car be shaped like a raindrop was difficult as the turning wheels forced the car to be thinner on the front, while the roll bar, being the widest part of the car, forced it to be at its widest well behind the middle of the body. Furthermore, the engine was not aligned with the center of the car, meaning that it further forced to car to be relatively wider near the rear end. Fortunately, after much work a design was completed that was usable. Although the raindrop shape was not obtained, the team was satisfied with the resulting design. A three dimensional model can be seen in the figure below.

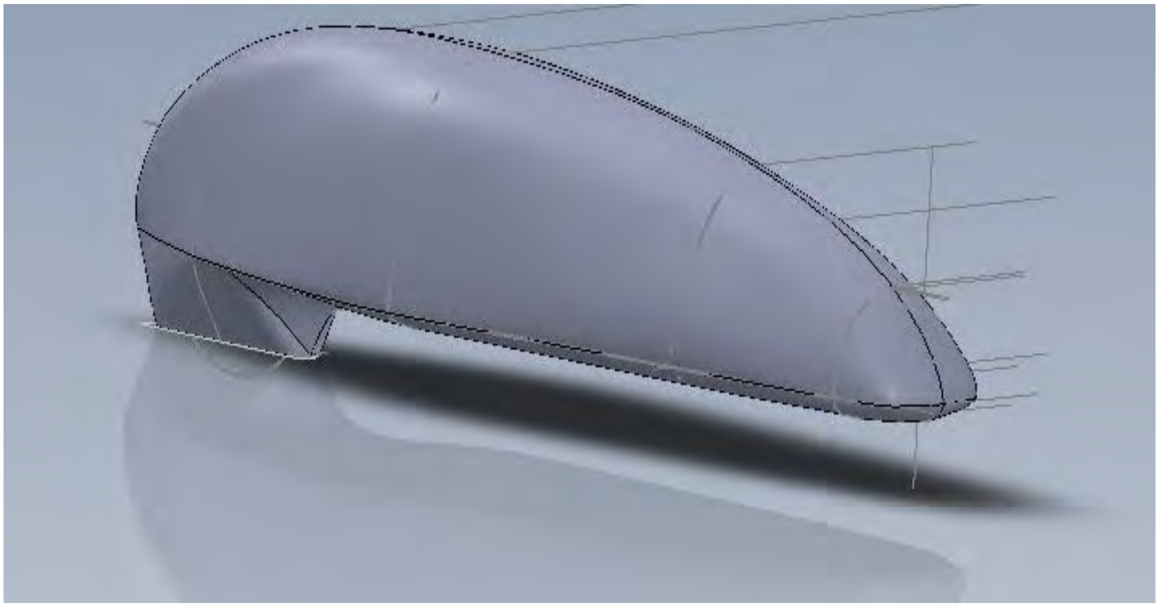


Figure 41 - Final Design

Given that this model took slightly over 2 weeks to design due to its complexity and consistent changes to conform to the frame and steering, less than 2 weeks were left until the car was shipped. As stated before, this meant that the team unfortunately, did not have the time to run the simulations to optimize this shape as they originally intended. The simulations were skipped, and the process of manufacturing began.

3.5 Final Design

Figure 42 - Car Final 1

4 Project Management

4.1 Overview

As a team working together for the best outcome in the competition, the team envisions to put in the same amount of work in the project. All members are fully aware of all meetings, expectations, objectives and tasks that must be met in order to make this journey a successful one and have all committed in putting equal time and effort into doing so.

4.2 Breakdown of Work into Specific Tasks

Naturally building a car prototype will involve putting several pieces of a puzzle together successfully in order for the final product to function ideally. The prototype can be divided in several different small sections such as Engine Selection, Body Design, Material Selection, Chassis (Frame), Steering System, Braking system, Wheel and Rim selection. Since the project design involves participation in a competition, it is also very important to assign members tasks that will assure the team is complying with the regulations and deadlines imposed by the organizers.

4.3 Project Timeline

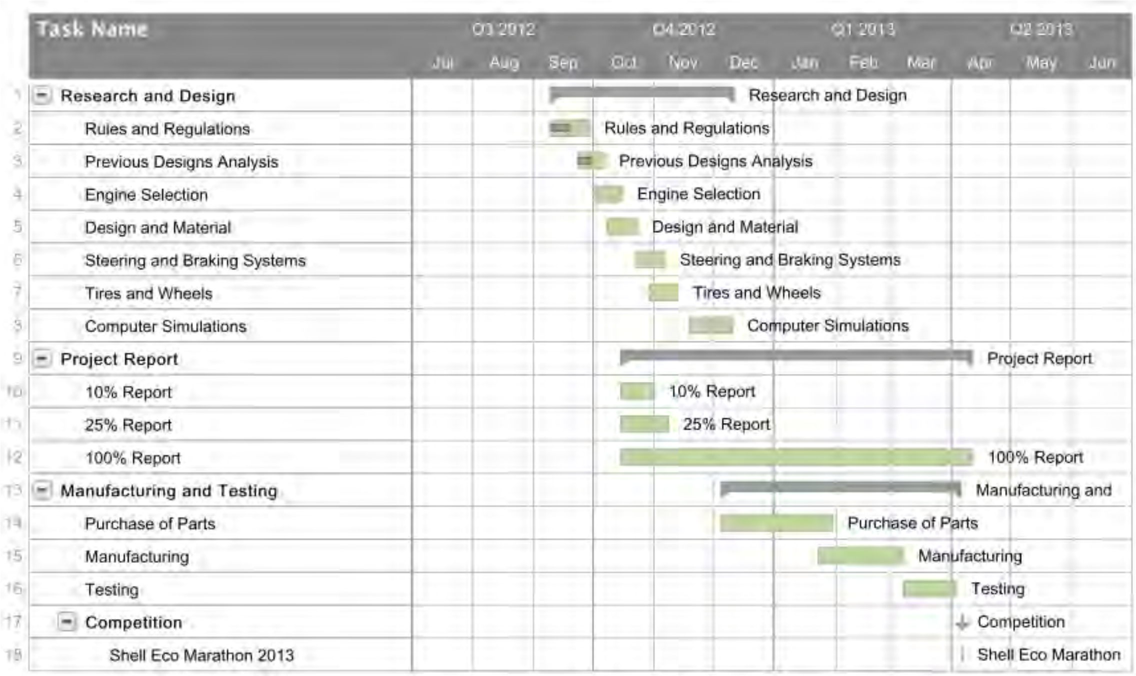


Figure 43 - Project Timeline

4.4 Breakdown of Responsibilities

For the 2013 Eco Shell Marathon team, the tasks have been distributed as follows:

- Marco Betancourt: Engine research and selection, Fuel selection and delivery system and Transmission system.
- Bryand Acosta: Aerodynamic research, body design, material selection and frame design.
- Fernando Pinheiro: Steering system, braking system, wheel and rim selection. Responsible for rules, regulations and competition deadlines.

All members put in equal amount of work into the project report and the same amount of hours into research and team meetings. The group has met for an average of 8 (ten) hours a week during the past five weeks and every member has also put in an average of 6 (six) hours a week into research on their own personal time. During Part I: Research and Design of the Senior Design Project, equivalent to Fall semester, an estimated 340 (three hundred and forty) hours. For the second part of the project Senior Design II, countless hours were spent in this car. Starting in the last week of January, when the first parts started to arrive, the group met consistently 3 or 4 times a week for several hours, sometimes even 16 hours a day. As the competition started to approach, the work load only increased. During Spring Break for example, the group met for 12 hours or more for at least 5 times. In the last two weeks before the competition, it is not an exaggeration to say that 72 hours were spent consecutively among the 3 of us in this car.

5. Engineering Design and Analysis

5.1 Estimated Cost Analysis

FIU Eco Shell 2013 group is currently at the stage of purchasing most of the parts that will be manufactured to the car. Below, a breakdown of the expected expenses before we started this project as well as a more detailed table of the expenses we have had so far are shown:

Table 4 - Expected Expenses

Expected Expenses			
Total Chassis Expenses			$800.00
Total Body Shell Expenses			$1,610.00
Total Engine Expenses			$600.00
Total Brake System Expenses			$550.00
Total Steering System Expenses			$319.00
Total Travel Expenses			$3,600.00
Total Money Fundraised			$300.00
TOTAL EXPENSES			*$7,479.00*
TOTAL REVENUE			$300.00
TOTAL COST	$7,179.00	3	$2,393.00

5.2 Actual Cost Analysis

Table 5 - Current Expenses

Actual Expenses		**Insert # of**	
Description	**Amount**	**Periods**	**Total**
Poster	$96.30	1	$96.30
250 ml Fuel Tank	$160.00	1	$160.00
Milton Valve	$12.82	1	$12.82
Driver's Suit	$125.00	1	$125.00
Fire exting + Bag check in	$44.58	1	$44.58
Chassis Frame:			
Wiring Machine	$27.36	*1*	$27.36
Jigsaw blade	*$5.97*	*1*	$5.97
Carbon Ribbon	*$60.00*	*1*	$60.00
Carbon Fiber tubes	$94.97	6	$569.82
Epoxy Resin	$104.95	1	$104.95
Fib Release	$26.95	1	$26.95
Epoxy Hardner	$44.95	1	$44.95
Total Chassis Expenses			$840.00
Body Shell			
Foam Mold	$956.00	1	$956.00
Fiber Glass 1	$221.06	1	$221.06
Lavend, Breather and stretch plastic	$221.05	1	$221.05
6 qt kit	$-	1	$-
Epoxy	$126.94	1	$126.94
HD materials	$155.44	1	$155.44
Total Body Shell Expenses			$1,680.49
Engine + Fuel Injection System			
Engine Cost	$385.00	1	$385.00
Fuel Injection	$399.00	1	$399.00
Spark Plug	$9.99	1	$9.99
Air Filter	$18.49	1	$18.49

Exhaust Caps	$1.99	1	$1.99
Exhaust Pipe	$14.99	1	$14.99
Coil	$24.95	1	$24.95
Battery	$49.95	1	$49.95
Lambda Meter	$239.00	1	$239.00
EmergencySwitch	$3.99	1	$4.23
Wire Harness	$90.00	1	$90.00
Total Engine Expenses			$1,237.59
Brake System			
Brake discs	$30.00	2	$60.00
Lever (pair)	$17.99	1	$17.99
Heidanau Tire	$96.14	1	$96.14
65'' Cables	$1.10	2	$2.20
20'' Wheels	$99.20	2	$198.40
Ceramic bearings	$60.00	2	$120.00
Total Brake System Expenses			$494.73
Steering System			
Hub Mount	$37.50	2	$75.00
Small tie rod	$25.99	1	$25.99
Big tie Rod	$17.99	1	$17.99
Al blocks (C-clamp)	$4.41	2	$8.82
Al Rod	$1.91	1	$1.91
Total Steering System Expenses			$129.71
Travel Expenses			
Flights	$2,246.50	1	$2,246.50
Vehile Shipping	$1,430.00	1	$1,430.00
Total Travel Expenses			$3,676.50
Shipping Expenses			
Marco	$52.53	1	$52.53
Fernando	$42.72	1	$42.72
Bryand	$40.76	1	$40.76

Total Shipping Expenses			$136.01
Acommodation			
Hotel	$761.30	1	$761.30
Acommodation Total			$761.30
Other expenses			
Marco	Welding,LEDs,HD,RadioShack		$191.40
Fernando	Walgreens,HD		$64.70
Bryand	Walgreens, HD		$65.30
Total Other Expenses			$321.40
TOTAL EXPENSES			*$5,943.63*
TOTAL EXEMPT			$3,676.50
TOTAL COST	$5,943.63	3	$1,981.21

6. Manufacturing

6.1 Steering System

The manufacturing process of the steering system involved several small steps. The first one was to create C-Clamps to be attached to the hub. In order to create those, two blocks of aluminum were order with 1.5 x 1.5 inches side and 3 inches length. With those blocks, we were cabable of using a mill to cut off a small rectangle from the inside, therefore resulting in the C shape needed.

Figure 44 - C-Clamps milling

After obtaining the expected results, we still had problems due to the fact that the turning was limited by the sharp angles of this support. In order to solve this, a grinder was used to create fillets in all sides of this piece, creating a semicircular shape on both sides. Once the C-Clamps where ready, there were welded to an aluminum pipe with .804 outside diameter, just big enough to be fitted into the carbon fiber tubes that were attached to the frame. This technique was using because we could not weld carbon fiber to the C-Clamp and we wanted to save some weight by not using a long aluminum rod. In order to make sure the aluminum would stick to the carbon fiber, epoxy was used.

Figure 45 - C-clamps welded

As briefly mentioned in the Proposed Design section of the report, other welds were needed for the system. One of them, a small metal sheet was attached to the hubs in order to create the necessary offset to give the car Ackermann turning.

Figure 46 - Axle connection

6.2 Braking System

Small manufacturing was done in order to achieve the desired braking outcome. In order to respect the rules of the competition, it was required to use both brakes in the front with one mechanism. The solution to that was welding two braking levers together, therefore pressing both with one motion.

6.3 Frame

The process of manufacturing began with the previously mentioned patent by Kotlinski. As mentioned before, the process entailed using carbon fiber tow as a means to create u-joints and attach them to the already purchased carbon fiber tubing. The process can be best depicted in the next figure, courtesy of the inventor, Kotlinksi:

Figure 47 - Method Of Adjoining tubes

The following three figures depict some real life applications as shown by Kotlinski. The first of the three depicts how the joints are right after being tied together, while the second and third show a finished product and the product in use, respectively.

Figure 48 - Result, Example 1

Figure 49 Result, Example 2

Figure 50 Result, Example 3

As can be seen in the previous figures, this method allows for multiple tubes to connect at a single vertex, or create a connection point along a tube. It is mainly because of these reasons, the affordability of this method, and the ability to connect many tubes at any angle that the team immediately decided to apply this method.

Although this method is innovative and hence not much information on it is available, the team proceeded to use it. But this lack of background knowledge made for much room for error. The steps where followed as closely as possible following the description provided in the patent. As a starting point, the team created the machine suggested by the inventor to wrap the mandrels with the tow. The machine, as below consists of a roll of tow being held in place, while string is pulled through some hooks that serve to create tension. As the tow is being wrapped around the spinning component that holds the mandrels to the right, it is also passing through a small container that houses a mixture of epoxy resin mixture. The proceeding figure is the actual machine being used after it was finished.

Figure 51 Winding Machine

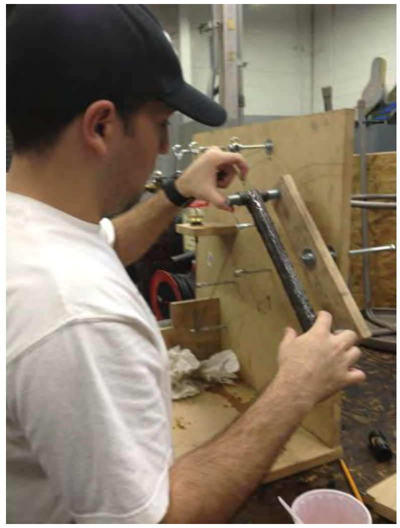


Figure 52 Winding Machine

It should be stated that although this machine was very helpful in the production of the u joints, several complications were met throughout the way. First, as carbon fiber tow has a relatively large modulus for tension but very low for compression and shear, the tow was prone to cutting easily. That is, the friction against the metallic hooks used was more than enough to cause the tow to break on several occasions. Also, it proved to be quite the challenge to have the aforementioned container house the resin mixture and have the tow pass through without causing the resin to escape through the exit hole of the tow. Moreover, the spinning part on the right required that the tow being wrapped be constantly guided in order to distribute the tow evenly along the mandrel. Originally the team intended to put a small motor on this moving part but because so much external guidance was needed for the tow, it proved to be much easier to avoid the motor and do the spinning manually. Although time consuming, this resulting u joints were of acceptable quality. The following figure shows the resulting u joint. The picture shows only one u-joint, but more than 30 were produced. Also important to notice, the loop has a circular shape. This is done purposely so that a tube may be inserted through there and a T-style vertex can be made.

Figure 53 - U Joints

After the u joints were fabricated, reinforcements were added as indicated by the patent. The reinforcement consisted in adding more tow to the joint at the point where they would all be joined together. The following figure is of said reinforced joint.

Figure 54 - Reinforced U Joints

With the joints reinforced, it was time to add them to the carbon fiber tubes, reinforce with more carbon fiber tow, and apply the resin as an adhesive between the u joints and the tube. The results can be seen in the figure below. Zip ties were used to hold the u joints in place while the reinforcing was done.

Figure 55 Joints and Tubes

The time came to connect all the tubes together. But before the tubes were all joined together, precautions were taken in order to avoid mistakes with the final product. These precautions consisted in adjoining all the tubes using zip ties in order to accurately portray the frame as a finished product. The frame with its zip ties can be seen in the figure to the right. After this was done, the team was pleased with the way everything assembled together and thus moved on to joining the tubes. Just like the patent indicates, these tubes were wrapped together

Figure 56 Assembled with Zip Ties

using carbon fiber tow. The figure below clearly shows the result. One should take notice at the diagonals that connect from the rollbar to the upper vertical tubes and the vertical tube that lies in the middle of the roll bar. As mentioned before, in the absence of these tubes, the upper tubes that connect to the engine would have been fully cantilever. These tubes were added in order to remove the cantilever effect. The vertical tube was intended to help add support in the vertical direction. Also worth mentioning, the team was dubious about the capacity of this method to withstand compressive forces. Although much confidence was placed on the ability of the carbon fiber tow to withstand tension, the same was not true for its ability to withstand compression forces. During the testing of the roll bar at the competition, a 700N force would be applied to the roll bar in all directions during different tests. The team recognized that when the direction of the force was down, many of the u joints would be in compression. This caused much worry and lead to adding the aforementioned additional vertical support. Both diagonal that connect to the roll bar are expected to be enough to withstand the 700 N forces applied with forward and backwards orientation. Initially, the team expected all the joints to be made by having tubes inserted into to loop of the u joints, but this proved to impossible as the reinforcement done in the loops significantly thickened the tubes and thus did not allow the tubes

to fit. Anyhow, the team was able to insert the vertical tube in the rollbar and apply it as was originally intended, as a T joint. The Figure below perfectly shows how the u joint holds both the vertical and horizontal tubes together rather than wrapping them together like the other two tubes at the extremes of the horizontal tube. This gave the team the confidence that the rollbar would withstand a great vertical force, and this proved to be correct when the team perform some testing on the rollbar by applying weight to it.

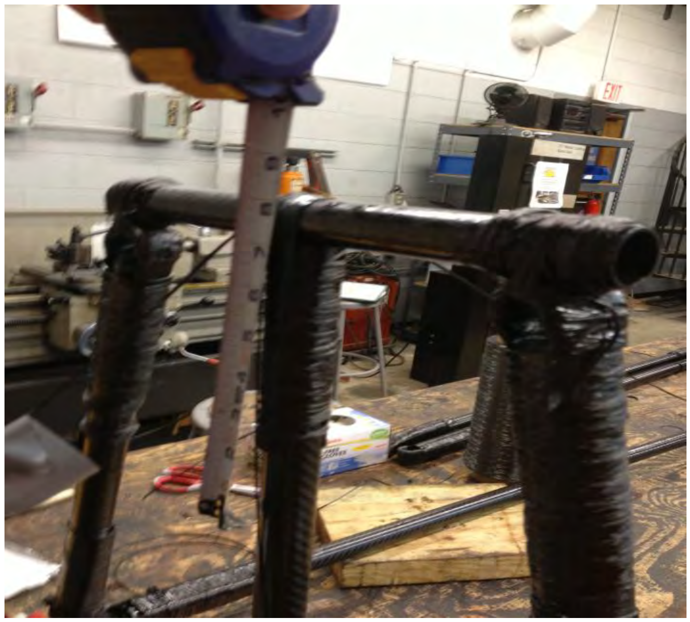


Figure 57 Example of Connections

With the frame completed, the steering system and body could finally be designed and completed.

6.4 Body

The manufacturing of the car began by making a solid body of the model to actual size. This was done through hotwire foam cutting. But before the model could be made, the company that was to perform the cutting requested that the team present the model based on cross sections. That is, looking from the front, the company needed a drawing of the cross section for every three inches along the length of the car. The following figure shows the drawing that was presented to the company. Once they had this drawing, they began cutting the foam. The method applied is that the front side of the foam would have one cross section, while the backside would have to following cross section. The company would then trace a profile between the front section and the back section, and thus creating the pieces that when joint together would form the body. A close look at the following picture will reveal the cross sections and how they began to take shape when put together, the proceeding picture shows the residual foam after the cross sections have been cut.

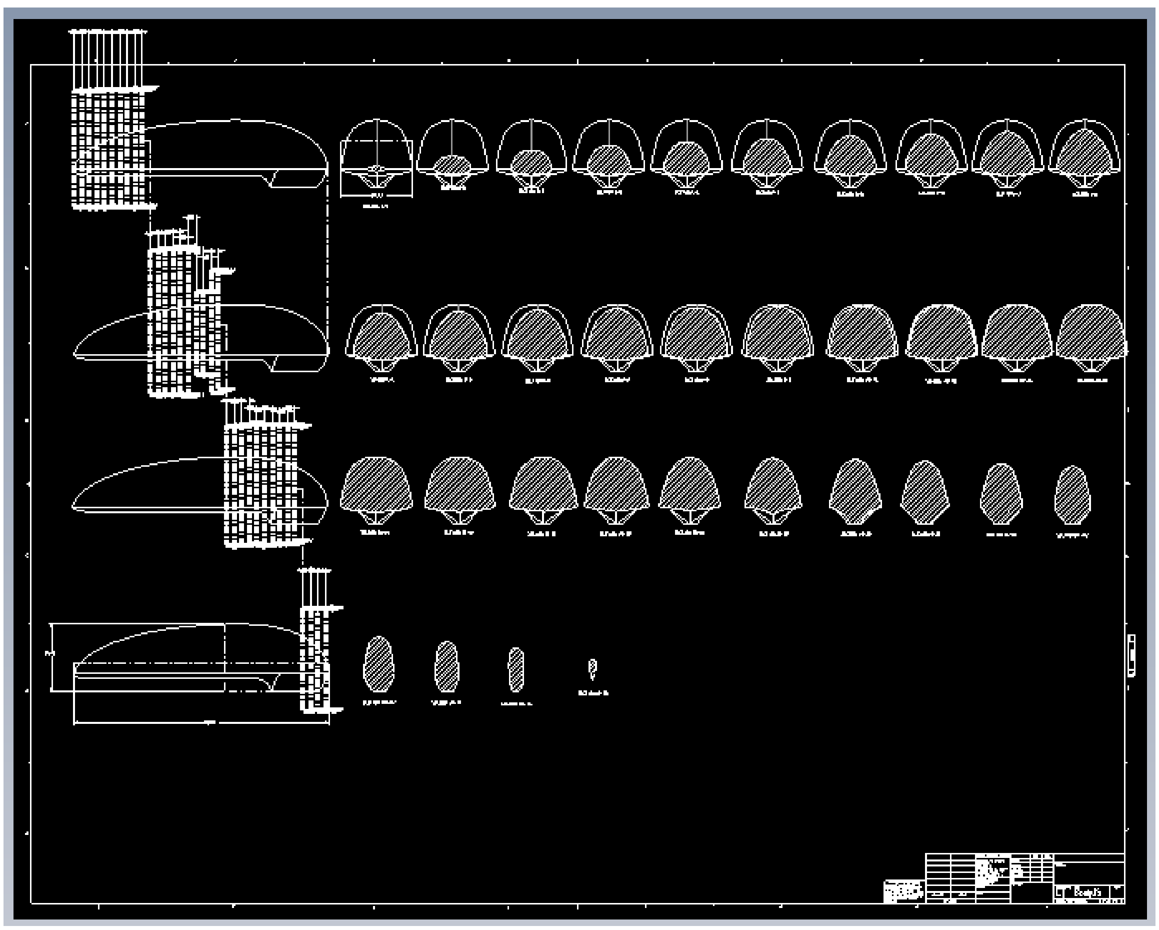


Figure 58 Cross Sections

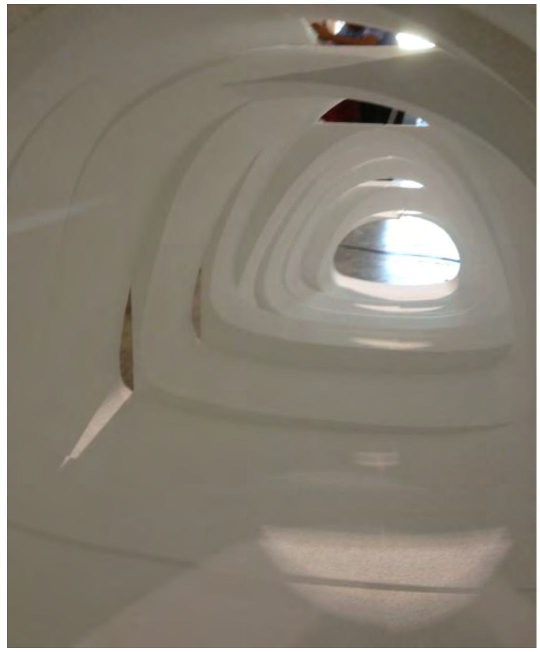


Figure 59 Spare Pieces **Figure 60 Pieces Asembled**

It is imperative to say, that because the hot wire cuts between the two cross sections in a straight line, a tremendous amount of sanding had to be performed. Because of this, one must state that hot wire foam cutting is a great way to make geometries and molds, but it has serious limitations. Because complex curves will demand sanding, human error will be incorporated with the sanding. Furthermore, the more sanding that is needed, the harder it becomes to maintain symmetry among the geometry. Also, because the hot wire is attached to springs, there are further limitations in that if the required angle to cut is high enough, the spring will extend and cause enough tension on the string to cause it to snap, as it did during the manufacturing process of the body. Ultimately, the final product of the mold was generally very similar to the design made, as seen in the next figure, but it is nearly impossible to gage how different one is to the other. To reiterate, this process has the potential to do complex molds, but if the end result requires precision, this method is not recommended.

Figure 61 Assembled Pieces

After the sanding was finished, it was easy to notice that sanding has caused some damage to the foam by taking some significant chunks out, rather than being sanded down. Because of this, a layer of only resin and hardener was applied to the foam in order to smoothen it and seal the holes. Afterwards, another layer of fairing filler was use in order to further improve the holes not covered by the resin alone. A picture can be seen with both coats applied.

Figure 62 Fairing Filler Applied

A few things need to be noted from the previous figure. The fairing filler was great for filling the holes, but it has its drawbacks. For starters, the fairing is a fairly solid and strong material, similar to peanut butter. Thus, it required a squeegee in order to spread the material. Had the team not laid a coat of resin beforehand, the act of spreading the fairing with the squeegee could have easily damaged further the mold rather than improving on it. Second, as seen in the picture, the brown color of the fairing is darker in some areas than other. This means that the application of the material is thicker on some areas than it is in others. This means that further sanding is required in order to level the surfaces and further sanding means further human error and less chance to maintain symmetry in the mold. This further expands on the idea that this method is not ideal for a model that requires precision.

Once the coat was dried, the team went on to sand the mold. As evidenced in the following figure, it proved to be too hard to do by hand, hence pneumatic sanders were used.

Figure 63 Sanding

Once sanding with a high grade sand paper was done, and a polish surface was achieved, the team began applying wax on the surface of the mold. This was done so the fiber glass cloth would not stick to the mold once it had dried. Six layers of wax were applied in total. Removing body without destroying the mold would only be possible if the body slid off easily off the mold. For the most part, it did.

As soon as the wax dried, the team went on to lay the fiberglass cloth on the body. The team laid down 4 layers of fiber glass cloth, while applying a new coat of resin in between each layer of cloth. This part proved to be quite difficult as it was difficult to make the fiber glass contour to the shape of the body. Once the resin mixed with the cloth, it became much easier to shape the cloth into the shape of the mold.

Figure 64 Vacuum Bagging

When the four layers of cloth were applied, the team went on to place the mold inside of a plastic bag in order vacuum forming with the bag. It was intended to compress the bag until 30psi of pressure was achieved, but unfortunately, this was not accomplished. There appeared to have been holes in the bag that did not allow for the vacuum to be able to achieve the desired pressure, and instead air leaked into the bag. The figure to the right shows the setup of the vacuum bagging.

Although the vacuum bagging failed, the end result of the body was very pleasing for the most part. The only significant errors were near the plane were the lower and upper molds were divided. The problem was that because the mold was laying in the ground, and the vacuum didn't work, the cloth seems to have detached from the surface, thus creating a sort of crest around the area of connection between the two molds. This could have been avoided very simply had the mold been lifted from the ground and instead laid to rest atop some object. Nonetheless, the team had to cut off the excess material. As seen in the figure, some parts were cut with simple scissors, but others had to be cut with pneumatic equipment.

Figure 65 Cutting Excess Material

Once the excess material was cut, another round of sanding began. By this point, this would be the third round of sanding. It should be clear by know that it is practically impossible to have maintained symmetry through the body. Moreover, at this point it was questioned if the body had actually experienced significant amount of change. That is, with the amount of material added and the amount of sanding performed at this point begs to question the tolerances from the initial foam mold.

After this round of sanding, a coat of special filler primer paint was used in order to fill any holes that might have been found at this point. The figure on the side depicts the body at this point and the paint job as it was performed.

Figure 66 Primer Applied

The next day, with the paint fully dried, drawing were made directly onto the body of the car in order to decide where the windows and cockpit would be. By competition regulations, the drivers was required to be able to see in the direction of 0, 30, 60, and 90 degrees. Noticeable in the following picture, directly at the top of where the driver's head would rest is a drawing that outlines those angles. This drawing was made in order to ensure that the windows would allow enough visibility to meet the required standards.

Figure 67 Window And Driver Exit Drawings

Once these dimensions were double checked, the cuts went underway. When cutting, some excess was purposely left so that sanding could be performed along the edge for more precision. Something to note, after the cuts were performed due to only applying 4 layers of cloth, the remainder of the body was very flimsy. For future projects, it would be recommended to completely omit the frame, and instead apply enough layers of composite to create a monocoque.

Once the window spaces were cut, Plexiglas was cut to size and attached to the body through the use of rivets. The glass was then heated with a heat gun with hopes that the Plexiglas would contour better to the shape of the body. Although this was definitely an improvement, the results were not perfect.

Lastly, the body was attached to the frame, also through the use of rivets. Initially, the team sought to attach the body in a way that the upper side of the body was removable, but this proved to be impossible, as the time did not allow for it. It wasn't until the car was shipped to Texas that the body was attached completely to the frame. The picture below shows the finished car, with the body attached.

Figure 68 Final Body

7. Testing/Inspection

7.1 Driver's and car's Weight

The first inspection test evaluated the overall weight of the driver with all his/her gear and the weight of the car (without the driver inside). Both our drivers passed the first test after weighing 53 kg and 54 kg, above the minimum weight of 50 kg. Our vehicle surpassed our expectations and weighed only 50 kg, a lot less than the maximum amount of 140 kg allowed by the competition. One of the major factors that contributed to this result was the carbon fiber frame, something that not that many teams had worked with.

Figure 69 - Car weight

7.2 Braking System

One of the tests that gives teams the most trouble is the braking system test. The prototypes are put on a 20-degree slope and have the brakes tested with the driver inside. First, the driver must be able to stop the car using both front and back brakes at the same time. After, both braking systems are tested separately. Fortunatelly, our car passed this test with flying colors. Using recumbent trikes disc brakes rather than bicycle brakes which is used by a good portion of the teams put us in great shape to pass this test without any problem.

Figure 70 - Brake Test

7.3 Turning Radius

The turning radius test is the most exciting one. The car is put through a slalom course and must completely without hitting the cones. Although this is a simple concept, a lot of teams may encounter problems in this test if their steering systems are not fully functional and/or the driver has interacted with the car before. During this test was the very first time our drivers got to experiment what it was like to conduct the vehicle and one of them had to attempt a few times before passing the test. In the end, however, both drivers were approved and were ready to enter the track.

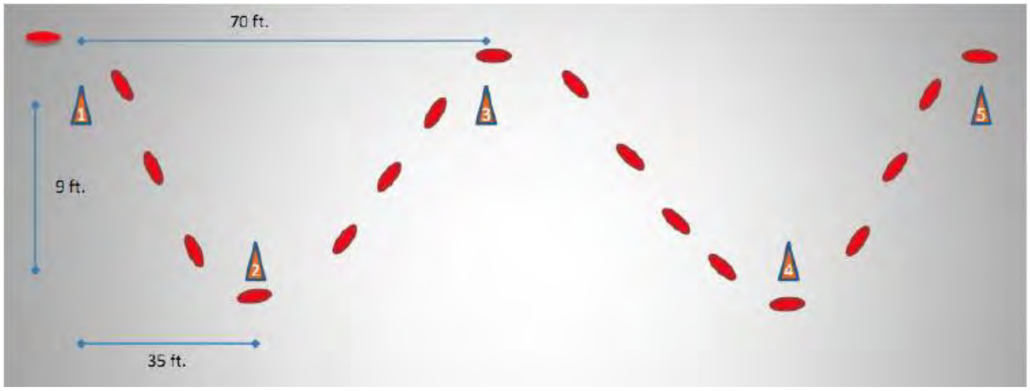


Figure 71 - Slalom

7.4 Safety Harness Test

The Safety harness test is a very simple one, the shell eco marathon staff puts a metal bar with cord that is wrapped around the seat belt. After that, this bar is pushed up and the seat belt must withstand 1.5x the weight of the driver. Since the vast majority of the teams picks extremely light drivers, this test is rarely a problem.

7.5 Emergency Evacuation

The emergency evacuation test is also another one that does not give teams much trouble. Every driver has 10 seconds to get out of the vehicle without any sort of help. Our drivers both passed the test on their first attempt, timing 6.5 and 7.3 seconds.

7.6 Visibility and Horn

The visibility test is most likely one of the most important ones out there. The car is parked in a small rectangle marked on the ground and they must read letters and numbers in cones that are placed every 30^{o} in a 4 m radius from the car. At the same position, the staff also checks for rearview mirrors. It is important that teams do not overlook this small detail that could give them many headaches. Although the rearview mirror test is quite simple, it is essential that the driver has a clear visibility of them during the race. Lastly in the same spot, the horn is tested. The car must be able to generate 85 decibels measured at a similar 4 m radius, fortunately, our car did just enough to pass this test.

Figure 72 - Visibility Test

7.7 Power System

Power system test is the strictest. Since this can put the safety of the drivers in jeopardy, the staff of Shell Eco Marathon takes it very seriously. The first time around our team was required to make minor adjustments, such as fixing the fuel tank to the back of the firewall and replacing the hose for the injection system. After the corrections were made, our team was approved without problems and we were ready to move on. This station is also responsible for filing up your gas tank for the turning radius test and for the teams that want to use the indoor practice test.

7.8 Dimensions

The dimensions test is also another quick one; this test is usually a major problem for urban concept cars only. As long as you read the rules and you follow the basic guidelines for measurements, the vechicle should pass without any problems. To test that, the car is put in a pre-marked location where the testers are able to visualize immediately any irregularities. It is also here where the firewall is check. It is crucial that the car has the cross section in between the engine and the cockpit completely insulated.

Figure 73 - Dimension Test

After our team passed all the inspection, we were given the approval to enter the track to race. As a proof of the approval, two stickers were placed in the car indicating that we were cleared. It is important to reiterate here for teams to not take these tests lightly. It is surprisingly high the number of teams that fail one test and are unable to compete. We spoke to many teams at the event who had had bad experiences in previous years without being able to compete.

Figure 74 - Inspection approval

8. The Event and Results

In between the days of April 4^{th} and April 7^{th} we departed to Houston, TX for the competition. This event was one of the greatest experiences of our lives. In the heart of downtown Houston, at discovery Green Park, once a year, the whole community gets together for the event. Shell Eco Marathon calls attention for being extremely well organized. From the moment we got to the event, to the second we left to the airport, we always had someone to help and direct us to the right path.

One of the most important aspects of SEM is safety. The organizers and staff pride themselves in what they call “goal zero” which means doing anything necessary to maintain absolute safety of all participants.

The first thing you must do once arriving is going through safety video where right after you receive complimentary gifts such as t-shirt and water bottle. Throughout the whole weekend, the organizers walk around enforcing the rules. They are extremely strict with members wearing safety glasses and goggles at all times. Overall, there are other meetings the drivers and team managers must attend but most of the time is dedicated to working individually in your cars.

The overall atmosphere of competition is fantastic, everyone is friendly and looking for the same thing you are, having fun, networking, exchanging engineering ideas and innovating concepts. The hotels are conveniently located at walking distance from the George Brown Convention Center, where all the action takes place.

In short, our team had an experience of a lifetime and we highly recommend the competition for anyone that wants to be challenged and learn hands on engineering in a fun environment.

Figure 75 - George Brown Convention Center

8.1 Crash Analysis

The crash was a product of driver error. The unfortunate event started when the driver suddenly veered left hitting the cones at the track's margin.

At this point the vehicle became entangled with the cones, and seemed to slow down, before the driver suddenly accelerated and crashed into the curb.

In further investigation the driver reported that she veered off course because another vehicle was about to cut her off, but footage from the incident revealed there was no other vehicle in the vicinity when this was taking place. further questioning into why the vehicle continued to accelerate revealed that the driver intended to "shake off the cones that had become lodged around the car's left wheel.

From a racing team standpoint, it could have been avoided by having a more skilled driver, and more time to practice driving the vehicle without the pressure of being in a competition.

From an engineering standpoint the crash could have been prevented by having a more conventional steering system, with a steering wheel in front of the pilot, something that any person with a driver's license is already used to, an option that was previously discarded because of the bulk and visibility constraints that would have been introduced by such a system.

Search options

Display units km/l: mpg (US): mpg (UK):

Number: Competition group: Prototype Organisation type: Country: Energy type: Gasoline

Consumption: CO2: Search Clear filter

Rank	Team no.	Team name		Institution name	Competition category	Energy type	Best result (km/l)
1	77	Alerion Supermileage		Laval University	Prototype	Gasoline	1524.7
2	82	Mater Dei Supermileage Team		Mater Dei High School	Prototype	Gasoline	981.2
3	95	G-Arrows		Sullivan High School	Prototype	Gasoline	616.7
4	12	Cedarville University Supermileage		Cedarville University	Prototype	Gasoline	591.5
5	101	UBC Supermileage Team		University of British Columbia	Prototype	Gasoline	587.8
6	103	Team Tatonka		University of Colorado at Boulder	Prototype	Gasoline	547.1
7	62	Cal Poly Supermileage		California Polytechnic State University	Prototype	Gasoline	514.4
8	65	Revenge of Engi-Nerds		Colorado School of Mines	Prototype	Gasoline	410.8
9	66	Sexton Supermilers		Dalhousie University	Prototype	Gasoline	410.3
10	58	Knights 3		Alden-Conger	Prototype	Gasoline	396.4
11	106	University of Michigan Supermileage Team		University of Michigan - Ann Arbor	Prototype	Gasoline	354.5
12	111	Wawasee Green		Wawasee High School	Prototype	Gasoline	295.5
13	110	Warsaw Super Mileage Team		Warsaw Area Career Center	Prototype	Gasoline	274.5
14	81	LMU Lions		Loyola Marymount University	Prototype	Gasoline	258.2
15	91	Rose-Hulman Efficient Vehicles		Rose-Hulman Institute of Technology	Prototype	Gasoline	248.5
16	80	LMU Mechanical Engineering Seniors		Loyola Marymount University	Prototype	Gasoline	222.6
17	83	Team Carbonair		Milwaukee School of Engineering	Prototype	Gasoline	222.2
18	86	Peak Performance		Northern Arizona University	Prototype	Gasoline	203.7
19	75	Kimberly Black		Kimberly High School	Prototype	Gasoline	199.1
20	72	Goshen Beta		Goshen High School	Prototype	Gasoline	193.7
21	93	Rowan Motorsports		Rowan University	Prototype	Gasoline	178.4
22	121	Schurr High School Spartans		Schurr High School	Prototype	Gasoline	175.9

Figure 76 – Competition Results

9. Conclusions & Recommendations

This team successfully created a competition worthy hyper mileage vehicle but did not have enough time to conduct all the testing necessary for proper vehicle optimization. Teams continuing this FIU tradition should begin vehicle manufacturing with a more proactive schedule, and choose a driver not only based on size and weight, but also in skill.

Damage Report

The driver reported no pain or ailments after the incident, except for minor bruising where the seatbelt harness held her in place.

Besides damaging the car's body, the impact sheared the left side of the front carbon fiber axle which took most of the impact against the curb, this also bent the connecting tierod. Furthermore, the left tire also blew up, and the rim was ground to the point that a sharp edge was created near the edge where it meets the rubber, creating a puncture hazard for any spare.

Figure 77 – Damage

Repair assessment

-The body has to be removed from the frame and it must undergo fiberglass repairs and a new paint job.

-The left axle can be repaired with an aluminum ferrule, carbon fiber tow and epoxy adhesive.

-The sharp edge on the rim can be repaired by fairing it with some epoxy

-A new tierod should be manufactured in order to replace the bent one

-Finally, new tires are required to restore traction to the front end.

Appendices

Appendix A: Shell's Rules and Regulations

Identification Requirements

a) Logos, official partner streamers and racing numbers must be fixed to the vehicle body in accordance with the diagram provided (see Chapter II) such that they can be clearly read during any public presentation, in promotional films and on all photographs for team use, school use, press or promotional material.

b) Under no circumstances may the Shell logos, the partner streamers or racing numbers be modified, either on the vehicle or on any other documentation. It is prohibited to cut the stickers supplied by the Organizers. Their dimensions are as follow:

For each side and for the front of the vehicle: a Shell logo, 20 x 20 cm.

For each side and for the front of the vehicle: racing numbers, 20 x 26 cm

For each side, on the lower part of the body: a partner streamer, 90 x 6cm.

c) A mandatory 10 cm space must be left free on all four sides of the Shell logo.

d) Any other sponsor names / logos must be smaller than the Shell logo. The sponsor stickers must fit within a surface of 400 cm2 (empty space included)

e) In the event of a breach of this rule, the Organisers reserve the right to remove any sponsor logos.

f) Furthermore, the trademarks or logos of other energy companies, direct competitors of event partners, tobacco companies and alcoholic drinks producers are prohibited.

g) All vehicles are subject to the Organisers' approval concerning these provisions.

Driver Weight

a) Drivers of Prototype vehicles must weigh at least 50 kg in full driving gear, including communication devices, prior to an attempt. Ballast must be fitted to the vehicle in the event the minimum weight requirement is not met. This ballast must be provided by the Team, and must be effectively tied down and secured to the vehicle to ensure no danger for the Driver in the event of collision or roll-over. It must be easily detachable for weighing.

b) The Driver (in full driving gear, including communication devices) and the ballast may be weighed before or after each official attempt. A weight loss of up to 1 kg during an attempt will be tolerated.

Driver Safety

a) For practice and competition, Drivers must wear Motorcycle or Motorsport style helmets that comply with the safety standards specified in Chapter II of the Official Rules of each Shell Eco-marathon event (bicycle/riding/skating type helmets are not permitted). The helmet labels must be clearly readable. Helmets worn by both the Driver and Reserve Driver will be subject to inspection.

b) Only full-face or three quarter helmets are permitted. Generally, the full-face and three quarter style helmets can be affixed with face shields which are highly recommended. If a face shield is not utilised, safety goggles are required. The helmets must correctly fit the Drivers; otherwise they will not be approved for the event.

c) All Drivers must wear a racing suit as the outermost layer of clothing (fire retardant highly recommended). Casual clothing and street wear are not permitted.

Chapter II provides further guidelines regarding the racing suit specifications and availability. Wearing synthetic outer clothes or underwear is strictly forbidden for Drivers when seated in their vehicle.

d) Gloves and shoes are required and must be provided by the team; bare feet or socks only are prohibited.

e) The Driver's seat must be fitted with an effective safety harness having at least five mounting points to maintain the Driver in his/her seat.

f) Each vehicle must be fitted with a fire extinguisher (ABC or BC type). All Drivers must be trained in the use of said fire extinguisher. This extinguisher must have a minimum extinguishing capacity of 1 kg (2 lb for US application); equivalent size extinguishers are not permitted. It must be full and have a certificate of validity bearing the manufacturer's number and the date of manufacture or expiry.

g) An emergency shutdown system, operable from both, the exterior of the vehicle and the interior driver position, must be permanently installed on all vehicles (not part of the detachable bodywork used to allow driver access).

Vehicle Design

a) Prototype vehicles must have three or four running wheels, which under normal running conditions must be all in continuous contact with the road.

b) Vehicle bodies must not be prone to changing shape due to wind and must not include any external appendages that might be dangerous to other Team members; e.g. pointed part of the vehicle body. Any sharp points must have a radius of 5 cm or greater, alternatively they should be made of foam or similar deformable material.

c) Windows must not be made of any material which may shatter into sharp shards. Recommended material: Polycarbonate (e.g. Lexan)

d) The vehicle chassis must be equipped with an effective roll bar that extends 5 cm around the driver's helmet when seated in normal driving position with the safety belts fastened. Any roll bar must be capable of withstanding a static load of 700 N (~ 70 kg) applied in a vertical, horizontal or perpendicular direction, without deforming (i.e. in any direction).

Visibility

a) The Driver must have access to a direct arc of visibility ahead and to 90° on each side of the longitudinal axis of the vehicle. This field of vision must be achieved without aid of any optical (or electronic) devices such as mirrors, prisms, periscopes, etc. Movement of the Driver's head within the confines of the vehicle body to achieve a complete arc of vision is allowed.

b) The vehicle must be equipped with a rear-view mirror on each side of the vehicle, each with a minimum surface area of 25 cm2 (e.g. 5 cm x 5 cm). The visibility provided by these mirrors, and their proper attachment, will be subject to inspection. An electronic device must not replace a rear-view mirror.

Clutch, Transmission and Exhaustion

a) All vehicles with internal combustion engines must be equipped with a clutch system.

b) For centrifugal / automatic clutches the starter motor speed must always be below the engagement speed of the clutch.

c) The installation of effective transmission chain or belt guard(s) is mandatory.

d) The exhaust gases must be evacuated outside the vehicle body.

e) All exhaust components must be made of metal.

Dimensions

a) The maximum height must be less than 100 cm.

b) The maximum height measured at the top of the Driver's compartment must be less than 1.25 times the maximum track width between the two outermost wheels.

c) The track width must be at least 50 cm, measured between the midpoints where the tyres touch the ground.

d) The wheelbase must be at least 100 cm.

e) The maximum total vehicle width must not exceed 130 cm.

f) The maximum total length must not exceed 350 cm.

g) The maximum vehicle weight, without the Driver is 140 kg.

Wheels, Braking and Steering

a) All types of tires and wheels are allowed.

b) Front wheel or rear wheels steering is permitted. If rear wheel steering is used then it should be easy for the driver to locate the straight-ahead position.

c) The turning radius must be sufficient to enable safe overtaking as well as negotiating the turns of the track.

d) Vehicles must be equipped with two independently activated brakes or braking systems; each system comprising of a single command control (lever(s) working together or foot pedal), command transmission (cables or hoses) and activators (callipers or shoes).

e) One system has to act on all front wheel(s), the other on all rear wheel(s). When braking on two steering wheels at the front, two activators (callipers or shoes) have to be used-one on each wheel, commanded by only one command control. In addition, the right and left brakes must be properly balanced.

f) The effectiveness of the breaking systems will be tested during vehicle inspection. The vehicle will be placed on an incline with a 20 percent slope. The brakes will be activated each in turn. Each system alone must keep the vehicle immobile.

Appendix B: Participant's Guide

PARTICIPANT HANDBOOK

Shell
Eco-marathon®

YOU ARE DRIVING INNOVATION

With growing global population and rising affluence driving increased demand for energy, the world will need to draw on all types of energy and make the most of valuable resources. Innovation will be vital to boosting efficiency and to unlocking the energy needed today and in the future.

Shell Eco-marathon encourages youthful creativity and clever use of technology to help address society's energy-related challenges. It brings together students, partners and the public to help drive innovation forward.

A BIT OF HISTORY...

Shell Eco-marathon can trace its roots back to 1939 and a friendly bet between scientists at a Shell research facility in Illinois, USA, as to who could drive their own car the furthest on the least amount of petrol. The winner managed a little over 21 kilometres on one litre of fuel (49.72 miles per gallon).

In 1985, Shell harnessed the same spirit of friendly competition and launched Shell Eco-marathon in Europe. The event inspires students to find creative approaches to efficiency, encourages a spirit of collaboration and gives hands-on experience in problem-solving. Now in its 29th edition Shell Eco-marathon has gone global and thousands of students sign up for the challenge.

SO WHAT HAPPENS THIS YEAR?

The Americas: From April 4-7, Shell Eco-marathon Americas competitors will take to the road in the heart of downtown Houston, at Discovery Green Park. This urban setting brings the event to the public and gives drivers the challenge of handling real streets.

Europe: Shell Eco-marathon Europe is taking place on a specially-designed street circuit in Rotterdam, the Netherlands, on May 15-19. The circuit poses challenges to drivers as they strive for top efficiency while negotiating five 900 corners.

Asia: The Sepang International Circuit in Kula Lumpur, which is home to the Malaysian leg of the Formula 1 World Championship, will host Shell Eco-marathon Asia from July 4-7.

In all three events, teams of students aged 16-25 will have the opportunity to test the energy efficiency of cars they have been developing for months, or even years.

SHELL ECO-MARATHON AMERICAS – KEY FACTS

- More than 1,100 students and teachers are expected on site in Houston, Texas.
- Currently 139 vehicles are registered to participate.
- 5 countries are represented from across the Americas:
  - Brazil, Canada, Guatemala, Mexico and the United States.
- This year, 78% (108) of the vehicles are in the Prototypes category while 22% (31) are in the UrbanConcept category.
- 53 vehicles make up the E-mobility class (Hydrogen, Battery Electric)
- 86 vehicles make up the Internal Combustion class (Gasoline, Diesel, FAME, Ethanol)
- There are six energy categories:
  - Internal combustion
    - Gasoline
    - Diesel
    - Fatty Acid Methyl Esther (100% FAME)
    - Ethanol E100 (100% Ethanol)
  - E-mobility
    - Hydrogen
    - Battery Electric

TEAMS RACING IN EACH ENERGY TYPE

FUEL CLASS	TEAMS	% OF TOTAL
Gasoline (Petrol)	62	45%
Diesel	11	8%
Ethanol	8	6%
Hydrogen fuel cell	11	8%
Battery Electric	42	30%
Fatty Acid Methyl Ester (100% FAME)	5	3%
Total	139	100%

2012 RESULTS TO BEAT

The following grids provide information on the top 2012 Eco Marathon Americas results.

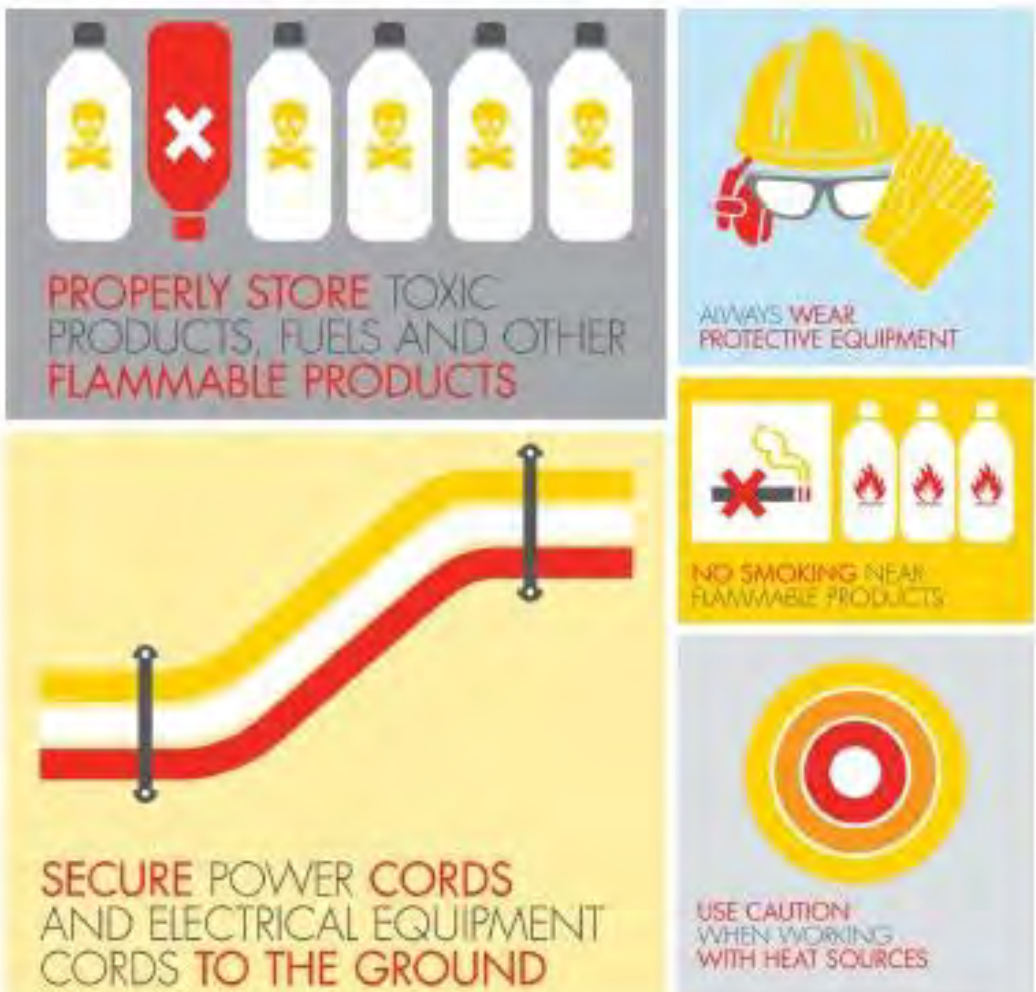
CATEGORY	ENGINE	MPG	INSTITUTION
Prototype	Gasoline Energy	2,188.6	Mater Dei High School in Evansville, Ind.
	Battery Electric	419 mi/kWh (1,587 MPG equivalent)	Mater Dei High School in Evansville, Ind.
	Alternative Gasoline Energy	1,441.5	Mater Dei High School in Evansville, Ind.
	Diesel Energy	1,289.8	Wawasee High School in Syracuse, Ind.
	Alternative Diesel Energy	674.9	Alden-Conger High School in Alden, Minn.
	Solar Power	63.2 mi/kWh (239 MPG equivalent)	The Newburgh Free Academy team from Newburgh, N.Y
	Fuel cell (hydrogen)	44.6 mi/kWh equivalent to 169 MPG	Cicero North-Syracuse High School team from Cicero, N.Y
UrbanConcept	Gasoline Energy	611	Mater Dei High School in Evansville, Ind.
	Diesel Energy	488.7	Louisiana Tech University in Ruston, La.
	Solar Power Energy	69 mi/kWh (261 mpg equivalent)	The Purdue University team from West Lafayette, Ind.
	Battery Electric	49.5 mi/kWh (187 mpg equivalent)	The Grand Rapids High School team from Grand Rapids, Minn
	Alternative Diesel Energy	106.1	The Warsaw Area Career Center team from Warsaw, Ind.
	Fuel cell (hydrogen)	7.6 mi/kWh equivalent to 66 MPG	The University of Illinois Urbana-Champaign team from Champaign, Ill.

GOAL ZERO AT SHELL ECO-MARATHON

Goal Zero: Zero harm to people, zero harm to the environment. Please remember:

- No smoking near flammable products.
- Always wear protective equipment.
- Use caution when working with heat sources.
- Properly store tools: products, fuels and other flammable products.
- Secure power cords and electrical equipment cords to the ground.

When you don't know... just ask. Let's work together to make Shell Eco-marathon 2012 the safest and most successful yet.



COMPETITION SCHEDULE

THURSDAY – 4/4	ACTIVITY	LOCATION	NOTES
8:00 AM – 12:00 PM	Team Pre-Registration Opens for Eligible Teams	GRB Convention Center	Hall C
11:00 AM – 11:45 AM	Smarter Driving Game Show with Mileage Experts John and Helen Taylor	GRB Convention Center	Upstairs Balcony D
12:00 PM – 9:00 PM	Team Registration Opens for All Teams	GRB Convention Center	Hall C
12:00 PM	Paddock Area Opens	GRB Convention Center	Hall BC
12:00 PM	Technical Inspection Opens	GRB Convention Center	Hall B
6:30 PM	Technical Inspection Queue Closes	GRB Convention Center	Hall B
7:00 PM	Technical Inspection Closes	GRB Convention Center	Hall B
7:30 PM	Team Safety Discussion	GRB Convention Center; Discovery Green	TBD
7:30 PM	Drivers Meeting; Walking Tour of Course MANDATORY (ALL DRIVERS MUST ATTEND ONCE)	GRB Convention Center; Discovery Green	Start Area
FRIDAY – 4/5	**ACTIVITY**	**LOCATION**	**NOTES**
All Day	Paddock Area Opens	GRB Convention Center	Hall BC
7:00 AM – 9:00 AM	Breakfast at Shell Hotels	Hotel	Hotel
7:00 AM – 9:00 AM	Breakfast at GRB Convention Center (Campers)	GRB Convention Center	Hall A3
7:30 AM	Drivers Meeting Walking Tour of Course MANDATORY (ALL DRIVERS MUST ATTEND ONCE)	GRB Convention Center; Discovery Green	Start Area
8:00 AM – 6:00 PM	Team Registration Open	GRB Convention Center	Hall C
8:00 AM	Team & Vehicle Staging for Group Photo	Discovery Green	Main Stage
8:30 AM	Really Big Group Photo	Discovery Green	Main Stage
8:45 AM	Team Safety Meeting – ALL	Discovery Green	Main Stage
9:00 AM	Official Opening Ceremonies	Discovery Green	Main Stage
9:30 AM	Technical Inspection Opens	GRB Convention Center	Hall B
9:30 AM – 1:15 PM	Prototype Starting Queue Opens	Discovery Green	Start Area
10:00 AM – 10:00 PM	Interior Practice Track Opens	GRB Convention Center	Hall A
10:00 AM – 2:00 PM	Prototype ONLY Runs	Discovery Green	Start Area
1:30 PM – 3:00 PM	UrbanConcept Starting Queue Opens	Discovery Green	Start Area
2:00 PM – 3:45 PM	UrbanConcept ONLY Runs	Discovery Green	Start Area

3:45 PM	Track Closed	Discovery Green	Start Area
5:30 PM	Technical Inspection Queue Closes	GRB Convention Center	Hall B
6:00 PM	Technical Inspection Closes	GRB Convention Center	Hall B
6:00 PM	Team Safety Meeting - ALL except drivers	GRB Convention Center; Discovery Green	Hall A
6:00 PM	Drivers Meeting: Walking Tour of Course (ALL DRIVERS MUST ATTEND ONCE)	Discovery Green	Start Area
7:00 PM – 10:00 PM	Dinner – Chipotle	Discovery Green	Jones Lawn
7:30 PM – 9:00 PM	Tribology Speed Matching Session	GRB Convention Center	Hall A
SATURDAY – 4/6	**ACTIVITY**	**LOCATION**	**NOTES**
All Day	Paddock Area Opens	GRB Convention Center	Hall BC
7:00 AM – 9:00 AM	Breakfast at Shell Hotels	Hotel	Hotel
7:00 AM – 9:00 AM	Breakfast at GRB Convention Center (Campers)	GRB Convention Center	Hall A3
7:30 AM – 8:00 AM	Drivers Meeting MANDATORY	GRB Convention Center	Hall A
8:00 AM – 6:00 PM	Team Registration Open	GRB Convention Center	Hall C
9:00 AM	Technical Inspection Opens	GRB Convention Center	Hall B
8:00 AM – 10:15 AM	Prototype Starting Queue Opens (Prototype Session #1)	Discovery Green	Start Area
8:30 AM – 11:00 AM	Prototype ONLY Runs	Discovery Green	Start Area
9:00 AM – 10:00 PM	Interior Practice Track Opens	GRB Convention Center	Hall A
10:30 AM	Last Prototype Run Starts	Discovery Green	Start Area
10:30 AM – 11:45 AM	UrbanConcept Starting Queue Opens (UrbanConcept Session #1)	Discovery Green	Start Area
11:00 AM – 12:30 PM	UrbanConcept ONLY Runs	Discovery Green	Start Area
12:00 PM	Last UrbanConcept Run Starts	Discovery Green	Start Area
12:30 PM – 1:30 PM	Track Closed – Lunch		
1:00 PM – 2:45 PM	UrbanConcept Starting Queue Opens (UrbanConcept Session #2)	Discovery Green	Start Area
1:30 PM – 3:30 PM	UrbanConcept ONLY	Discovery Green	Start Area
3:00 PM	Last UrbanConcept Run Starts	Discovery Green	Start Area
3:00 PM – 6:15 PM	Prototype Starting Queue Opens (Prototype Session #2)	Discovery Green	Start Area
3:30 PM – 7:00 PM	Prototype ONLY Runs	Discovery Green	Start Area
5:30 PM	Technical Inspection Queue Closes	GRB Convention Center	Hall B
6:00 PM	Technical Inspection Closes	GRB Convention Center	Hall B
6:30 PM	Last Prototype Run Starts	Discovery Green	Start Area

7:00 – 10:00 PM	Dinner – Buffet at The Grove Restaurant	Discovery Green	The Grove
8:00 – 10:00 PM	Entertainment - TBD	Discovery Green	Main Stage
SUNDAY – 4/7	**ACTIVITY**	**LOCATION**	**NOTES**
All Day	Paddock Area Opens	GRB Convention Center	Hall BC
7:00 AM – 9:00 AM	Breakfast at Shell Hotels	Hotel	Hotel
7:00 AM – 9:00 AM	Breakfast at GRB Convention Center (Campers)	GRB Convention Center	Hall A3
7:30 AM – 8:00 AM	Drivers Meeting MANDATORY	GRB Convention Center; Discovery Green	Hall A
8:00 AM – 8:15 AM	Team Safety Meeting – ALL	GRB Convention Center	Hall A
8:00 AM – 12:00 PM	Team Registration Open	GRB Convention Center	Hall C
8:30 AM	Technical Inspection Opens	GRB Convention Center	Hall B
8:00 AM – 9:15 AM	UrbanConcept Starting Queue Open (UrbanConcept Session #3)	Discovery Green	Start Area
8:30 AM – 10:00 AM	UrbanConcept ONLY Runs	Discovery Green	Start Area
9:00 AM – 3:00 PM	Interior Track Opens	GRB Convention Center	Hall A
9:30 AM	Last UrbanConcept Run Starts	Discovery Green	Start Area
9:30 AM – 2:15 AM	Prototype Starting Queue Opens (Prototype Session #3)	Discovery Green	Start Area
10:00 AM – 3:00 PM	Prototype ONLY Runs	Discovery Green	Start Area
2:30 PM	Last Prototype Run Starts	Discovery Green	Start Area
2:30 PM	Technical Inspection Queue Closes	GRB Convention Center	Hall B
2:30 PM – 4:15 PM	UrbanConcept Starting Queue Opens (UrbanConcept Session #4)	Discovery Green	Start Area
3:00 PM	Technical Inspection Closes	GRB Convention Center	Hall B
3:00 PM – 5:00 PM	UrbanConcept ONLY Runs	Discovery Green	Start Area
4:30 PM	Last UrbanConcept Run Starts	Discovery Green	Start Area
5:00 – 6:00 PM	Dinner – Italian Buffet	Discovery Green	Discovery Green
6:00 PM – 7:30 PM	Awards Ceremony	GRB Convention Center	General Assembly
MONDAY – 4/8	**ACTIVITY**	**LOCATION**	**NOTES**
7:00 AM - 9:00 AM	Breakfast at GRB Convention Center (Campers)	GRB Convention Center	Hall A3
9:00 AM	GRB Convention Center Closed	GRB Convention Center	Halls ABC/A3

TRACK MAP

PADDOCK (1)

The paddock area is home to more than 130 vehicles registered to compete in this year's Shell Eco-marathon Americas, representing Brazil, Canada, Guatemala, Mexico, and the United States.

SAFETY AND TECHNICAL INSPECTIONS (2)

Safety is priority number one at Shell Eco-marathon – both off and on the track. Vehicles must pass a safety inspection prior to accessing the track for test runs. Strict regulations apply for drivers to wear flame retardant racing suits, safety harnesses and helmets.

SPONSORS (3)

Our sponsors help us provide a premier competition experience for student participants with access to technical experts, software and other tools and resources. We have three of our sponsors with us this year: Michelin, SKF, and Southwest Research Institute (SwRI).

SHELL RECRUITMENT (4)

Interested in driving innovation at Shell? Visit our recruitment team to learn about opportunities for graduate and experienced hires.

MERCHANDISE (5)

Want your own Shell Eco-marathon merchandise? Visit our merchandise area and browse through commemorative merchandise from events over the years.

MOBILITY FOOTPRINT ZONE (6)

An interactive, enlightening exhibit highlighting how innovation is helping to solve energy challenges and keep the world moving in cleaner, more energy efficient ways. You'll also be challenged to join a special group of one million smart drivers around the world and win prizes!

KINETIC DANCE FLOOR (7)

Come check out our kinetic dance floor. You can see how much energy you can build up while dancing the day away. And all of that energy can be used to charge your cell phone at the cell phone docking stations.

SALT WATER CARS (8)

Come get your salt water car and compete against your friends!

UN MPOWERING (9)

Visit the state of the art Mobile Recording Studio that travels all over the world to capture unique and exclusive content from top music artists, athletes and other celebrities for mPowering Action. mPowering Action is a global movement that leverages entertainment and mobile technology to connect people around global issues, while providing them tools to play an active role in the solutions. As a founding corporate partner of mPowering Action, Shell is instrumental in empowering youth everywhere to address critical issues that affect the future or our world. Come check out the bus and exciting mPowering Action digital activities!

PARTICIPANT DRIVING TEST SLALOM COURSE (10) HALL A

Shell Eco-marathon Americas takes place in an urban environment on city streets, therefore, to help ensure driver safety and reduce the chance of any inadvertent damage to vehicles, we require all drivers to pass a driving test on this slalom course before they can take their vehicle on the track.

INDOOR PRACTICE TRACK (11) HALL A

This indoor practice track allows student teams to log more practice time and fine-tune their driving strategy before they make their official competition attempts.

NATIONAL CSTEM CHALLENGE (12) 3RD FLOOR AUDITORIUM (SATURDAY)

The International CSTEM Challenge features student teams (P-12) from 18 schools across the U.S. and Dominican Republic, showcasing their "Everyone is an Artist and an Engineer" projects to present solutions to water pollution and the growing size of Dead Zones in various bodies of water across the globe. CSTEM, a 501 (c)(3) organization since 2002, provides STEM support services to teachers and students to assist Pre K through 12th grade schools with closing the achievement gap among underserved and underrepresented students. Learn more about CSTEM at www.cstem.org.

START / FINISH LINE (13)

When teams bring their cars out on the track, they enter the Start Fuelling Tent and their vehicles are inspected and prepared for their start. Once a team finishes an attempt, they proceed to the Finish Line and into the Timing Tent, where the Official Timekeeper determines whether they completed their attempt within the required time allotted for their vehicle class.

PARK EXHIBITORS (14) DISCOVERY GREEN

While visiting Discovery Green, stop by and visit the No. 22 Shell-Pennzoil Ford, Radio Disney, Shell 1959 Fiat and learn more about the upcoming Shell and Pennzoil Grand Prix of Houston. There's also plenty of fun for the kids with activities by San Jacinto College, Houston Museum of Natural Science, Society of Women Engineers, Shell Pipeline, Subsea Intervention and TAME Trailer. You can also try to spin and win at the Shell Fuel Reward Network booth!

TRACK INFORMATION

- Lap = 0.6 miles
- Total laps for a complete run = 10 for a total of 6 miles
- Average speed = 15mph (may change pending review of Event Organizers)
- Time requirements = 24:15 Prototype vehicle / 24:45 UrbanConcept vehicle
- The maximum number of Prototype or UrbanConcept vehicles safely permitted on track will be determined by the Race Marshalls.

PAVEMENT

- Main straightaway (Avenida De Las Americas) – asphalt (4 lanes)
- La Branch – asphalt (3 lanes)
- McKinney and Lamar – concrete (3 lanes)
- Average lane width – 11.0'

PADDOCK AREA MAP

FUEL CATEGORY

Battery Electric	43
Diesel	11
Fatty Acid Methyl Ester (100% FAME)	5
Ethanol E100 (100% Ethanol)	8
Gasoline	62
Hydrogen	11
TOTAL NO. OF CARS	140

LIST OF PARTICIPATING TEAMS – AS OF 3/25/13

DIESEL

RACE NO.	PADDOCK	SCHOOL	TEAM NAME	STATE / COUNTRY	CLASS
37	10	Alden-Conger High School	Alden-Conger	MN / USA	Prototype
300	43	Aurora High School	Aurora High School	MO / USA	UrbanConcept
38	36	Gordon Cooper Tech Center	The Coopers	OK / USA	Prototype
39	25	Granite Falls High School	ShopGirls	WA / USA	Prototype
301	30	Granite Falls High School	UrbanAutos	WA / USA	UrbanConcept
40	62	Livingston High School	EcoLancers	NJ / USA	Prototype
302	33	Louisiana Tech University	Louisiana Tech Eco-Car	LA / USA	UrbanConcept
303	34	North DeSoto High School	Griffins	LA / USA	UrbanConcept
41	35	Sullivan High School	G-Arrows	IN / USA	Prototype
42	146	University Alaska Fairbanks	Nanook	AK / USA	Prototype
44	29	Wawasee High School	Wawasee Gold	IN / USA	Prototype

RACE NO.	PADDOCK	SCHOOL	TEAM NAME	STATE / COUNTRY	CLASS
54	141	University of Illinois at Urbana-Champaign	Eco Illini	IL / USA	Prototype

GASOLINE

RACE NO.	PADDOCK	SCHOOL	TEAM NAME	STATE / COUNTRY	CLASS
57	48	Airline/Haughton	Airline/Haughton	LA / USA	Prototype
58	23	Alden-Conger High School	Knights 3	MN / USA	Prototype
60	55	Baton Rouge Magnet High School	Baton Rouge High	LA / USA	Prototype
61	54	Bradley University	Bradley University	IL / USA	Prototype
62	27	California Polytechnic State University	Cal Poly Supermileage	CA / USA	Prototype
3	46	Cedarville University	Cedarville University Supermileage	OH / USA	UrbanConcept
12	53	Cedarville University	Cedarville University Supermileage	OH / USA	Prototype
64	87	Central High School	Bear Racing	IN / USA	Prototype
65	37	Colorado School of Mines	Revenge of Engi-Nerds	CO / USA	Prototype
66	125	Dalhousie University	Sexton Supermilers	NS / CAN	Prototype
119	11	Durand High School	Durand Motorsports	WI / USA	Prototype
67	82	East Los Angeles College	Husky Pack	CA / USA	Prototype
69	126	Fairfield Jr/Sr High School	Falcons	IN / USA	Prototype
70	64	Florida International University	FIU Eco Shell 2013	FL / USA	Prototype
71	79	Goshen High School	Goshen Alpha	IN / USA	Prototype
72	84	Goshen High School	Goshen Beta	IN / USA	Prototype
74	91	Kimberly High School	Kimberly White	WI / USA	Prototype
75	95	Kimberly High School	Kimberly Black	WI / USA	Prototype
76	100	Kimberly High School	Kimberly Red	WI / USA	Prototype
501	107	Kimberly High School	Kimberly Green	WI / USA	UrbanConcept
77	137	Laval University	Alerion Supermileage	QC / CAN	Prototype
78	65	Livingston High School	EcoLancers	NJ / USA	Prototype
79	40	Louisiana Tech University	Louisiana Tech Eco-Car	LA / USA	Prototype
502	32	Louisiana Tech University	Louisiana Tech Eco-Car	LA / USA	UrbanConcept
503	39	Louisiana Tech University	Louisiana Tech Eco-Car	LA / USA	UrbanConcept
80	63	Loyola Marymount University	LMU Mechanical Engineering Seniors	CA / USA	Prototype
81	66	Loyola Marymount University	LMU Lions	CA / USA	Prototype
82	15	Mater Dei High School	Mater Dei Supermileage Team	IN / USA	Prototype
504	22	Mater Dei High School	Mater Dei	IN / USA	UrbanConcept

BREAKDOWN OF PARTICIPATING TEAMS – AS OF 3/25/13

CLASS	
UrbanConcept	31
Prototype	108
Total	139

ENERGY SOURCE	
Gasoline	62
Diesel	11
Hydrogen	11
Battery Electric	42
FAME	5
Ethanol	8
Total	139

COUNTRIES	
USA	72
Brazil	3
Canada	7
Guatemala	1
Mexico	3
Total	139

VEHICLE SNAPSHOT	
Prototype	108
UrbanConcept	31
Total	139

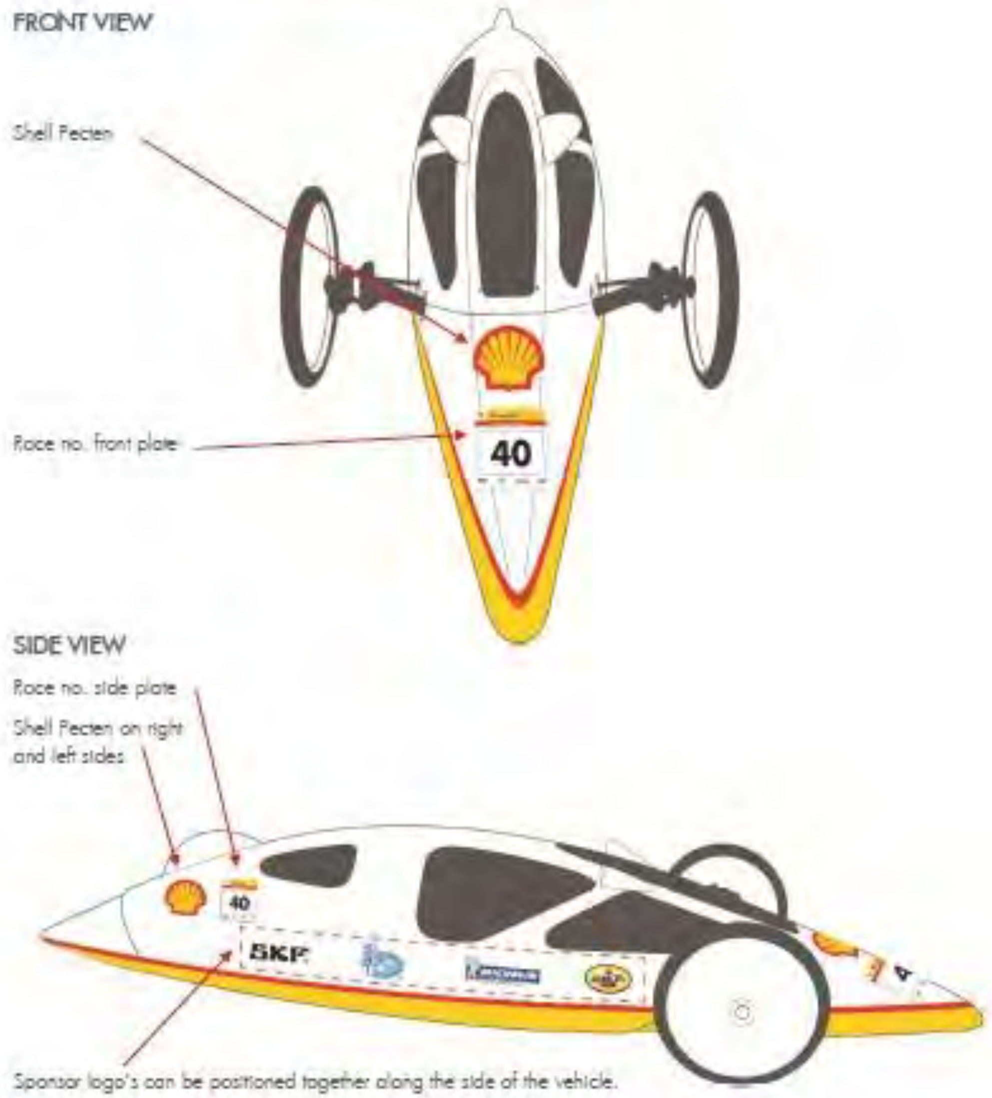
SCHOOLS	
High Schools	38
Universities	47
Total	85

CATEGORY	
E-mobility	53
Internal Combustion	86
Total	139

U.S. STATES	
Alaska	6
Alabama	1
Arizona	2
California	7
Colorado	3
Connecticut	1
Florida	1
Idaho	1
Illinois	5
Indiana	22
Louisiana	16
Michigan	2
Minnesota	9
Missouri	2
New Jersey	4
New York	7
North Carolina	4
Oklahoma	1
Ohio	6
Pennsylvania	3
Texas	10
Washington	2
Wisconsin	10
Total	125

IDENTIFICATION OF PROTOTYPE VEHICLES

Note: On the front of the vehicle, the Pecten may be above the race no.



Sponsor logo's can be positioned together along the side of the vehicle.
Dimensions will vary depending on shape and design of vehicle.

Appendix C: Trial Sample

SHELL ECO-MARATHON 2013

Date: 4/6/13 **Session No.** P2

Team No. 10

Run No. 1 2 3 4

Approx Start of Run: 6:20

Total Time of Run: ______

Energy Category

Gasoline Ethanol Diesel Bio-Diesel Hydrogen GTL BEV

Vehicle's Operating Fuel Pressure: 35 psi

Volumetric Measure

Initial Temp. at Start 24.0 °C

Pre Addition Temp. at Burette ______ °C

Final Temp. after Refill ______ °C

Volume of Fuel Added ______ mls

Gravimetric Measure

Starting Weight of Fuel System ______ grams

Final Weight of Fuel System ______ grams

Total Fuel Consumed ______ grams

Hydrogen Measure Battery Volts - SoR

Flow Meter at Start of Run ______

Flow Meter at End of Run ______

Battery Electric Measure Battery Volts - SoR

Joulemeter must be **zeroed** at Start of Run (Initial)

Joule-Meter at End of Run ______

Battery Electric with Solar Measure

Joulemeters must be **zeroed** at Start of Run (Initial)

Joulemeter 1 (Solar Panel) @ End of Run ______

Joulemeter 2 (Battery) @ End of Run ______

Valid Run: YES NO

Control Number: 00355

White: Time Keeper Yellow: Finish Line Pink: Driver

531

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