جامعة الأمير محمد بن فهد

PRINCE MOHAMMAD BIN FAHD UNIVERSITY

College of Engineering

Department of Mechanical Engineering

Spring 2019-20

Senior Design Project Report

Aerodynamic of Solar Car (CFD)

In partial fulfillment of the requirements for the Degree of Bachelor of Science in Mechanical Engineering

Team Members

	Student Name	Student ID
1	Abdulaziz Alwakeel	201501068
2	Omar Albuainain	201602964
3	Ibrahim Almajed	201700331
4	Abdullah Almessairei	201600094
5	Abdullah Almazyad	201502740

Project Advisors:

Advisor Name: **Dr. Esam Jassim**

Abstract

Aerodynamics is a science that studies the movement of air and its effects on a solid body, where this body will be positioned in the flow field as an obstacle. As a matter of fact, aerodynamics is a sub-field, where the fundamentals of mainly fluid dynamics and thermodynamics are implemented, including all governing equations, boundary layer theory, ideal gas assumption, and turbulence. This project adopts the method of using computational fluid dynamics (CFD) to design a body for a solar car, and this is a branch from fluid mechanics that applies numerical analysis as well as data structures to analyze problems involving fluid flows. In other words, it is a tool for generating solutions for fluid flows whether with or without solid interaction. Furthermore, in a CFD analysis, the conductance of examinations is done according to multiple properties such as velocity, pressure, temperature, density, and viscosity. These properties have to be simultaneously considered in order to virtually generate a solution for any physical phenomenon that involves fluid flow. For this project, a car body is designed using SOLOD WORKS, where this body is required to have a drag coefficient of at least 0.2 after testing the design in ANSYS. Consequently, a car body was finalized having all required geometries, in addition to having streamlined, smooth body shape that will surely boost its aerodynamic capabilities. This, after manufacturing the car and having it driven, will enable it to be extremely efficient (having relatively long range), as well as improved performance. Therefore, students must have basic fundamental knowledge in the fields of fluid mechanics and thermodynamics at least to sufficiently meet all requirements, and come up with an adequate design using a software that offer CFD analysis such as ANSYS, and a software that will enable them to design a detailed body such as SOLIDWORKS.

Acknowledgments

Our work would never come to light if it wasn't for the people behind us who gave us the proper guidance and assistance throughout the way. Specifically, we would like to thank our advisor, Dr. Esam Jassim for his continuous efforts in helping us with every detail, as he never hesitated in giving us his point of view on almost everything, including difficulties and confusing points along the way. His assistance is kindly appreciated, and we are extremely thankful for everything he has done. In addition, we would like to recognize the exemplary efforts of Dr. Mohamed ElMehdi Saleh for his constant availability to answer our questions and inquiries, his efforts are very much appreciated. Moreover, we would like to express our kind and honest appreciation to the entire Mechanical Engineering Faculty at Prince Mohammed Bin Fahd University for their help and assistance, during our classes with them, they offered their opinions and knowledge regarding our project every time the subject came up, and their assistance is well recognized and valued. Finally, special thanks to the group members, the leader Abdulaziz Alwakeel for his constant supervision and interest in reviewing all work done to make sure everything is intact, Omar Albuainain for his continuous ambition in achieving the best outcomes and results by keeping track of time and quality, Ibrahim Almajed for his ever expanding motivation for overcoming obstacles and difficulties that faced us throughout the semester, Abdullah Almessairei for all the efforts he has done to reach sources and information needed for the project, and Abdullah Almazyad for his well-known determination for achieving perfection and cooperation.

List of Acronyms (Symbols) used in the report:

Symbols	**What it represents**
A	Frontal Area
CFD	Computational fluid dynamics
ρ	Air Density
C_D	Drag Coefficient
F_D	Drag Force
V	Air Velocity

List of Figures:

List of Tables:

Table of *Contents*

Chapter 1: Introduction

1.1 Project Definition

This project is about designing and manufacturing a car that runs on solar power. Our car design is a special type of electric vehicle that only get its power from the sun; thus, we will be using solar cells implemented on the surface of the car to produce electricity to power the motor. Hence, we will be using SOLIDWORKS that will be based on dimensional optimization analysis. Moreover, the aerodynamics of any vehicle can significantly increase its range by reducing the amount of drag on the body, as this will result in less consumption of power. Core manufacturers nowadays would improve their cars' aerodynamics in order to reduce drag, which eventually can result in greater fuel economy, and better performance when it comes to acceleration and top speed. Therefore, aerodynamics is a key aspect to consider when designing any type of vehicles for the purposes of better fuel economy and performance, and in certain areas, sustainability.

1.2 Project Objectives

1. The main objective of this project is to design, manufacture, and test a solar car.
2. The specific objective of this group is to design the body of the car and implement all necessary aerodynamic knowledge to come up with a body that allows as much as smooth flow to go pass with minimal drag force.
3. To implement SOLIDWORKS and ANSYS background knowledge to design the body using these latest programs.
4. To come up with a prototype that has all the design language of our subject, which is aerodynamics, and that prototype needs to demonstrate all design ideas we gave implemented.
5. To test the prototype using a wind tunnel in both software, as well as physical wind tunnels.
6. To calculate the coefficient of drag and drag force after testing the prototype.
7. To compare designs, and choose the most suitable, and viable design to begin manufacturing.

1.3 Applications

- Aerodynamics is used in the aerospace industries as in planes and rockets.
- HVAC systems also relies heavily on it.
- Widely used in the automotive industry as it plays a vital role in determining the efficiency of the cars.
- Naval shipbuilding implements the fundamentals of aerodynamics as well, and a submarine is an adequate example for that.
- In the military sector as well, as bullets are designed with the fundamentals and knowledge of aerodynamics in mind.

Chapter 2: Literature Review

2.1 Project background

Solar cars were invented in order to save our environment and adapt to our latest technologies. We aim to design the body of a solar car using applications such as Ansys, and SolidWorks to get different kinds of measurements, and compare it with the latest car designs. The whole purpose is to design and build the body with minimal cost and minimal drag force. The flow has to travel in various speeds facing the car in order to determine the drag force and the coefficient of drag for different circumstances. The car must have a streamlined body because that will cause the body to penetrate through the air with minimal resistance. Hence, a bulky looking body would be a disastrous design to rely on, as the coefficient of drag will be significantly high. Furthermore, the challenges we will be facing is material selection, and building the actual prototype accurately to test it in a wind tunnel. The idea we have is to design different kind of bodies with different materials and geometries to calculate and compare the drag force for each design.

Key words: Solar car, Aerodynamics, CFD simulation, Drag Coefficients, Drag Force.

2.2 Previous Work

To achieve great efficiency numbers in a vehicle, aerodynamics is a major aspect to consider. Thus, aerodynamics is vital to reach adequate efficiency, which means designing the vehicle in a way that the drag force and drag coefficient are minimal. To minimize the drag force and drag coefficient, we have to do several designs, and these designs have will be tested. Furthermore, designs were made by using CAD software (Computer Aided Design) which hold the necessary tools to conduct software tests. Then, transferring it to CFD (computational fluid dynamics) program to apply all parameters and test the smoothness and fluency of the car. As a result, we have chosen one of the 8 designs we did, and that is the 6th design. We have achieved our target with the lowest coefficient of drag force and drag force act on solar car body (Mark, Partap & Salim, 2013).

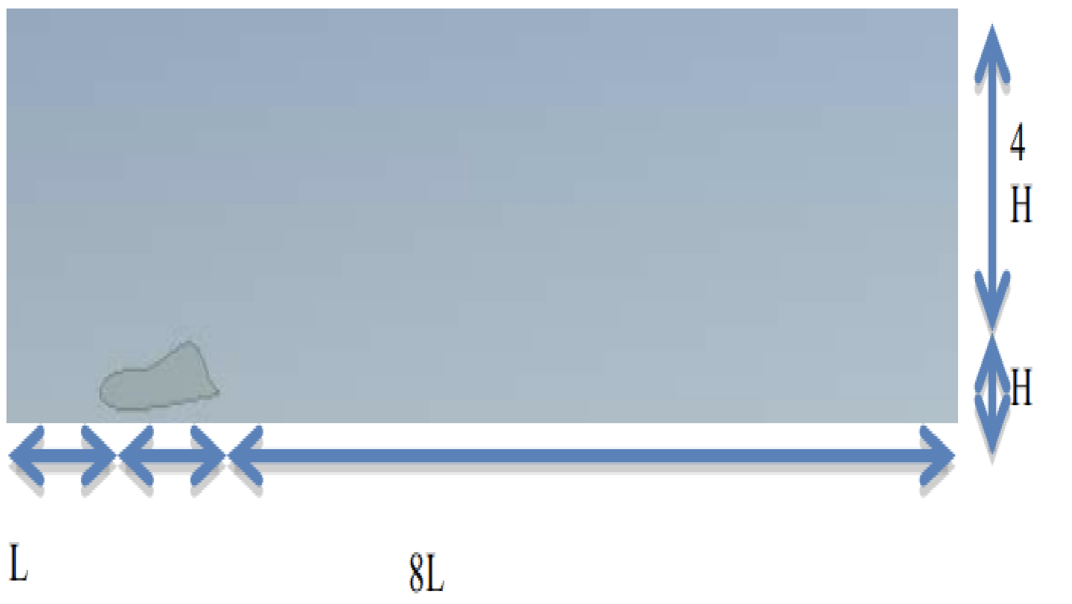


Figure #2.1 Computational Domain for CFD Simulation Setup (Front View)

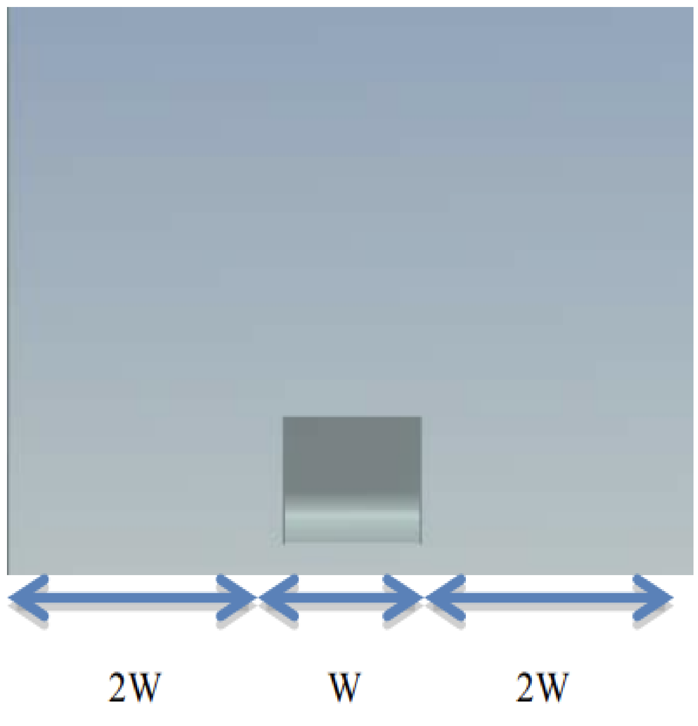


Figure #2.2 Computational Domain for CFD Simulation Setup (Side View)

A car with low drag force is essential to achieve great results with respect to efficiency and performance. Most solar cars that are used in the World Solar Challenge event have the shape of a “Cockroach” which was considered the best shape to achieve optimum speed and aerodynamics characteristics. However, the team of University of Malaya have designed a solar car with the shape of a box fish. This shape has even better aerodynamics that resulted in less drag force, and a small coefficient of drag. They have designed their shape using numerical studies and advanced programs to simulate their car. They used computational fluid dynamics (CFD) with a code termed FLUENT. In addition, they reached reasonable results compared to normal road solar cars (Taha, Passarella, Rahim, Sah & Ahmad-Yazid, 2011).

In the case of solar vehicles, due to the fact that the number one necessity is to optimize the energy efficiency for the duration of motion, many efforts are addressed by designers in searching for the suitable aerodynamics. That means that we have to minimize the drag force on different speeds and that can be done by creating a certain design and test it by several programs. There are two programs which are used in this research, CAD and CFD programs. The CAD software is used to create the design, while CFD is used to test the aerodynamics of the design. This design will be created by composite manufacturing processes which will decrease the weight of the car and facilitate the formation of the desired shape. After the manufacturing of the car, a reverse engineering manner is performed with the purpose of scanning the vehicle’s body and examine it to the preliminary theoretical design (Betancur, Fragassa, Coy, Hincapie & Osorio-Gómez, 2017).

Chapter 3: System Design

3.1 Design Constraints and Design Methodology

3.1.1: Geometrical Constraints

Every engineering design involves some sort of geometrical constraints and limitations. In our case, in computational fluid mechanics' perspective, we are faced with multiple limitations. For instance, the body's aerodynamic must be active enough to produce a maximum of 0.2 in terms of drag coefficient. In addition, in designing the body shape of the vehicle using SOLIDWORKS, we are entitled to certain geometrical limits, such as the fact that the wheelbase of the vehicle must be 3 meters, with 1.32 meters distance between the inner surfaces of the left and right wheels. Furthermore, the width of the whole car should be 2 meters long, and the length of the vehicle should be 5 meters long. Moreover, the distance of the gap between the front and back doors to the front end of the car should be 2 meters long, and 3 meters long between the very same gap and the back end of the car. Finally, the height from the lower end of the body itself and the upper most point should be 1.2 m high. These limits were given in order to easily construct the vehicle with enough surface area to place solar panels on the whole roof, as well as having comfortable space to implement our other necessary designs such as steering and braking systems. Additionally, the body will then have enough surface area to easily construct the technical specification in terms of material selection and weight determination, along with other aspects such as measurement of performance. Specifying geometry helps overwhelming barriers that could impede the process of conducting the tests and measurements mentioned earlier. Hence, it is crucial to specify certain geometry that helps mitigating all processes with minimum difficulties that could be emerged in the way of manufacturing.

3.1.2: Sustainability

To ensure the vehicle's durability for a long period of time, certain materials with specific quality of mechanical properties must be chosen to avoid any damage-causing processes such as corrosion. However, in our case, to ensure the sustainability of the vehicle, the geometry of the body and its aerodynamics must be designed in a way that during high speeds, the vehicle won't be affected by the adverse wind force that could cause various issues such as disassembly, vibrations, and loud internal wind noises. This will be achieved by designing the vehicle in a way that its aerodynamics would allow the vehicle to penetrate through the wind with maximum fluency and smoothness to avoid harmful drag forces.

3.1.3: Environmental

Nowadays, emissions of harmful gases such as carbon dioxide are reaching high and record-breaking amounts. This process of emitting harmful gases to the atmosphere is increasing, unfortunately, in an exponential manner. As the industry expands, cities are built, and population is increasing, the demand for energy is increasing as well. Thus, burning of fossil fuels is what is being adopted right now to meet this demand. However, this is causing major and mind-blowing effects to the environment, as it is the cause of what we are experiencing right now with global warming and climate change. This man-made disturbance of nature's balance may be the starting point on a way to a major catastrophe. Therefore, bold and immediate actions must be taken to tackle this ever-expanding issue, and the main answer to this problem is renewable resources. In our project, we aim to use the reusable source of solar energy. This is part of our plan to shift towards renewable energy, which is using vehicles that run on environmentally friendly fuels such as electricity, which is produced using solar energy by implementing solar panels on the vehicle in our case. This idea aims to inspire other members of our society and try to open their minds to whole new horizons as they witness their cities, ecosystems, and health get battered from pollution.

3.1.4: Social

This vehicle is totally an effort to plant an idea in people's minds that the time to shift towards green energy is today. In addition, it has a goal of trying to show the easiness and simplicity of a green vehicle to oppose some sort of stereotypes that state that these kinds of cars are extremely complex, difficult to repair, and expensive. Moreover, it is planned that our vehicle will showcase itself by moving in public roads to mainly grab the attention of people not to show-off our achievement, but to reflect the need for these types of vehicles as soon as possible.

3.1.5: Economics

One of our goals in this project is to reflect the idea of simplicity in a vehicle that does not run on ordinary, familiar fossil fuels. To achieve this, we must reduce the cost of producing the vehicle, as well as cost of maintenance. Hence, we will carefully select the right materials that include a balance between sustainability, cost-reduction, and efficiency to construct and build the vehicle. In addition, specifically in our case in computational fluid dynamics, we aim to design the shape of the car in a way that its aerodynamic should produce less drag and consequently, consume less energy. This would eventually lead to improve the travel range and the efficiency, as large drag force causes the vehicle to consume more energy.

3.1.6: Safety

In terms of design, the vehicle's ride height should make it easy for a person to get in and out, with side pillars being as thin as possible to increase outer vision and minimize blind spots around the vehicle. This is essential for the safety of the driver and people around it. Therefore, the windscreen, side windows, and rear window should be big enough to look around the car easily. Also, the side pillars' thickness should be reduced to increase sight as it blocks a significant amount of outer view.

3.1.7: Ethical

Designing and building a solar car is not a new idea, it was performed by numerous people around the world. However, we intend to build this car in order to implement our mechanical engineering knowledge effectively, and to improve on areas where people have left it as it is. For example, we have chosen a bold and distinctive design (a truck made by Tesla), to implement the ideas and procedures that will convert it from a car that runs on rechargeable lithium-ion batteries from charge points on the streets, to solar panel charged batteries that is keeps on recharging as long as the sun is up and bright. It is essential to state the fact that this project does not include any type of unethical actions, intents, or purposes. In fact, this project and every process within is planned and agreed upon by us, and hopefully it will make a positive effect.

3.2 Engineering Design standards

The material of the body is Aluminum 6061-T6 and the property is shown below:

Property	Value
Density	2.7 g/cm3

Table #3.1 Physical Properties

Element	Maximum Unless Range is Specified
Silicon	0.40 - 0.8
Iron	0.7
Copper	0.15 - 0.40
Manganese	0.8 - 1.2
Magnesium	0.8 - 1.2
Chromium	0.04 - 0.35
Zinc	0.25
Titanium	0.15
Others Each	0.05
Others Total	0.15
Aluminum	Balance

Table #3.2 Chemical Properties

Properties	Values
Ultimate Tensile Strength	310 MPa
Tensile Yield Strength	276 MPa
Elongation at Break	12%
Hardness, Brinell	95
Modules of Elasticity	68.9 GPa

Table #3.3 Mechanical Properties

Properties	Values
Melting temperature (T_m)	585 °C (1,085 °F)
Thermal conductivity (k)	151–202 W/(m·K)
Linear thermal expansion coefficient (α)	2.32×10^{-5} K^{-1}
Specific heat capacity (c)	897 J/(kg·K)

Table #3.4 Thermal Properties

3.3 Theory and Theoretical Calculations

3.3.1: Calculating the frontal area of the car:

The frontal area of the car can be calculated by dividing the car into different parts and sum the areas of these parts, we will then have the total frontal area. On the other hand, we can measure the frontal area in an easier way with computer programs.

We used ANSYS software to calculate the frontal area of the designed car and we have found it as shown below:

$$A = 4.824415 \text{ m}^2.$$

3.3.2: Calculation of Drag coefficient and Drag force:

To calculate the drag coefficient, we have to use either the normal equations we have learned in fluid mechanics course or use the program by performing a simulation for our design depending on several components and parameters. Moreover, we have imported our geometry, designed in SolidWorks program, to the simulation software modeling “FLUENT” in Ansys then the coefficient of drag force and drag force were calculated by the program.

The Ansys version we used was the student version 2019. This version has limitations in usage and can’t conduct the work properly, as demonstrated in the result that we got. We were forced to use this version because were choked by limited time, but we managed to design the car in time with the required geometry given to us. Due to the corona virus epidemic, we were also forced to use the free version of Ansys which is provided to students, since we can’t use the full version which is provided in the university campus. The version found in the campus is more accurate and gives a perfect result compared to the one in hand, which is 2019.

The frontal area is calculated by the program and is shown below:

$$A = 4.824415 \text{ m}^2.$$

The density of air as we know is fixed with respect to the atmospheric temperature and pressure which is shown below:

$\rho = 1.225$ Kg/m3.

The speed of the fluid in the wind tunnel which we have calculated the Drag coefficient and Drag force:

V= 80 km/h = 22.222 m/s.

The drag force and drag coefficient has been calculated in the program as follows:

Zone	**Drag Force (N)**	**Drag Coefficient**
pressure	94.478035	0.064744726
Viscous	1.5699013	0.0010758356
Total	96.047936	0.065820561

Table #3.5 The most acceptable results drag coefficient and drag force

We can prove this measurement using equations of fluid mechanics for calculating the coefficient of drag force on external surfaces which is shown below:

$$C_D = \frac{2F_D}{\rho A V^2} \quad \textbf{(3.1)}$$

$$C_D = \frac{2 \times 96.047936}{1.225 \times 4.824415 \times 22.222^2} = 0.06582198845.$$

As we can see, both ways work to have the same results but if we need to use the equations that we used in fluid mechanics, we have to determine the drag force to calculate the drag coefficient, in other words if we're using Ansys, it will use try and error in simulation until it reaches the value of drag force and drag coefficient of designed car with respect to air speed and frontal area of the car.

We've also measured the drag coefficient and conducted simulations for several velocities. Consequently, we found that there is a positive relationship between the velocity and the drag coefficient, which means that as the velocity increases, the drag coefficient and drag force will increase as well. In addition, as we've discussed earlier that the measurement wasn't accurate due to the student version of 2019. This version gives different readings in every simulation for the same geometry and design, as the values shown above are the most reasonable values measured by ANSYS 2019. However, this version has limitations in usage.

The relationship between velocity, drag coefficient, and drag force are shown in the table and the figure below:

V (km/h)	**C_D**	**F_D (N)**
10	5.28E-06	0.0001205
20	0.000401	0.0365691
40	0.000573	0.2090237
60	0.0006906	0.5668918
80	0.0014945	2.1807786

Table #3.6 Velocity Vs Drag Force & Drag Coefficient

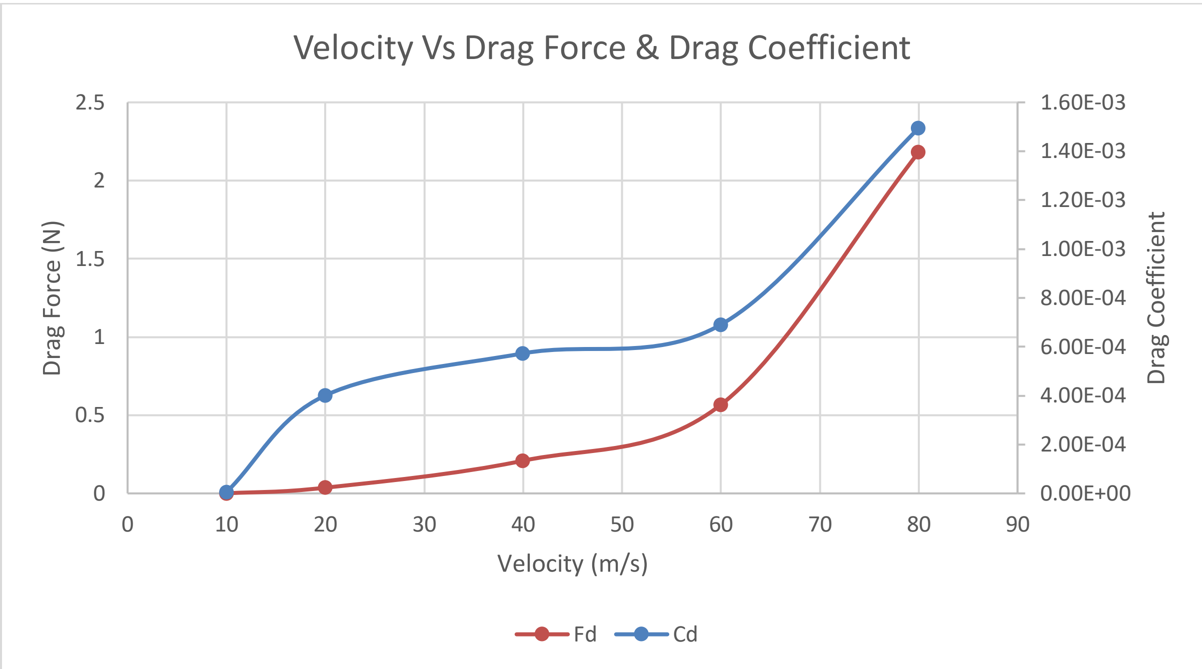
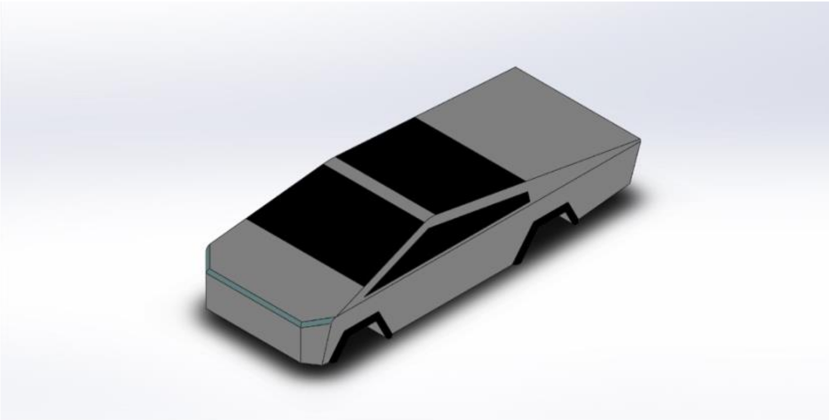


Figure #3.1 Velocity Vs Drag Force & Drag Coefficient

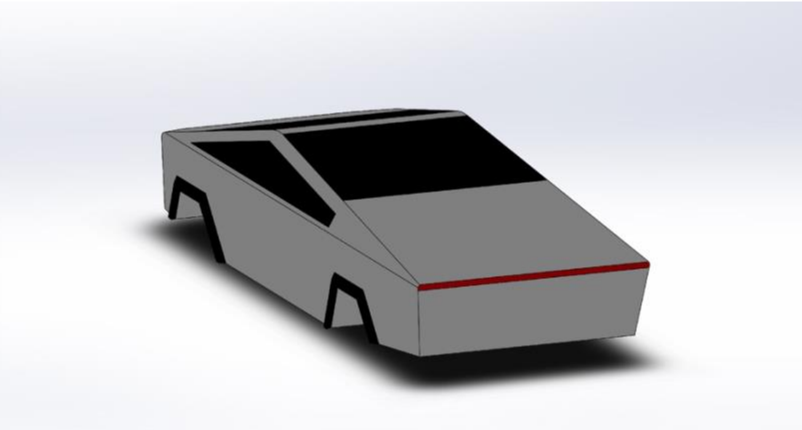
3.4 Product Subsystems and selection of Components

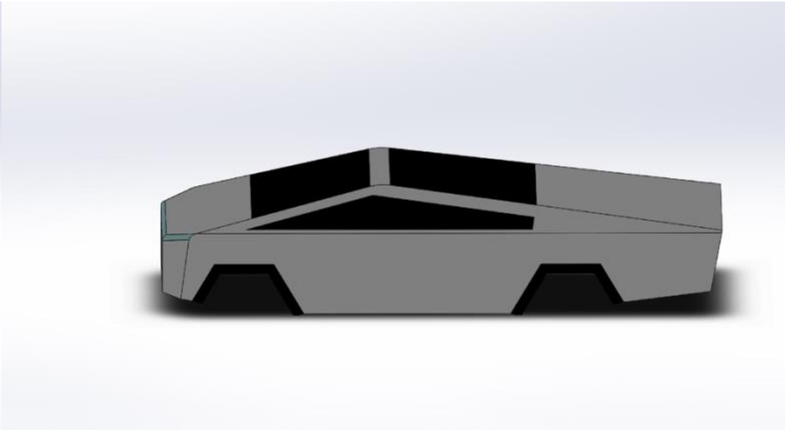
3.4.1 Design of the car

We designed the solar car with dimensions given as 5 meters for the length of the car, 2 meters for the width, 1.2 meters for the height, and 3 meters for the wheelbase. We also designed the front of the car to be streamlined so the coefficient of drag will be small so it will have minimum drag. We also chose for the material to be Aluminum 6061-T6 because it distributes stress equally and it also allows more interior volume. The top figure shows an isometric view of the final design of the car. The figure on the left shows the rear side of the car, while the right figure shows the car from the right view. We also chose different colors to show the different parts such as windows, rear lights, front lights, and the body of the car itself.



Figure#3.2 Isometric view of the final design





Figure#3.3 The rear side of the car

Figure#3.4 The right view of the car

3.4.2 Selection of materials:

Component	Details
Body	Aluminum 6061-T6
Solar Panel	Type: Monocrystalline Front cover: Tempered Glass Frame material: Anodized aluminum alloy
Glass	Laminated glass

Table #3.7 Table of Material

Body:

We used Aluminum because it is a relatively light material which can result in better acceleration, braking, and handling. It has high strength to weight ratio and much safer than other traditional mild steel structure. It is commonly used and available everywhere. It is known for its weldability, easy machining, and resistance to corrosion.

Glass:

Laminated glass is known for its durability, it is commonly used for automobiles. It is manufactured to provide maximum strength and it doesn't shatter in case of an accident, which is why it's called safety glass. It protects passengers and interior materials from UV ray penetration. It is also known for its low weight compared to tempered glass, and it is a commercially available glass.

Solar Panel:

We will be using Monocrystalline due to its high efficiency 15%-20% which is better than the polycrystalline 14%-16%. The front cover will be tempered glass to increase its strength which is six times more than a normal plate glass, and frame material is anodized aluminum alloy to increase the corrosion resistance.

3.5 Manufacturing and assembly (Implementation)

Because of the corona virus epidemic, we haven't manufactured any component of the body, nor have we assembled any part.

Chapter 4: Conclusions and Future Recommendations

4.1 Conclusions

In the end, because of the difficulties we faced with this version of ANSYS, there were some unreasonable and non-viable results reached, because of the limitations that are in that specific version we used. Nevertheless, we managed to simulate our design in multiple conditions and scenarios, which are in other words, different velocities the wind is hitting the car with, and they are 10, 20, 40, 60, and 80 Kilometers per hour. As a result, we reached some conclusions such as that the coefficient of drag will increase dramatically between 10 and 20 Km/h, as well as 60 and 80 Km/h. However, from 20 to 60, the drag coefficient increased in a significantly lower rate as demonstrated in Figure #3.1. In this project, we gained a few new skills, mainly the ability to use ANSYS and navigate well in it, in addition to the fact that numerous aerodynamic knowledge being understood and learned, such as the fact that the geometry of a vehicle can significantly affect the coefficient of drag and drag force. In addition, it is an adequate project to do given the current circumstances, with all the environmental issues that are facing the world, with this solar car we are becoming a part of a much wider group of people around the globe that are sending a clear message that the earth needs cleaner air to stop catastrophic outcomes to come to light. Hence, there was a sense of motivation within us as soon as we began with our tasks. Furthermore, the subject of aerodynamics is quite interesting to work on, as we found it relatable to our everyday lives, whether with our cars, planes, mechanical systems such as ducting systems, or even wildlife such as birds. Finally, we achieved our goals and met the requirements for every task given, with giving our absolute best to do so. However, the challenges we faced were not merciful, as the process of design and simulation gave us a hard time when we tried to open our Solid Works file in ANSYS, as well as the fact that the version of ANSYS we are using is actually filled with limitations that prevented us from actually coming up with a viable result. Nevertheless, all group members did their best to produce what this group produced, and every single one of them did their absolute best to achieve that.

4.2 Future Recommendations

Along the way of working on, and completing our project, we faced numerous difficulties, and we managed to overcome these difficulties by learning from our mistakes. Hence, for the people who will work on projects with similar aspects, there are multiple recommendations that we would like to give to them. First of all, to make sure that all necessary software for doing the work are available and functional, as this issue gave us a really hard time during the semester. Secondly, all tasks required for the project need to be known from the beginning to ensure smoothness in working on the project with no delays, as we had our stops because of the fact that we didn't know what to do next. Nevertheless, we managed to complete everything on time, but knowing everything from the start is still essential and a wise thing to do. In addition, distributing tasks amongst members of the group is a fundamental thing to do before everything else, as it is important that every member has a clear understanding of his tasks in order to make sure that no one will be held up, thus holing everybody else up. This is a major problem that faced many groups including ours. Finally, motivation is the most important aspect of any group work, if only one member lacks it, problems will rain down on the entire group. It is vital to find what motivates everyone so that everyone would do his own work with full competency.

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Appendix A: Progress Reports

	SDP – WEEKLY MEETING REPORT
	Department of Mechanical Engineering **Prince Mohammad bin Fahd University**

SEMESTER:	**Spring**	**ACADEMIC YEAR:**	**2019/2020**
PROJECT TITLE	**Aerodynamics of a Solar Car (CFD)**		
SUPERVISORS	**Dr Esam Jassim**		

Month 2: March

ID Number	Member Name
201501068	Abdulaziz Alwakeel (leader)
201602964	Omar Albuainain
201700331	Ibrahim AlMajed
201600094	Abdullah Almessairei
201502740	Abdullah Almazyad

List the tasks conducted this month and the team member assigned to conduct these tasks

#	Task description	Team member assigned	Progress 0%-100%	Delivery proof
1	**Designing the vehicle (SolidWorks)**	Ibrahim Almajed	100%	
2	**Improving the design, applying detailed design points and geometry**	Abdulaziz Alwakeel	100%	
3	**Materials selection**	Abdullah Almessairei	100%	
4	**Simulation via ANSYS**	Omar Albuainain	100%	
5	**Calculating Drag Coefficient**	Abdullah Almazyad	70%	

List the tasks planned for the month of April and the team member/s assigned to conduct these tasks

#	Task description	Team member/s assigned
1	**Completion of drag coefficient calculations**	Abdullah Almazyad
2	**Chapter 3:** System Design	All team members
3	**Chapter 4:** Conclusion and Future Recommendations	All team members

4	**Midterm Presentations**	All team members
5	**Finalizing and submission of the project report**	All team members

- **To be Filled by Project Supervisor and team leader:**
- **Please have your supervisor fill according to the criteria shown below**

Outcome MEEN4: an ability to recognize ethical and professional responsibilities in engineering situations and make informed judgments, which must consider the impact of engineering solutions in global, economic, environmental, and societal contexts				
Criteria	**None (1)**	**Low (2)**	**Moderate (3)**	**High (4)**
MEEN4A. Demonstrate an understanding of engineering professional and ethical standards and their impact on engineering solutions in global, economic, environmental and societal context	Fails to demonstrate an understanding of engineering professional and ethical standards and their impact on engineering solutions in global, economic, environmental, and societal contexts	Shows limited and less than adequate understanding of engineering professional and ethical standards and their impact on engineering solutions in global, economic, environmental, and societal contexts	Demonstrates satisfactory understanding of engineering professional and ethical standards and their impact on engineering solutions in global, economic, environmental, and societal contexts	Understands appropriately and accurately the engineering professional and ethical standards and their impact on engineering solutions in global, economic, environmental, and societal contexts

Outcome MEEN5: an ability to function effectively on a team whose members together provide leadership, create a collaborative and inclusive environment, establish goals, plan tasks, and meet objectives				
Criteria	**None (1)**	**Low (2)**	**Moderate (3)**	**High (4)**
MEEN5A: Ability to develop team work plans and allocate resources and tasks	Fails to develop team work plans and allocate resources and tasks	Shows limited and less than adequate ability to develop team work plans and allocate resources and tasks	Demonstrates satisfactory ability to develop team work plans and allocate resources and tasks	Properly and efficently makes team work plans and allocate resources and tasks
MEEN5B: Ability to participate and function effectively in team work projects to meet objectives	Fails to participate and function effectively in team work projects to meet objectives	Shows limited and less than adequate ability to participate and function effectively in team work projects to meet objectives	Demonstrates satisfactory ability to participate and function effectively in team work projects to meet objectives	Function effectively in team work projects to meet objectives

MEEN5C: Ability to communicate effectively with team members	Fails to communicate effectively with team members	Shows limited and less than adequate ability to communicate effectively with team members	Demonstrates satisfactory ability to communicate effectively with team members	Communicates properly and effectively with team members

Indicate the extent to which you agree with the above statement, using a scale of 1-4 (1=None; 2=Low; 3=Moderate; 4=High)

#	Name	Criteria (MEEN4A)	Criteria (MEEN5A)	Criteria (MEEN5B)	Criteria (MEEN5C)
1	Abdulaziz Alwakeel	4	4	4	4
2	Omar Albuainain	4	4	4	4
3	Ibrahim Almajed	4	4	4	4
4	Abdullah Almessairei	4	4	4	4
5	Abdullah Almazyad	4	4	4	4

Comments on individual members

Name	Comments
Abdulaziz Alwakeel	
Omar Albuainain	
Ibrahim Almajed	
Abdullah Almessairei	
Abdullah Almazyad	

Appendix B: Engineering Standards

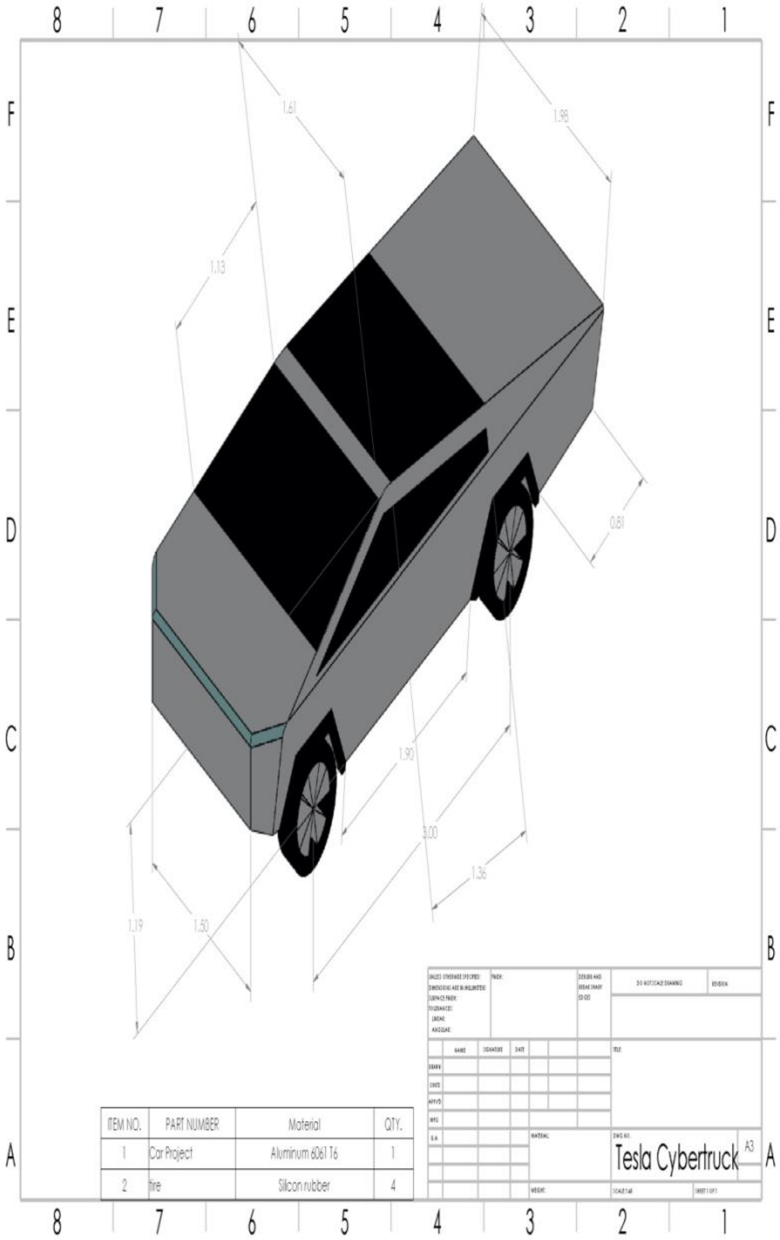
Property	Value
Density	2.7 g/cm^3

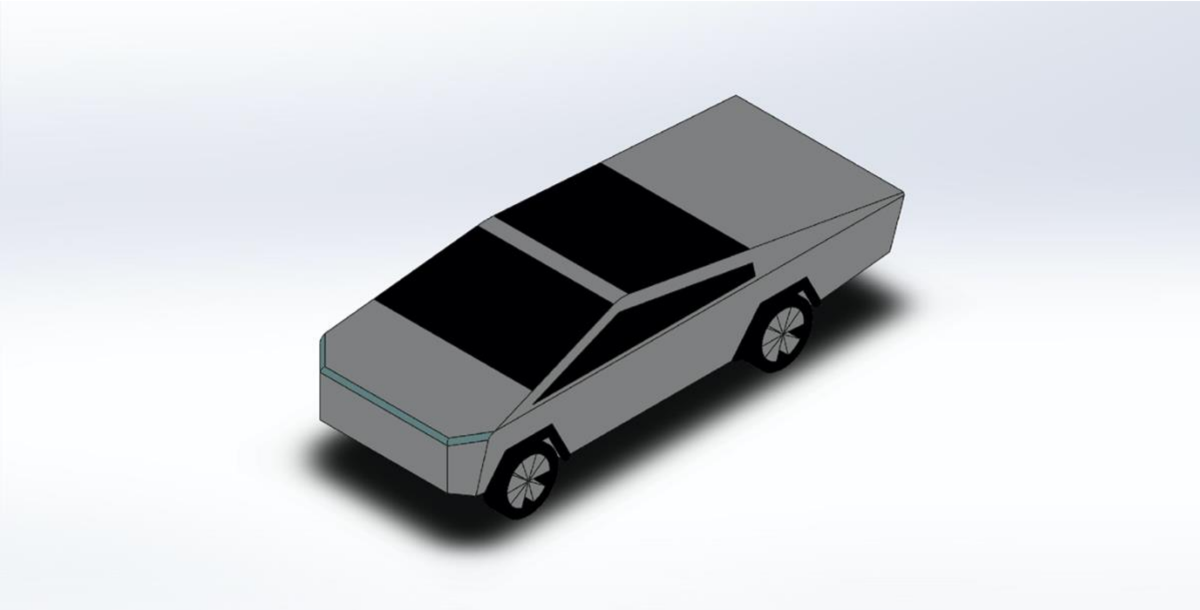
Element	Maximum Unless Range is Specified
Silicon	0.40 - 0.8
Iron	0.7
Copper	0.15 - 0.40
Manganese	0.8 - 1.2
Magnesium	0.8 - 1.2
Chromium	0.04 - 0.35
Zinc	0.25
Titanium	0.15
Others Each	0.05
Others Total	0.15
Aluminum	Balance

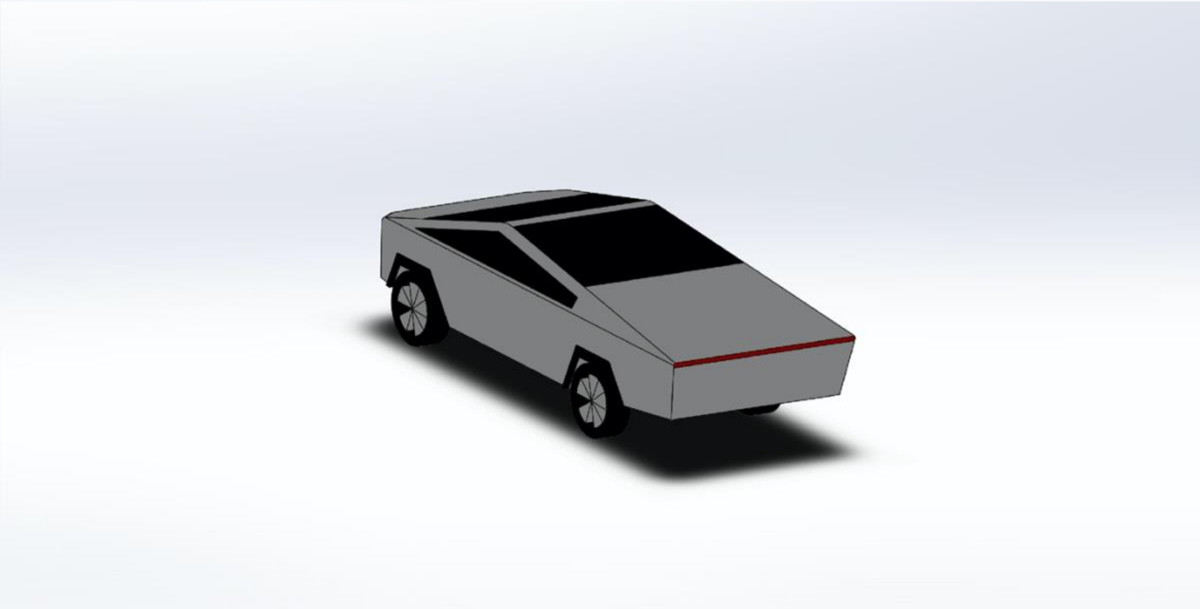
Properties	Value
Ultimate Tensile Strength	310 MPa
Tensile Yield Strength	276 MPa
Elongation at Break	12%
Hardness, Brinell	95
Modules of Elasticity	68.9 GPa

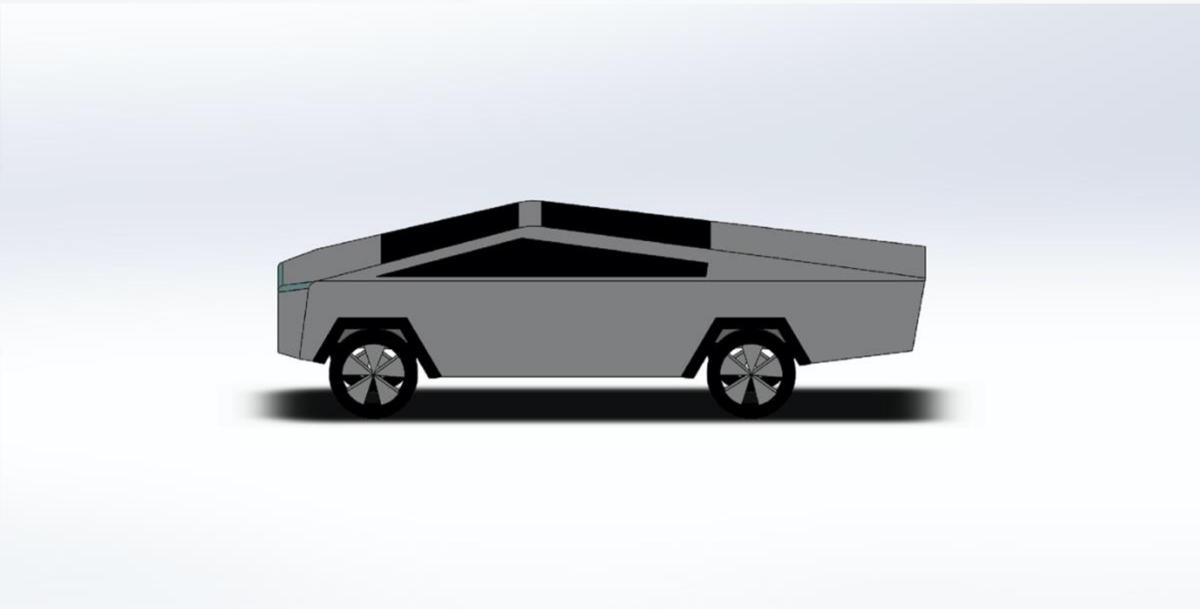
Properties	Value
Melting temperature (T_m)	585 °C (1,085 °F)
Thermal conductivity (k)	151–202 W/(m·K)
Linear thermal expansion coefficient (α)	2.32×10^{-5} K^{-1}
Specific heat capacity (c)	897 J/(kg·K)

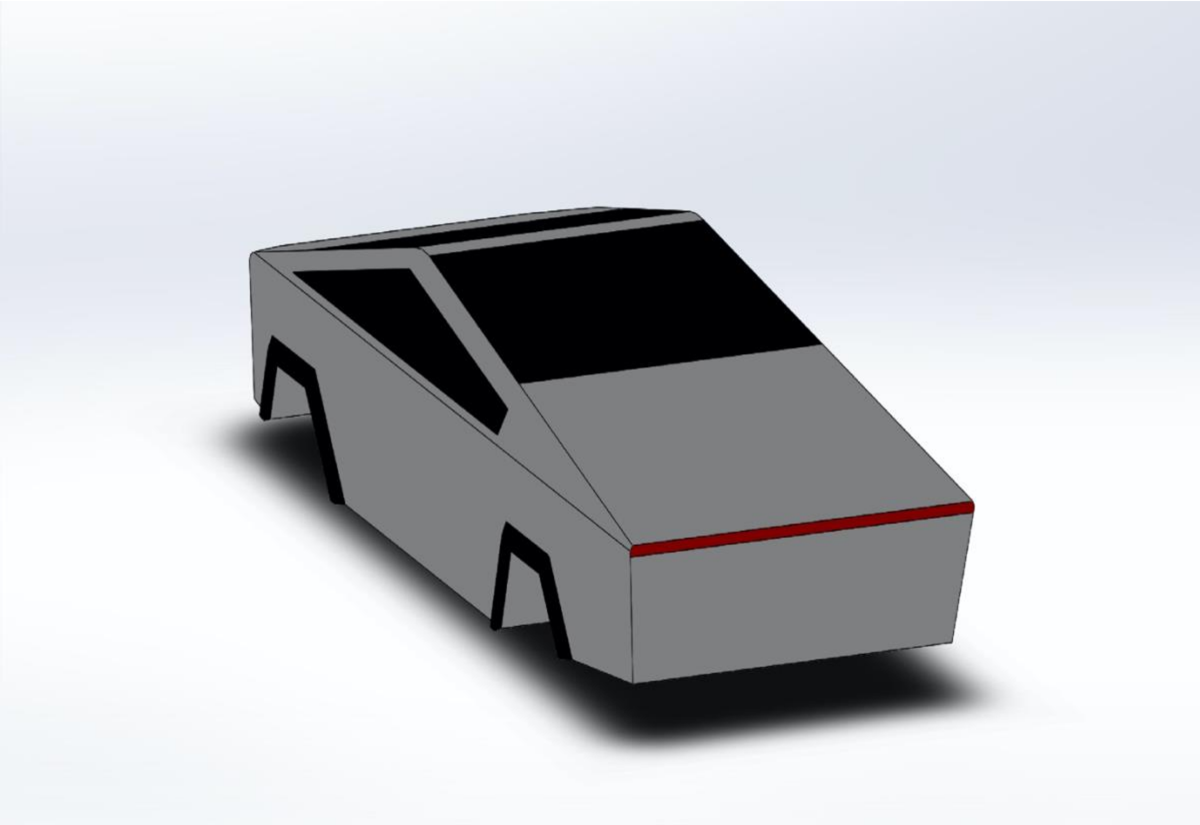
Appendix C: CAD drawings and Bill of Materials

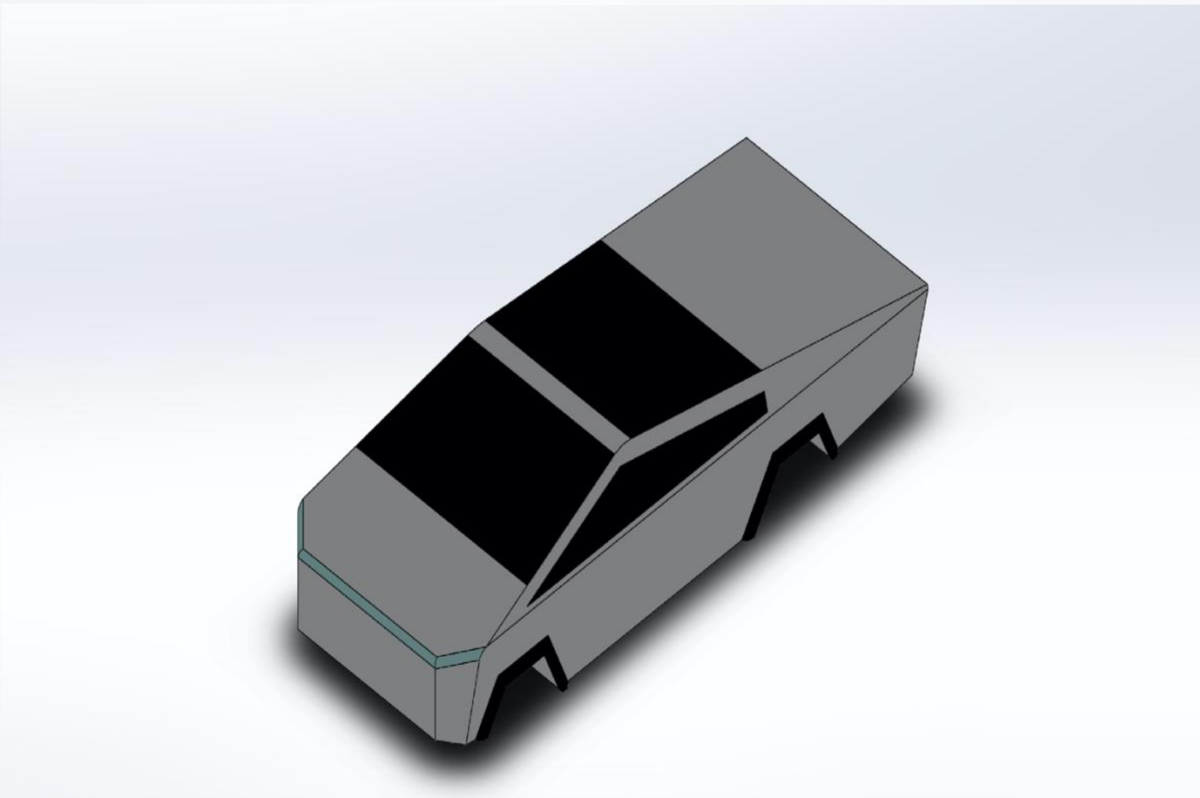


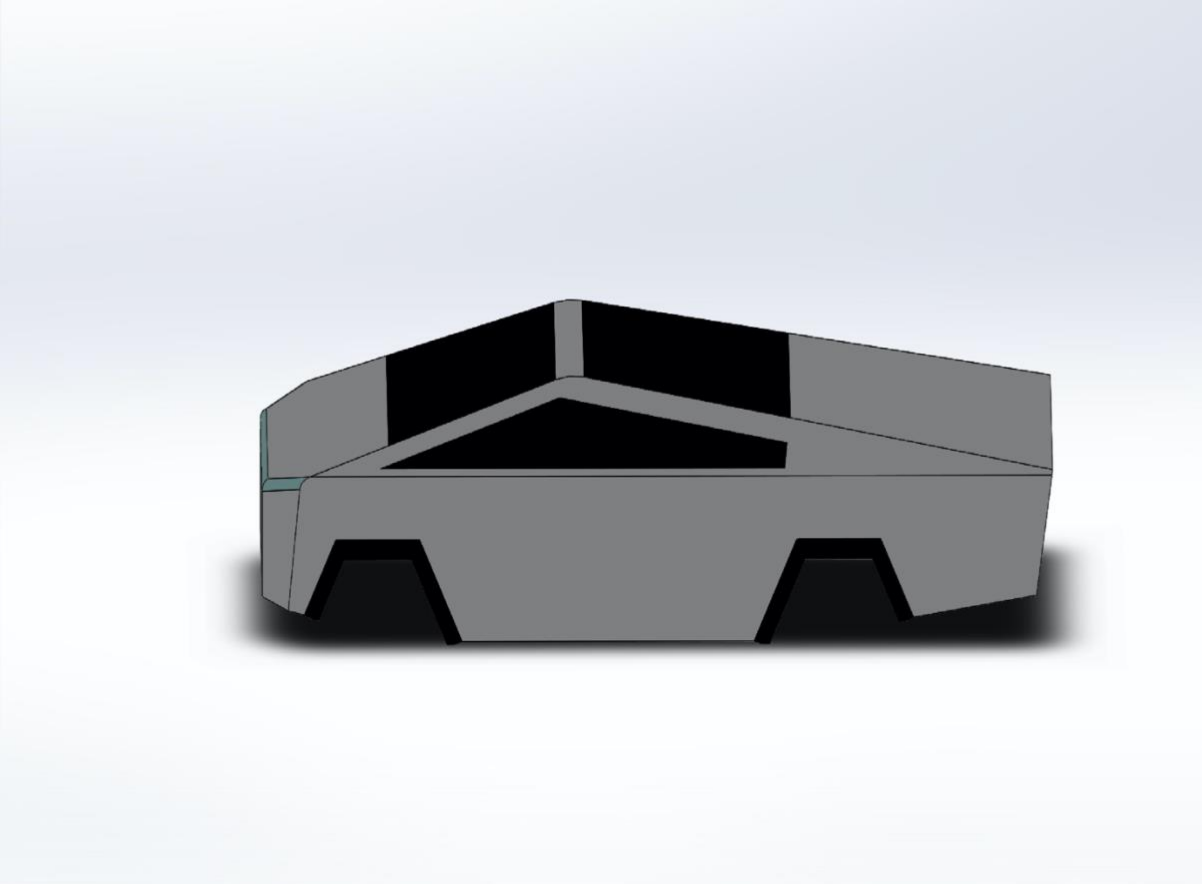


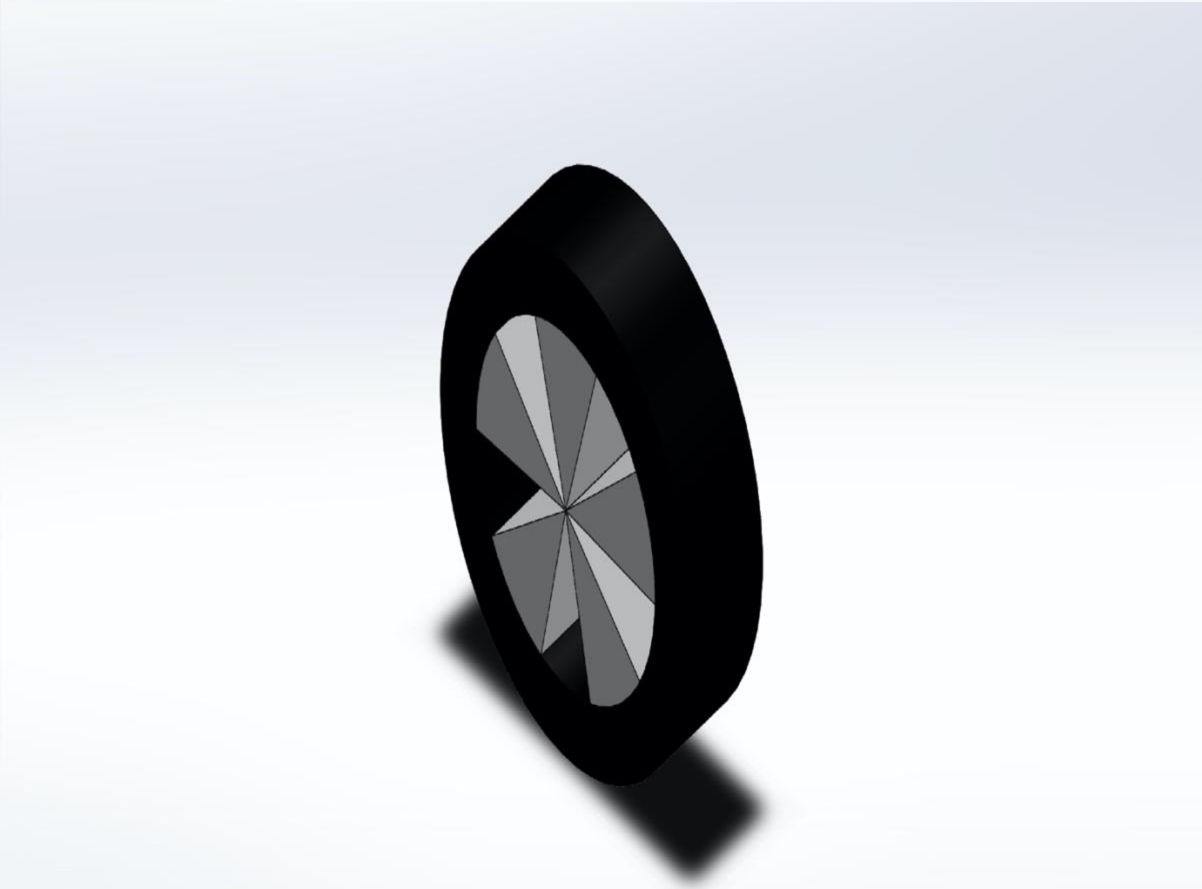












Appendix D: Datasheets

Zone	Drag Force (N)	Drag Coefficient
pressure	94.478035	0.064744726
Viscous	1.5699013	0.0010758356
Total	96.047936	0.065820561

V (km/h)	C_D	F_D (N)
10	5.28E-06	0.0001205
20	0.000401	0.0365691
40	0.000573	0.2090237
60	0.0006906	0.5668918
80	0.0014945	2.1807786

Component	Details
Body	Aluminum 6061-T6
Solar Panel	Type: Monocrystalline Front cover: Tempered Glass Frame material: Anodized aluminum alloy
Glass	Laminated glass