ME 481, DG23 Senior Capstone Design

Solar Car Body Design

Final Report

Tanaka Chonyera, Sammy Dickow, Angelo Bartolome, Isaiah DeVougas, Tyra Treadway

Industrial Advisor: Ethan Stull

Academic Advisor: Dr. Ahmed Naguib

Table of Contents

Introduction to the Problem

Michigan State University's Solar Racing Team (MSU SRT) is composed of students who race full-sized solar cars, which are designed and manufactured by the team, that are powered electrically. Our capstone team is tasked with designing a body for the solar car that is aerodynamic, lightweight, and easy to manufacture. We are to compare and advise as to the manufacturability versus theoretical performance of carbon fiber aeroshells, monocoque body/chassis, and segmented flat paneling for future car build cycles. The new designs are to be novel or modeled after the 3 previous shells. Body design plays a critical role in the vehicle's overall performance as drag and other aerodynamic effects directly impact top speed, acceleration, and maneuverability of the car by improving or worsening these factors.

Identification of Needs

The team's primary focus should be on producing a clear, feasible body design that enhances the aerodynamic performance of the solar car. This enhancement must directly address crucial factors such as drag reduction, airflow optimization, and overall vehicle efficiency. However, it is imperative to balance this focus with considerations for manufacturability. The chosen body designs should be easy to manufacture, considering factors such as material availability, fabrication techniques, and production costs. Priority must be given to reducing manufacturing time and costs without compromising the structural integrity or aerodynamic properties of the vehicle. Exploring cost-effective solutions and streamlined manufacturing processes is essential to achieve this objective. By effectively addressing these key needs, the capstone team can guide the design process towards developing a solar car body that not only improves aerodynamic performance but also ensures manufacturability and cost-effectiveness.

Problem Constraints

Our design is constrained by the rules and regulations for the 2024 Formula Sun Grand Prix and American Solar Challenge. According to the American Solar Car Challenge 2024 Revision C, the solar car must adhere to specific dimensions: a maximum length of 5.0 m, height of 1.6 m, and width of 2.2 m when in motion, with allowances for wheel extensions during turns. Ground clearance of at least 100 mm is required for all parts except tires, wheels, and hubs. Occupants' eyes must be at least 700 mm above the ground, and the driver must maintain visibility of points 8 m in front, 6.4 m above, and 100° to either side of the car. Additionally, the driver must identify 75 mm high letters 3 m ahead and 50 mm high letters 3 m to the side, with minimal obstruction to forward vision from the roll cage. We will also need to design around the existing chassis and ensure the proposed designs are realistic regarding manufacturability and cost.

Solution Research and Benchmarking

Our research and benchmarking process involved gaining insight from our industrial advisor, analyzing designs and performance of other solar car teams, and utilizing key resources like "Fluid-Dynamic Drag" by Dr. Sighard F. Hoerner and "A Solar Car Primer" by Erica Forsta Thatcher. We used drag coefficient plots and dimensional ratios for Hoerner's book to optimize the cockpit design, resulting in a 50% reduction in drag coefficient. For the fairing designs, we compared various symmetric NACA airfoil shapes using the equations from Thatcher's book and selected a design that significantly reduced the drag coefficient. The main body design was evaluated using Xfoil software to obtain lift and drag coefficients for several NACA airfoil profiles at the vehicles operating Reynolds number, with special consideration for factors like driver space and manufacturing ease. By utilizing these insight and through careful analysis, we developed a novel solar car body design that reduces drag and weight, improving the vehicles overall performance.

Problem and Solution Impact on Public Welfare, the Environment and Sustainability

This product can potentially draw more attention to solar power and other clean energy solutions. The more successful the team is the more likely people are to investigate alternative energy solutions. Racing is a great frontier to promote renewable energy and vehicle electrification for the following reasons:

1. *Public Interest and High Visibility*

   Racing events typically attract large audiences and media attention which provides a unique opportunity to showcase the capabilities of electric vehicles and renewable energy.

2. *Performance Demonstration & Excitement*

   Racing allows manufacturers to demonstrate the potential of electric vehicles and renewable energy in a competitive space. There are pervasive notions about electric vehicles, they have no soul, or they are not as loud and exciting as internal combustion engines but events like the American Solar Challenge or Formula E can turn the tide.

3. *Innovation*

   Racing has historically been a vector for inspiring technological breakthroughs that eventually find their way into mainstream consumer vehicles. This is analogous to the space race which led to the development and mainstream adoption of technology now used for Bluetooth, athletic shoe cushioning and firefighting equipment. Competition + constraints = creative innovation.

In a world where everyone is constantly looking for new ways to reduce emissions or their carbon footprint, solar cars can serve as a powerful education tool. Only 3.8% of electricity in the US is solar powered, there is a significant potential for growth.

Concise Problem Definition and Deliverables

We must produce clear, feasible body design that improves the aerodynamic performance of the car while maintaining relative ease of manufacturing, in our case the relative ease of 3D printing. Provide clear data that shows the benefits of the innovative design. Follow the rules given by the Formula Sun Grand Prix and the American Solar Challenge.

Initial Plan and Contingency Plan

Our initial plan was to first obtain data on the current solar body car design of the MSU solar race team. This data includes the shape of the car obtained through a CAD file given to us by the body lead in the solar race team and dimensions of the original car. This was accomplished by meeting with our industrial advisor who is a current engineering lead in the solar race team. More information was obtained by visiting their workshop and taking more measurements on the dimensions of the vehicle. Once we had a precise understanding of how the current car looks, we now went into what we can do to improve their current design. To do this, we looked at three integral parts of the car which were the shape of the cockpit, the body, and the pontoons which encased the wheels at the bottom of the car. The main goal of our team was to make the current car more aerodynamic, so we decided to accomplish this through designing various shapes of airfoils and applying them into our new design. Reasons why we wanted to go with the airfoil shaped will be explained further in the report, but the airfoil is the most aerodynamic shape which eliminates pressure drag in the trailing edge which is a significant factor in slowing the car down.

Once the design is finalized and modeled in NX Siemens, both the original design and our new improved design will then be 3D printed and will be tested in a wind tunnel at the engineering facility at Western Michigan University. Through this, a platform would have to be made from scratch to attach our 3D printed model to the platform to hold it in place. A pressure sensor would then be placed at the trailing edge of the platform which gives us the drag that its experiencing through the wind tunnel. The wind tunnel would first run with just the platform itself and the drag for that would be noted. Then the wind tunnel would run again, but this time the car would be attached to the platform in the wind tunnel and the drag recorded. We would then subtract the drag of the platform from the drag of the car with the platform and the result would be the drag that we would use.

With the wind tunnel testing, time is a big issue. Since the wind tunnel is around two hours away from East Lansing, travel time must be accounted for. Another time cost that comes with wind tunnel testing is the 3D printing. To produce results such as drag that can be comparable to a true size model, a quarter scale model will have to be printed for both the original and improved design and both models will have to have wind velocities of around 100 miles per hour in the wind tunnel to produce usable data. The issue that comes with this is that for a one quarter scale design, the design would take around two weeks to print so if wanted both designs printed and tested, a month will need to be accounted for.

After deciding that the wind tunnel method presents too many time constraints, a contingency plan was then drafted. The contingency plan was to do hand calculations of our improved design to find the drag. These hand calculations are the analytical approach to explaining how and why the cockpit and the fairings were designed.

Due to the limited time that we have for the project, the contingency plan is what we decided as the best approach for the rest of the project.

Cockpit design

The cockpit design was the initial design change proposed. It was theorized that making the cockpit longer and lowering the height would reduce drag. The book Fluid-Dynamic Drag by Dr. Sighard F. Hoerner confirms this. Using a series of ratios and drag coefficient plots, optimized dimensions for the cockpit were obtained. The first thing to note is the constraints. The first was accommodating a driver. The team informed us that the maximum height of the driver will be around 5 foot 7 inches. The Cynisca design had a cockpit height of 16.25 inches. Note that the cockpit height is defined as the maximum height above the main body. The other constraint was the length of the cockpit. The main car body is 170 inches long so it cannot surpass that length. There also needs to be enough flat space on the body for the solar array. Figure 1 below shows a plot of the length to height ratio versus the drag coefficient.

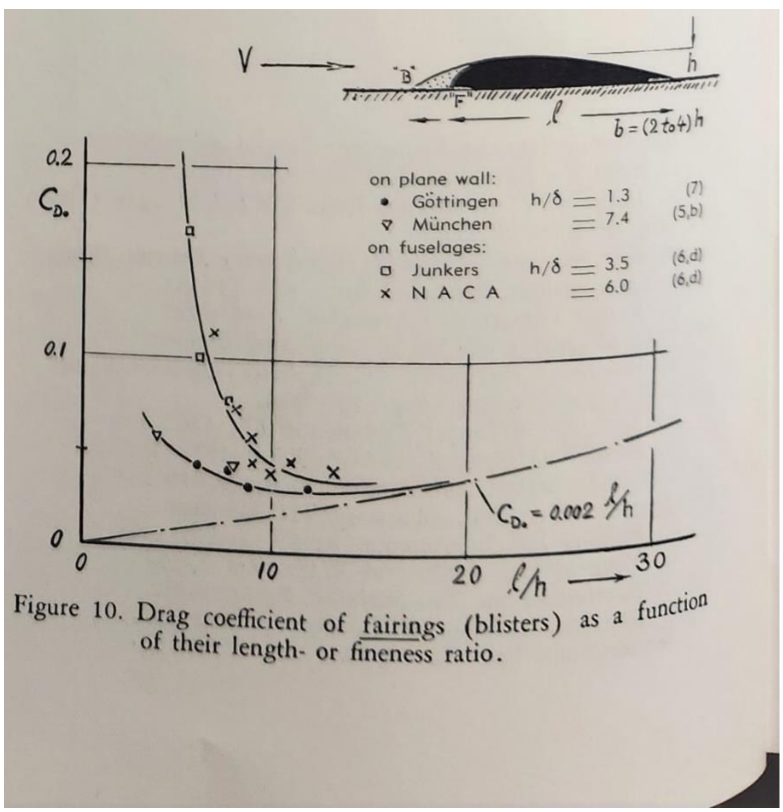

Figure 10. Drag coefficient of fairings (blisters) as a function of their length- or fineness ratio.

Figure 1: Figure 10 from Hoerner

The ideal ratio is around 10 but with our height constraint this would make the length too long. The current ratio is 79.12/16.25 or 4.86. In the current design, there are about 4 inches available to be taken off the cockpit's height. To ensure the driver's head is not touching the top of the roll cage inside, only 1.25 inches were taken off. This leaves a cockpit height of 15 inches. To leave enough room for the array a length of 90 inches was determined. This height and length give a ratio of 6 which reduces the drag coefficient of the cockpit from around 0.15 to 0.1, a 50% reduction. The next step in the cockpit design was the maximum width and width in the rear. In Figure 2 below the maximum width is defined as "b" and the width in the rear is defined as "e". The reading shows there is a benefit for not having the cockpit's rear come to a point shown by 0 on the plot.

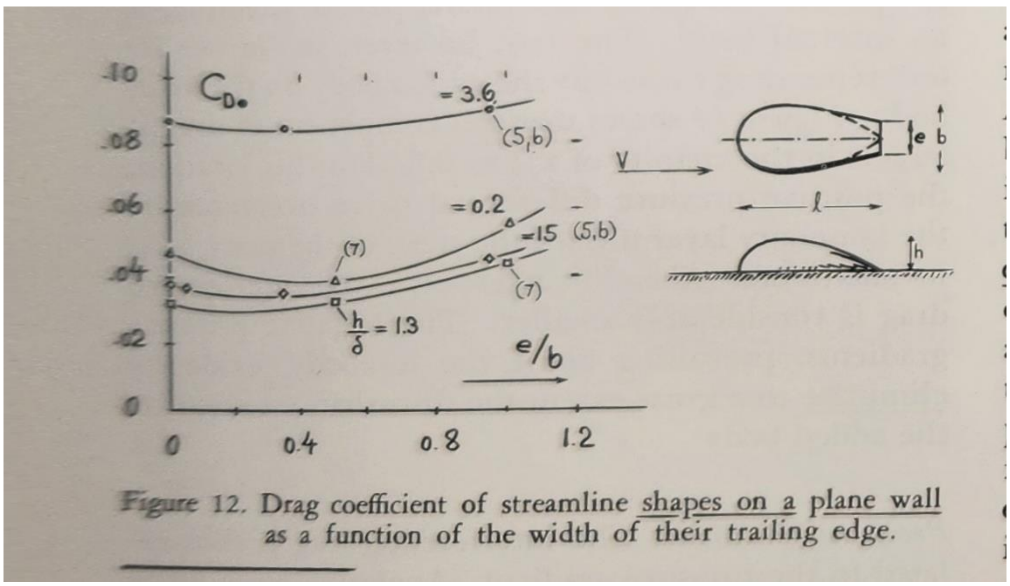

Figure 12. Drag coefficient of streamline shapes on a plane wall as a function of the width of their trailing edge.

Figure 2: Figure 12 from Hoerner

The current cockpit maximum width (20 inches) was kept the same because the driver needs room to sit and steer. The current design also comes to a point which is not the lowest drag coefficient that can be obtained. The plot above shows the ideal ratio is between 0.2 and 0.3. This means that based on the ratio and a b of 20 inches, the rear width is 10 inches. This new design raises the ratio from 0 to 0.2 which gives a slight decrease in drag coefficient. A top and side view of the cockpit can be found below.

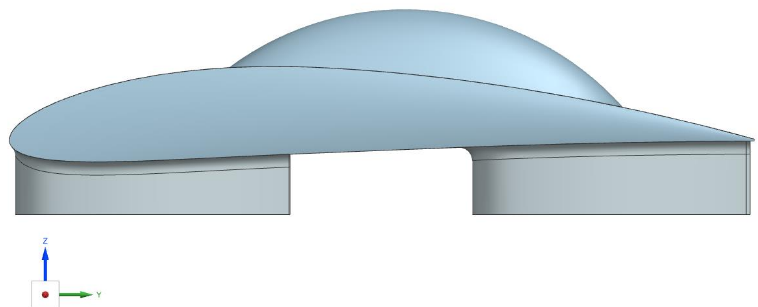

Figure 3: Side view of new cockpit

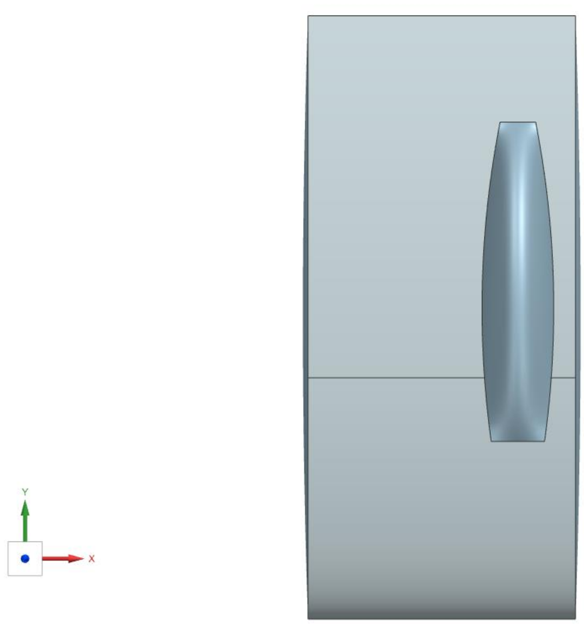

Figure 4: Top view of new cockpit

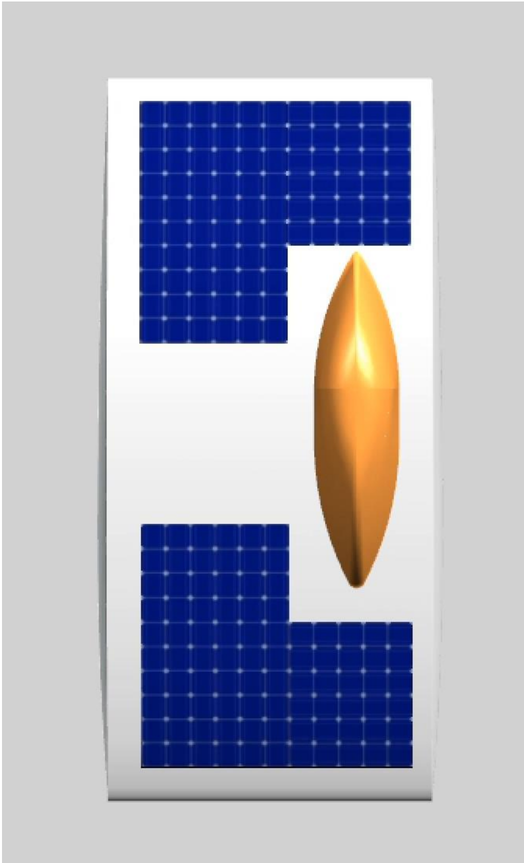

Figure 5: Top view of old cockpit (orange)

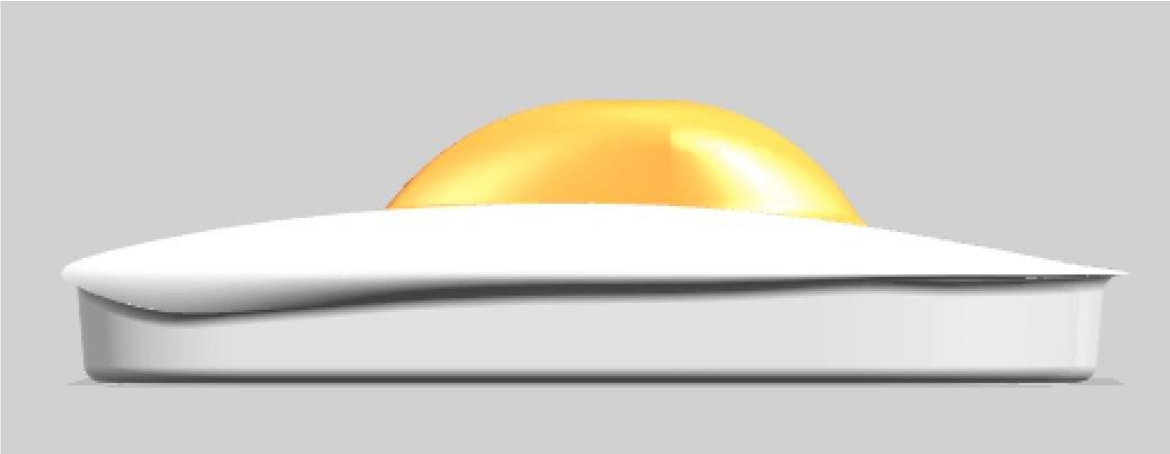

Figure 6: Side view of cockpit (orange)

Fairing Design

The fairing design change is the most noticeable of the 3 changes. This change not only reduces drag but also reduces weight. The current fairing design would be best described as a pontoon. There are 2 on either side of the car that house the wheels. They are shown below.

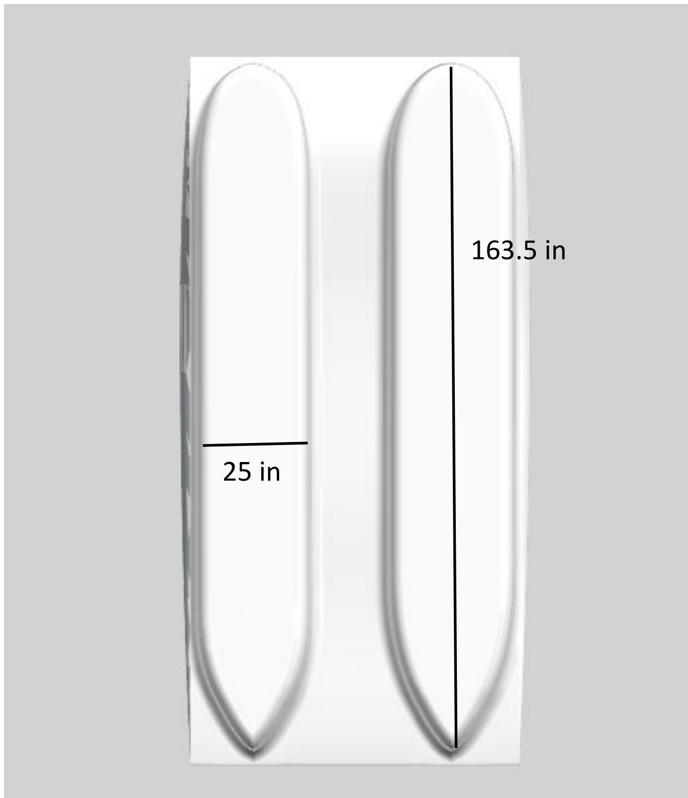

Figure 7: Old pontoon design

By researching other solar cars, we found that many of them use more than 2 fairings. We decided on a design that would use one fairing per wheel and they would each be a symmetric airfoil shape. Our calculations and decisions were made with guidance from the book A Solar Car Primer by Erica Forsta Thacher which was provided to us by the MSU Solar Racing Team. Calculations were done in Microsoft Excel where different airfoil shapes were compared. The shapes tested were the NACA 0006, 0009, 0012, 0018, 0025, and 0040. Airfoils that start with "00" means they are symmetric. The last 2 digits are the maximum thickness as a percentage. It is a percentage of the chord length. For example, a NACA 0006 with a chord length of 100 inches has a 6-inch maximum thickness. Some dimensions that needed to stay constant were the span (b), the thickness (t), and y_{min}. The first step to finding the drag coefficient and dimensions for the fairings was to do calculations of the fairings in free air. Based on a constant thickness, the chord length (c) could be found for each shape. With a length for each shape the Reynolds number was calculated using the equation below.

$$Re = \frac{u_\infty \cdot L}{\nu} \tag{1}$$

Where u_∞ is the speed of the car, L will be the chord length, and v is the kinematic viscosity of air. The average car speed is 45 mph, which will be used in all calculations. A sample calculation for a NACA 0040 is shown below.

$$t = c \cdot \% \rightarrow \frac{t}{\%} = c \rightarrow \frac{25\ (in)}{0.40} = c = 62.5\ inches \tag{2}$$

$$Re = \frac{45\ (mph) \cdot 62.5\ (in)}{0.0242\ \left(\frac{in^2}{s}\right)} = \frac{792\ \left(\frac{in}{s}\right) \cdot 62.5\ (in)}{0.0242\ \left(\frac{in^2}{s}\right)} = 2045454.55 \tag{3}$$

Using the Reynolds number and a table in the book, the drag coefficient was estimated. The first table was used for the NACA 0006, 0009, 0012, 0018, and 0025. The plot below was used for the NACA 0040 but could also be used for the others.

Table 17.2 Free-air airfoil section drag coefficients (Lift = 0)

R_C	$3(10^6)$	$6(10^6)$	$9(10^6)$
NACA section			
0006	0.0043	0.0050	0.0053
0009	0.0052	0.0055	0.0055
0012	0.0057	0.0057	0.0057
2415	0.0070	0.0065	0.0065
2418	0.0074	0.0066	0.0065
2421	0.0078	0.0070	0.0070
2424	0.0087	0.0081	0.0075
63_2–015	0.0053	0.0051	0.0048
63_3–018	0.0057	0.0052	0.0049
63_4–021	0.0064	0.0056	0.0053

Table 17.3 More free-air airfoil section drag coefficients (Lift = 0)

$R_C(10^{-6})$	1.75	2.00	2.50	3.00	4.00	5.00	6.00	7.50
NACA section								
0018	0.0080	0.0079	0.0077	0.0076	0.0075	0.0073	0.00715	0.0070
0025	0.0089	0.0088	0.0082	0.0081	0.0081	0.0081	0.0081	0.0081

Figure 8: Reynolds number and drag coefficient table from A Solar Car Primer

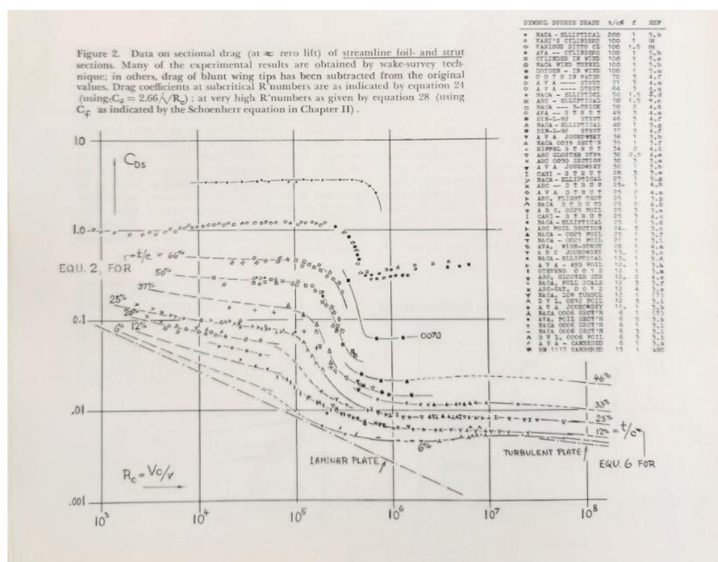

Figure 9: Reynolds number v drag coefficient plot from Hoerner

Although we now have a drag coefficient for each shape, it is not fully accurate. The calculations need to be corrected for various interferences such as ground effect, being connected to a wall, being parallel with another fairing, and having one behind/in front of another. Ground effect is assumed to not have any effect on the drag for the fairing so it can be ignored. The first interference that will be considered is the wall interference. The current drag coefficient is based off free air, but our airfoil is connected to the bottom of the main body on one side. The equation below is from Hoerner and uses the thickness and chord lengths to find the correction drag coefficient.

$$\Delta c_{Dt} = 0.75 \cdot \left(\frac{t}{c}\right) - \frac{0.0003}{\left(\frac{t}{c}\right)^2} \tag{4}$$

$$\Delta c_{Dt} = 0.75 \cdot \left(\frac{25\ (in)}{62.5\ (in)}\right) - \frac{0.0003}{\left(\frac{25\ (in)}{62.5\ (in)}\right)^2} = 0.298 \tag{5}$$

Now that we have the wall correction it can be added to the free air drag coefficient. The next correction is from 2 airfoils in parallel. The book provides an equation to find this correction. The equation uses the y_{min} and thickness to find the correction. As mentioned before the y_{min} and thickness are kept constant. The y_{min} is the distance between 2 parallel airfoils. This is further explained in the figure below.

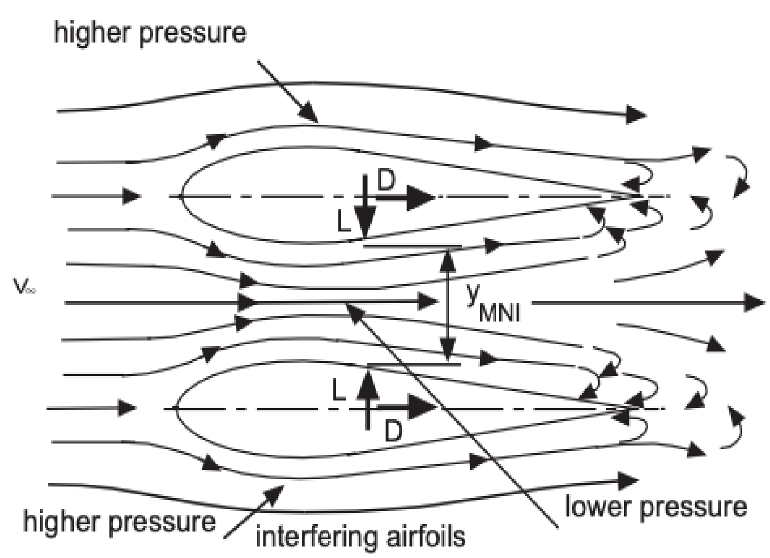

Figure 10: y_{min} example from A Solar Car Primer

With the current frame design the y_{min} was kept at a constant 17 inches. The equation used is listed below.

$$\frac{\Delta c_{DI}}{c_{D\infty}} = 2.819929 - 2.084828\left(\frac{y_m}{t}\right) + 0.614002\left(\frac{y_m}{t}\right)^2 - 0.084466\left(\frac{y_m}{t}\right)^3 + 0.00450\left(\frac{y_m}{t}\right)^4 \quad (6)$$

Note that the equation is then multiplied by the free air drag coefficient to obtain the correction. The new equation and sample calculation for a NACA 0040 are below.

$$\Delta c_{DI} = c_{D\infty}\left(2.819929 - 2.084828\left(\frac{y_m}{t}\right) + 0.614002\left(\frac{y_m}{t}\right)^2 - 0.084466\left(\frac{y_m}{t}\right)^3 + 0.00450\left(\frac{y_m}{t}\right)^4\right) \quad (7)$$

$$\Delta c_{DI} = 0.0747 \quad (8)$$

This correction can now be added to the new drag coefficient we obtained from the wall interference correction. The next correction is from 2 airfoils in series. This correction is fairly easy from the figure below.

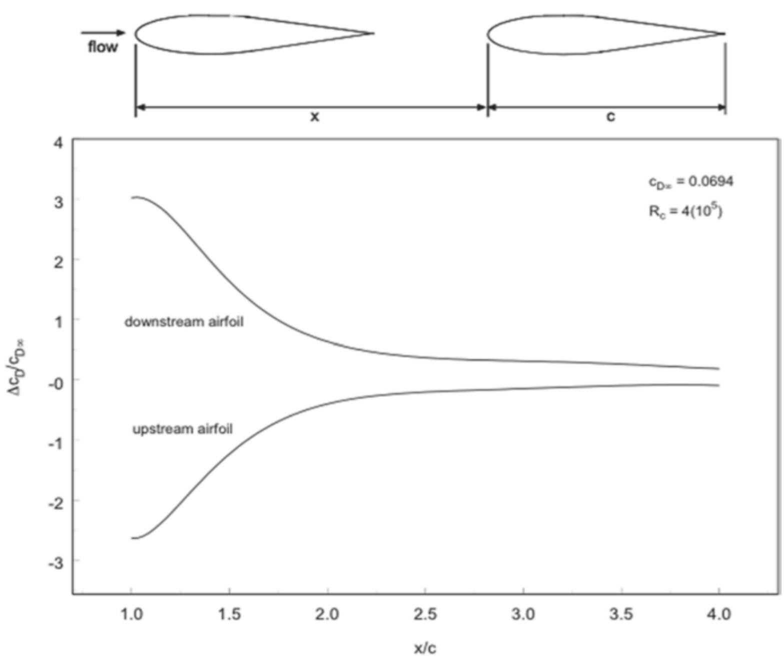

Figure 11: Drag coefficient plot for two airfoils in line from A Solar Car Primer

Using estimations from the figure above, the total drag cancels each other out and can be ignored. This plot is still useful to ensure that the airfoils are placed properly. The x distance above could not be changed but it could still be confirmed. Our x value is 105 inches. This gives a ratio of 1.68. Ideally the number would be higher but due to constraints this is the best value. All these calculations and relationships bring us to the final decision. The NACA 0040 gives us the best drag coefficient for our system. The final design of the fairings on the car can be viewed below.

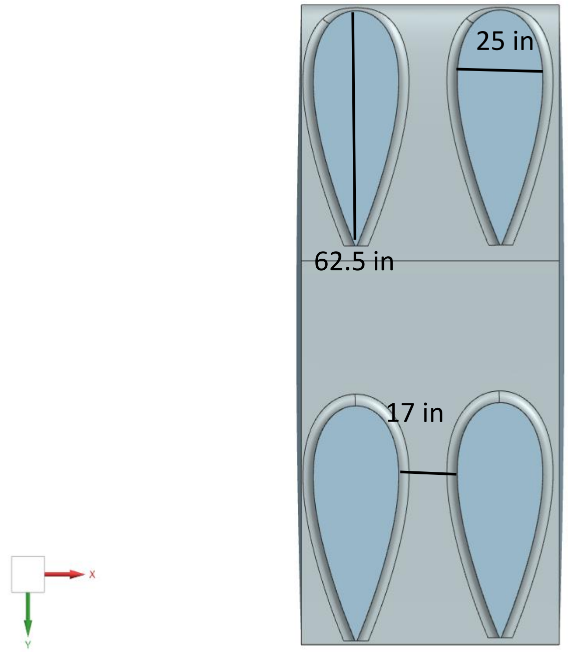

Figure 12: Bottom view of new fairing design

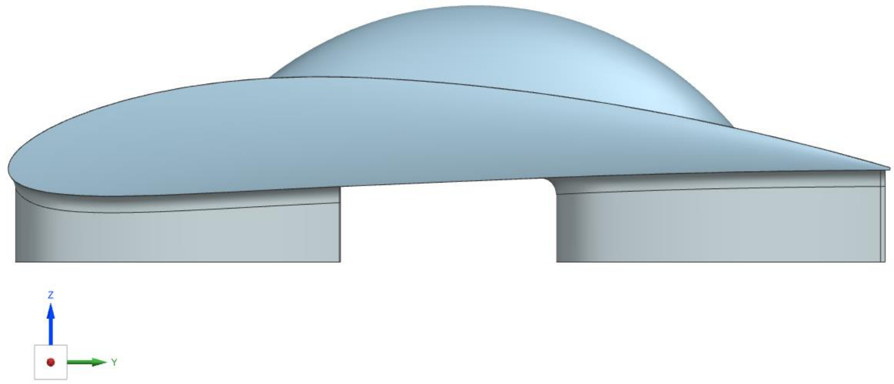

Figure 13: Side view of new fairings

The total drag force of the fairings was calculated with the new drag coefficient using the equation below. A sample calculation for the NACA 0040 is included.

$$c_d = \frac{F_d}{\frac{1}{2}\rho u_\infty^2 cb} \quad (9)$$

$$F_d = c_d \cdot \frac{1}{2}\rho u_\infty^2 cb = 0.0225 \cdot \frac{1}{2}\left(4.25 \cdot 10^{-5}\ \frac{lb}{in^3}\right)\left(792\ \frac{in}{s}\right)^2 (62.5\ in)(12\ in) = 224.93\ N \quad (10)$$

Compared to the initial design of the pontoons, the new airfoil design has a lower drag coefficient and reduces the vehicle's weight. The precious drag coefficient was estimated from Hoerner to be around 0.8 from the given length to diameter ratio. The figure used can be seen below. It is important to note that this value is a free air drag coefficient. With a corrected drag coefficient of 0.395, the new design is over 50% better than the original.

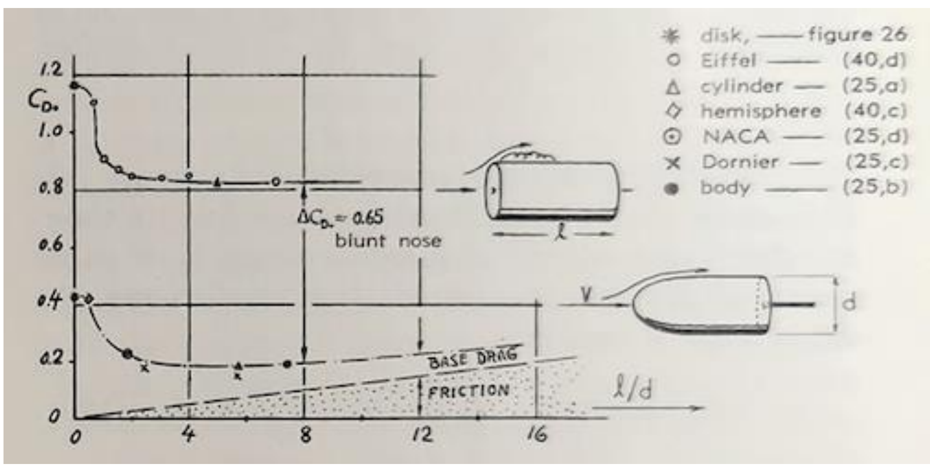

Figure 14: Drag coefficient plot from Hoerner

Main Body design

The main body of the car plays a crucial role in the vehicle's performance. In addition to housing the driver, it must be a smooth, low-drag surface for airflow that supports the solar array. The weight of the current body is around 150lbs. A design constraint provided by our industrial advisor was not to exceed this value in lift generated by the body. The car is assumed to operate at a zero-degree angle of attack as the endurance race occurs over mostly flat terrain. The reason we want the body to generate lift is improved handling and stability as well as energy savings leading to enhanced range for the car. The body generating lift effectively counteracts a portion of the vehicles weight. The lift force acts in the upward direction, opposite the downward gravitational force on the car. The result is that the net weight pressing down on the wheels and suspension is reduced. This reduction in net weight at operating speeds leads to better handling and improved stability due to more even weight distribution. The lift produced also effectively reduces the normal force acting on the car which in turn reduces the kinematic friction force requiring less energy to overcome it. Too much lift is undesirable as this would compromise traction and stability. A delicate balance between lift and traction must be achieved.

Several airfoils and their zero-degree angle of attack characteristics were considered. It is important to note that the evaluated airfoils are not the only suitable geometries, they were chosen for their extensive preexisting testing data simple geometry for manufacturing. It would be unrealistic to evaluate all suitable candidates in our timeframe. The NACA 4412, 4415, 4418, 6409 and 2412 were our primary candidates for achieving a realistic lift coefficient at zero-degree angle of attack, while maintaining ease of manufacturing and integration with other body parts.

The length of the car is 170 inches. Its operating speed is 45 mph. The kinematic viscosity of air is taken to be 0.0242 in^2/s at standard atmospheric conditions. using equation (1), the Reynolds number is:

$$Re = \frac{u_\infty \cdot L}{\nu}$$

$$Re = \frac{45\ (mph) \cdot 170\ (in)}{0.0242\ \left(\frac{in^2}{s}\right)} = \frac{792\ \left(\frac{in}{s}\right) \cdot 170\ (in)}{0.0242\ \left(\frac{in^2}{s}\right)} = 5563636$$

Xfoil was used to obtain the coefficient of lift C_L, moment coefficient C_M, coefficient of drag C_D, and lift/drag ratio L/D at zero-degree angle of attack α for all candidate airfoils at the calculated Reynolds number above as illustrated in figures 15-19. Note, N_{cr} is the critical amplification factor, this is a parameter used in airfoil analysis to determine the transition point where laminar flow turns turbulent. The typical range is 7 to 14. Higher values assume more stable laminar flow and delayed transition to turbulent flow, which can result in lower drag results. Lower values conversely assume earlier transition which leads to higher drag predictions. A value of 9 was chosen for N_{cr}. The value is a reasonable choice for the expected moderate free stream turbulence, smooth surface, and Reynolds number on the order of 10^6. The value 9 strikes a balance between assuming laminar flow and taking other factors into consideration, it is also the default value used in Xfoil consistent with industry practice for related applications.

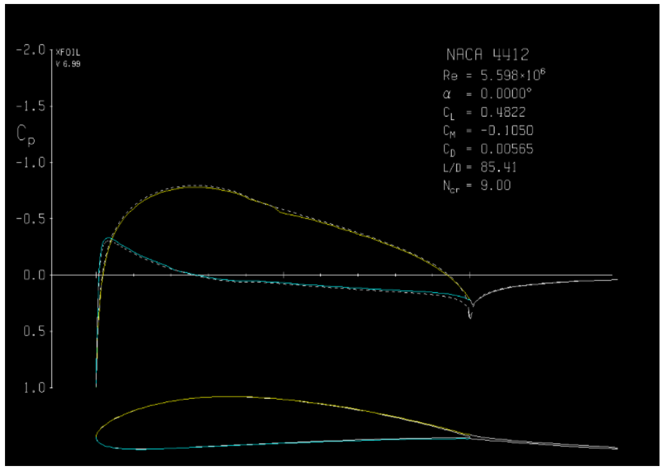

Figure 15: NACA 4412 airfoil data

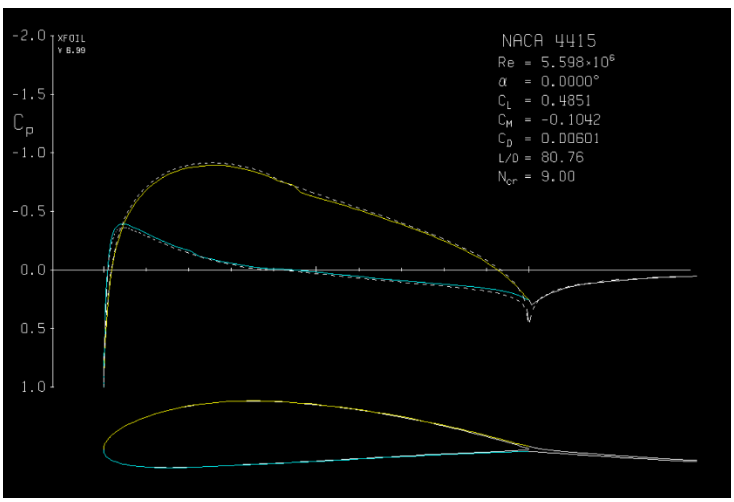

Figure 16: NACA 4415 airfoil data

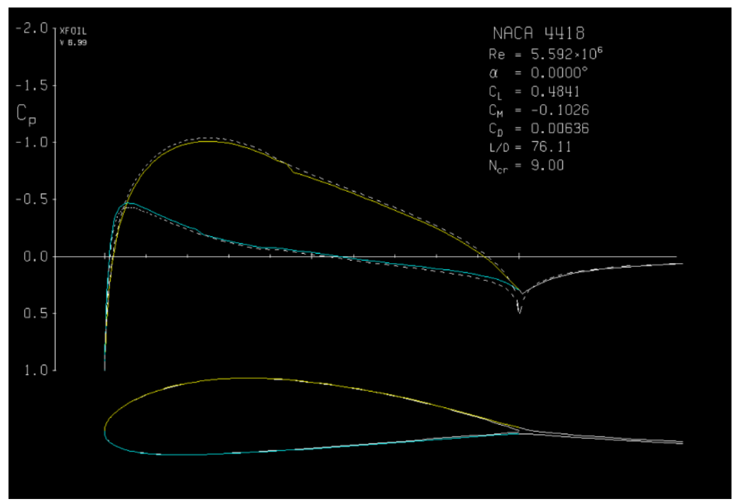

Figure 17: NACA 4418 airfoil data

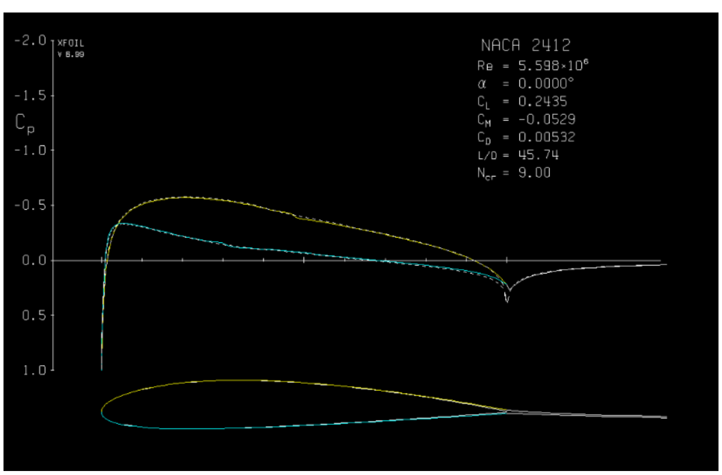

Figure 18: NACA 2412 airfoil data

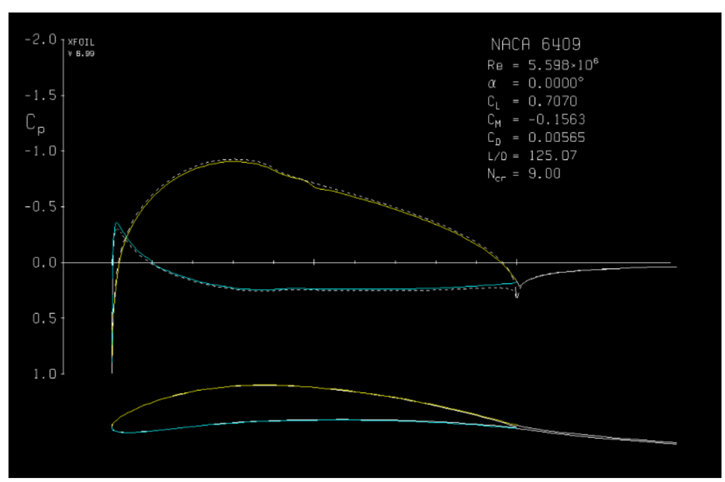

Figure 19: NACA 6409 airfoil data

The primary design constraint for the body is the height of the driver. The team typically utilizes drivers around 5ft (60 inches). The next constraint is ensuring the driver has enough clearance to fit in the car. 2.75 inches is allocated above the driver's head (per the cockpit design) and 5 inches between the base of the seat and the bottom of the car (this is the average in industry). This results in a total required clearance of 7.75 inches. The driver will sit in the car at an inclined angle of 30 degrees from the vertical position, similar to seats used in Formula one cars. The leading edge of the cockpit is 50 inches from the leading edge of the body, an ideal position obtained from the current solar team's design. The maximum height of the cockpit is 45 inches from the leading edge of the cockpit. Therefore, the maximum height of the cockpit is 95 inches from the leading edge of the body. A thickness distribution calculator (shown in figure 20) was used to obtain the thickness of the body 95 inches away from the leading edge, as this is where the maximum height of the cockpit is located. That value (upper surface + |lower surface| at x = 95 in figure 20) was then added to the maximum height of the cockpit to determine the total vertical space available for the driver. This process was performed for all candidate airfoils. The results are shown in table 1. Note that the thickness includes the maximum height of the cockpit (15 inches).

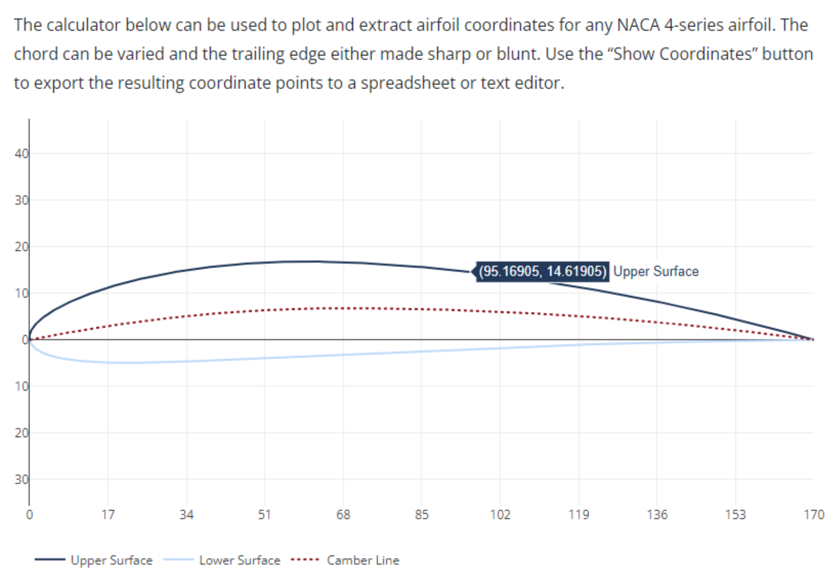

Figure 20: Thickness distribution calculator for NACA 4412

Table 1: Thickness 95 inches from body leading edge

Airfoil	Thickness at 95" from leading edge (inches)	Vertical space available after subtracting clearence (inches)
NACA 4412	31.56	23.81
NACA 4415	35.69	27.94
NACA 4418	39.7	31.95
NACA 2412	31.4	23.65
NACA 6409	27.3	19.55

A 5ft woman was measured from the top of her head to the base of her spine. This length was 26 inches. Using Pythagoras' theorem, at a 30-degree inclination from the vertical upright position, she will occupy 22.52 inches of vertical space (seating position shown in figure 21). From this result, the NACA 6409 airfoil was eliminated.

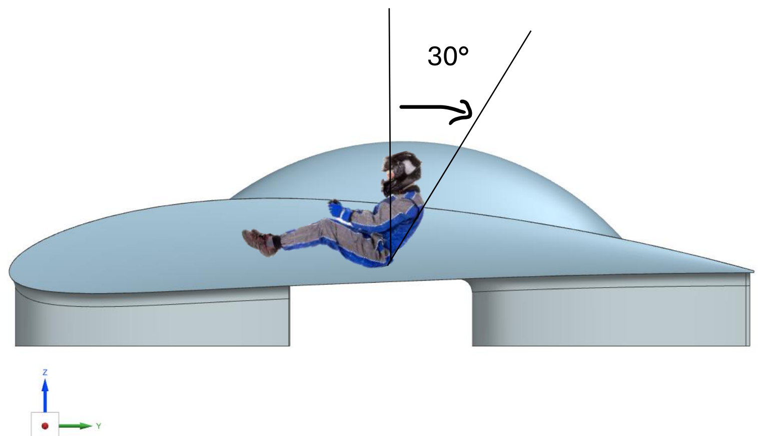

Figure 21: Driver seating position

The next point of consideration is lift and drag coefficient. The lift generated by all the candidate airfoils has been determined to be insufficient to cause traction issues, so we optimize for the highest coefficient of lift while minimizing drag. From the Xfoil data, the NACA 2412 has the lowest coefficient of lift, so it is eliminated. The dominant parameter is the drag coefficient, so we want to select the airfoil with the lowest value from the remaining airfoils. This leaves us with NACA 4412. It has sufficient space for the driver and satisfies the rest of our design criteria. It also has a moderate camber for ease of manufacturing and integration to other components of the car, resulting in minimal interference drag. From the lift equation and calculation at (11), the 4412 airfoil with chord length 170 inches produces approximately 19.206 lbf of lift while travelling at 45mph, well below our 150lbf limit.

$$F_L = 0.5 \cdot \rho \cdot V^2 \cdot C_L \cdot S = 0.5 \cdot 0.07647 \frac{lb}{ft^2} \cdot 66 \frac{ft}{s} \cdot 0.4822 \cdot 7.694\, ft^2 = 19.206\, lbf \tag{11}$$

Conclusions and Recommendations

The primary goal of this project was to design an improved solar car body for the MSU Solar Racing Team that enhances aerodynamic performance while maintaining ease of manufacturing. Through extensive research, benchmarking, and analysis, our team developed a novel design that significantly reduces drag and weight in comparison to the current design.

Key improvements include:

1) Cockpit design: By optimizing the length-to-height ratio and the width of the rear, the new cockpit design achieves a 50% reduction in drag coefficient.
2) Fairing design: Moving from a pontoon design to individual symmetric airfoil shaped fairings at each wheel decreases weight and results in a drag coefficient reduction of 50%.
3) Main body design: The NACA 4412 airfoil was selected for the main body due to its superior lift-to-drag ratio, sufficient driver clearance and ease of manufacturing and integration with other components.

The design improvements collectively contribute to increased efficiency as less power is required to travel the same distance. The reduced weight and improved aerodynamics also led to better handling, stability, and overall performance.

We strongly recommend implementing these changes in future iterations of the Solar Team's car. The new designs can be implemented into the current manufacturing process using carbon fiber, thereby minimizing the learning curve and additional resources required.

For further validation of the performance gains, we suggest wind tunnel testing on scale models of the new design. From our initial planning, the wind tunnel at Western Michigan University is available for testing a 1/4th scale model without significant error. This will provide valuable data to refine the design and optimize its operating condition encountered in the race.

Appendix A:

MICHIGAN STATE UNIVERSITY

design program

Department of Mechanical Engineering
Return to Jim Lang, ME481 Capstone Coordinator: langjame@msu.edu

Project Non- Confidential Project Summary

Distributed to all ME 481 Capstone design students for review. Students provide project preferences to course faculty.

Project Title: Solar Car Body Design
Project Technical Contact (Name & Title): Ethan Stull, Body Lead
Technical Contact Email and phone # stulleth@msu.edu, (269) 491-4683

Questions you may want to address in your summary include: If students may not be familiar with your company you may want to include a couple of sentences describing your company or division. What is the problem you hope to solve with this project? What are the project objectives? What is the scope of the project? Are there any specific skill sets or tools that will be required? Describe how this project will positively influence your company through, for example, reduced costs, a new product, higher quality, faster production, a healthier workplace etc.? Feel free to include pictures or graphics.

Company Background: Michigan State University's Solar Racing Team (MSU SRT) is a student-led undergraduate team composed of passionate students that design, manufacture, and race full-sized solar powered electric vehicles. We strive to promote sustainability, renewable energy, and STEM education in our community. We are one of the largest sustainability organizations on campus. Over the past 22 years, we have designed and built 4 single-occupant vehicles and 1 multi-occupant vehicle. We are currently building a cost-effective single-occupant vehicle named 'Cynisca.' Our current project is set to be our most competitive car yet, with a brand new electrical and mechanical design. The goal for this vehicle is to successfully compete in the 2024 Formula Sun Grand Prix and American Solar Challenge and perform well with consistency. Every year we modify and improve the solar car to become more competitive, safer, and faster.

Objective: To design a body that is aerodynamic, lightweight, and easy to manufacture. Compare and advise as to the manufacturability versus theoretical performance of carbon fiber aeroshells, monocoque body/chassis, and segmented flat paneling for future car build cycles.

Project details: The current body for the solar car is a significant development over previous years, however, it still has room for improvement. Development is still needed in minimizing the use of material, reducing aerodynamic drag further, and improving the ease of manufacture.

Skills required: CAD surface modeling, FEA, fluid dynamics experience

Project effects: The body provides air a path around the car minimizing the formation of vortexes and high pressure zones reducing the drag on the vehicle. By reducing the force of drag the car requires less energy to move allowing for greater efficiency.

Intellectual Property Considerations – If necessary, students can sign confidentiality and/or intellectual property agreements with the sponsor company. Please indicate if these agreements will be needed so students can be informed before selecting a project.

Will students need to sign a company confidentiality agreement? No

Will the students need to sign an agreement to assign any intellectual property generated as part of the project? No

Appendix B:

Hoerner, S. F. (1965). *Fluid-dynamic drag: Practical information on aerodynamic drag and hydrodynamic resistance*.

Thacher, E. F. (2010). *A Solar Car Primer*. Nova Science Publishers.

Appendix C:

The CAD file of the car is located at:

"T:\courses\ME\481\Sections\001\Teams\Team 23\Models\New Designs\FINAL BODY\DONT EDIT ITS ACTUALLY FINAL.prt"

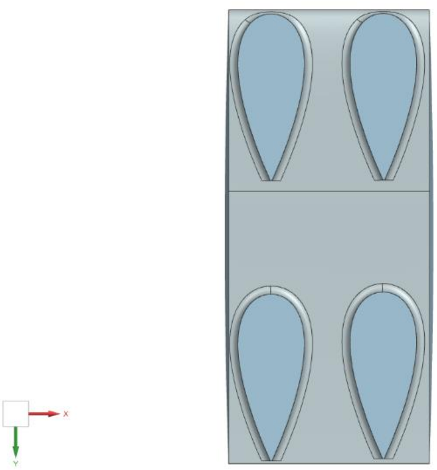

Figure 22: Bottom view of body

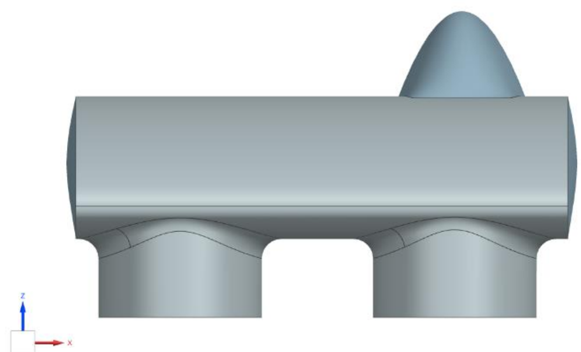

Figure 23: Front view of body

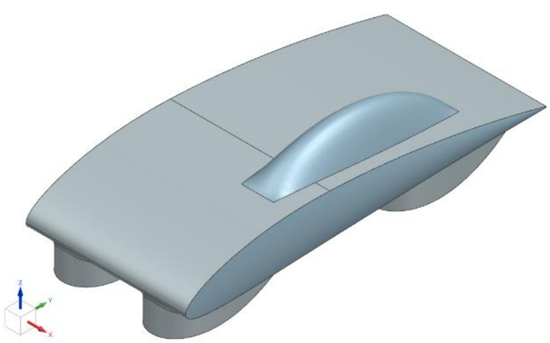

Figure 24: Isometric view of body

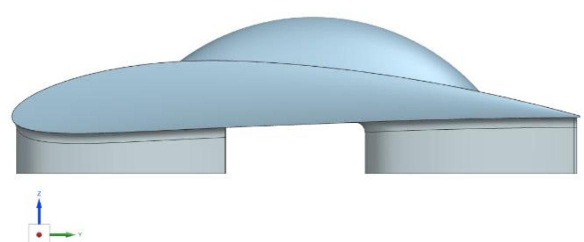

Figure 25: Side view of body

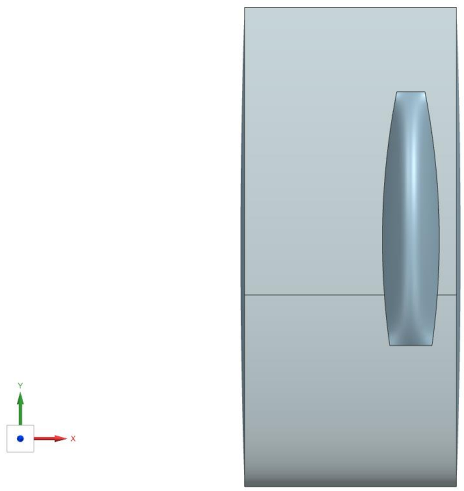

Figure 26: Top view of body

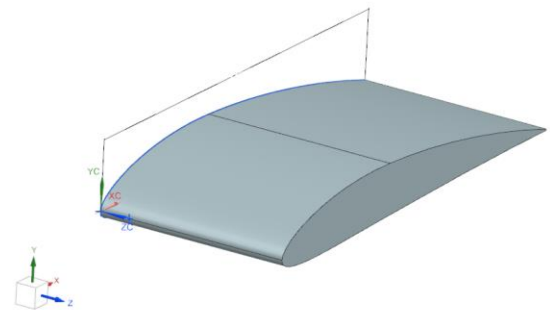

Figure 27: Main body airfoil

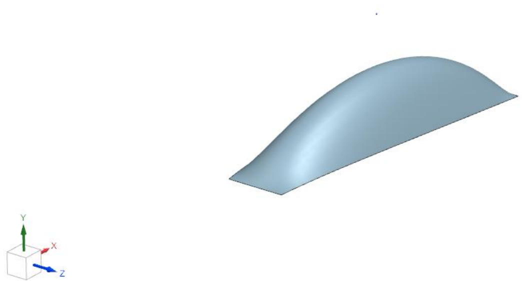

Figure 28: Cockpit

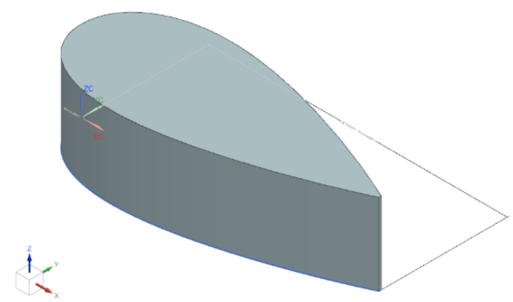

Figure 29: Wheel Fairing

Table 2: NACA airfoil calculations

NACA	chord (in)	Re	cdinf	deltacDt	deltacDI
0006	416.666667	13636363.6	0.005	-0.0383333	0.01660564
0009	277.777778	9090909.09	0.0055	0.03046296	0.0182662
0012	208.333333	6818181.82	0.0057	0.06916667	0.01893043
0018	138.888889	4545454.55	0.0073	0.12574074	0.02424423
0025	100	3272727.27	0.0081	0.1827	0.02690113
0040	62.5	2045454.55	0.0225	0.298125	0.07472537

Table 3: Corrected NACA airfoil calculations

NACA	cDI/cDinf	x (in)	CORRECTED CD	Fd
0006	1.66056383	1041.66667	-0.016727695	-1114.8473
0009	1.66056383	694.444444	0.054229165	2409.46688
0012	1.66056383	520.833333	0.093797094	3125.63809
0018	1.66056383	347.222222	0.157284973	3494.18004
0025	1.66056383	250	0.217701134	3482.18015
0040	1.66056383	156.25	0.395350373	224.93295