## Journal #1 Initial Deconstruction Phase

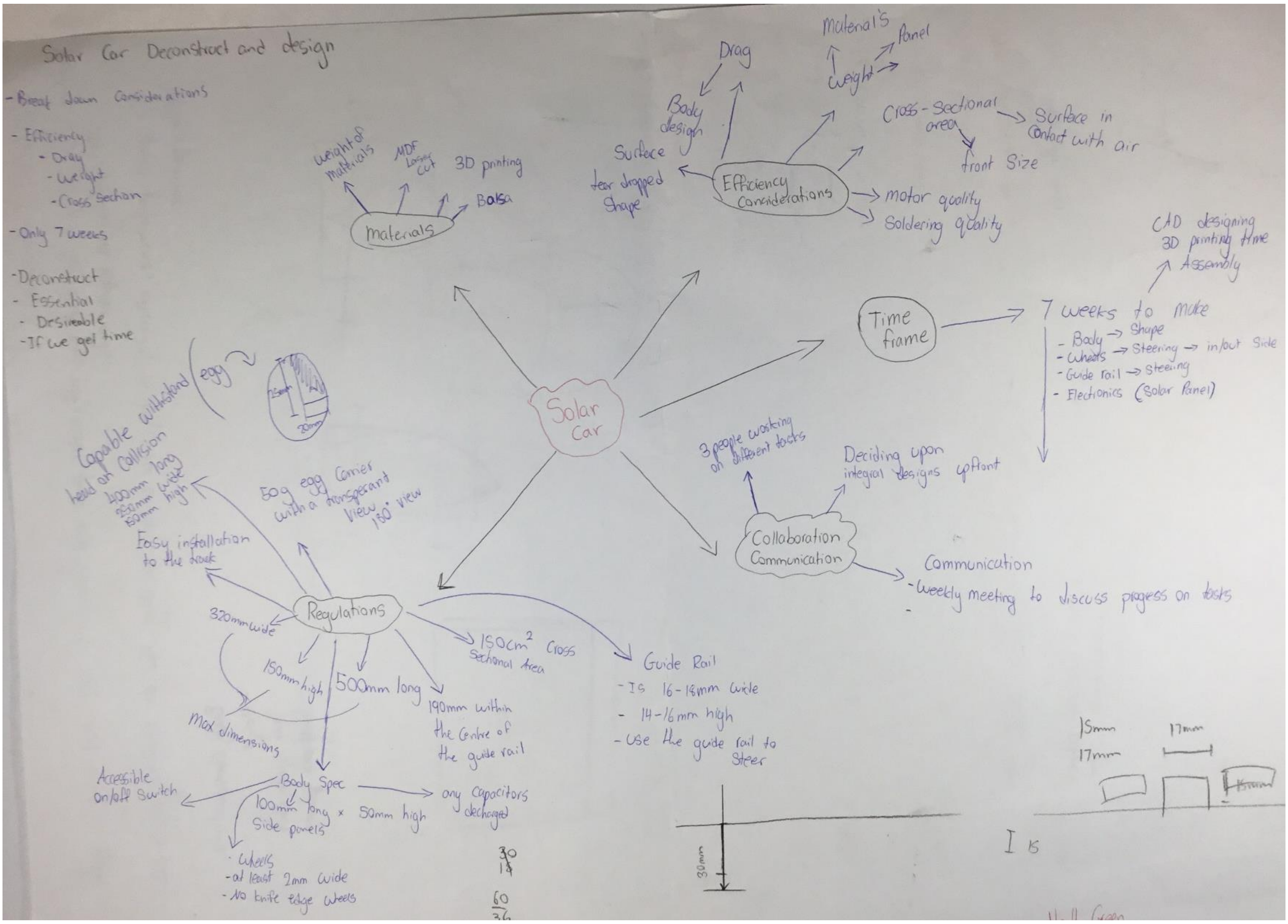


*Figure 1 shows the original deconstruction of the problem identifying the main areas of variables for the collaborative inquiry.*

To begin the project an individual deconstruction was commenced using the Australian-International Model Solar Car Challenge (AIMSC) regulations to break apart the project. There was a focus on the parameters and limitations of the project in terms of AIMSC's regulations and the time frame provided for this task. Breaking apart the solar car problem as seen in figure 1 identified the possible materials available, efficiency considerations, time frame provided, how collaboration and communication can be used, and the regulations for the cars build. Delving into this it was found that to complete all the requirements in 7 weeks meant that the group would need to be productive early to delegate tasks and set up an agreed upon timeline. To do so as seen in figure 2 the main parts of the car were broking apart into areas of relevant concern. For example, as seen in figure 2 the person that takes on the electronics and egg carrier would need to be aware of deconstructing the parameters around the electronics board assembly, solar panel wiring, the egg carrier, and how these components will be mounted into the car dependent on the frame produced from someone else. Hence, effective collaboration is vital between group members otherwise problems may arise. For example, if the person making the frame does not communicate with the person mounting the electronic components, then the electronics person won't be able to design their pieces to integrate into the vehicle. Similarly, this would occur with the wheels and the frame, if the person making the wheels doesn't specify a size of wheel, then the person making the frame will be unable to place where the axle would need to be positioned.

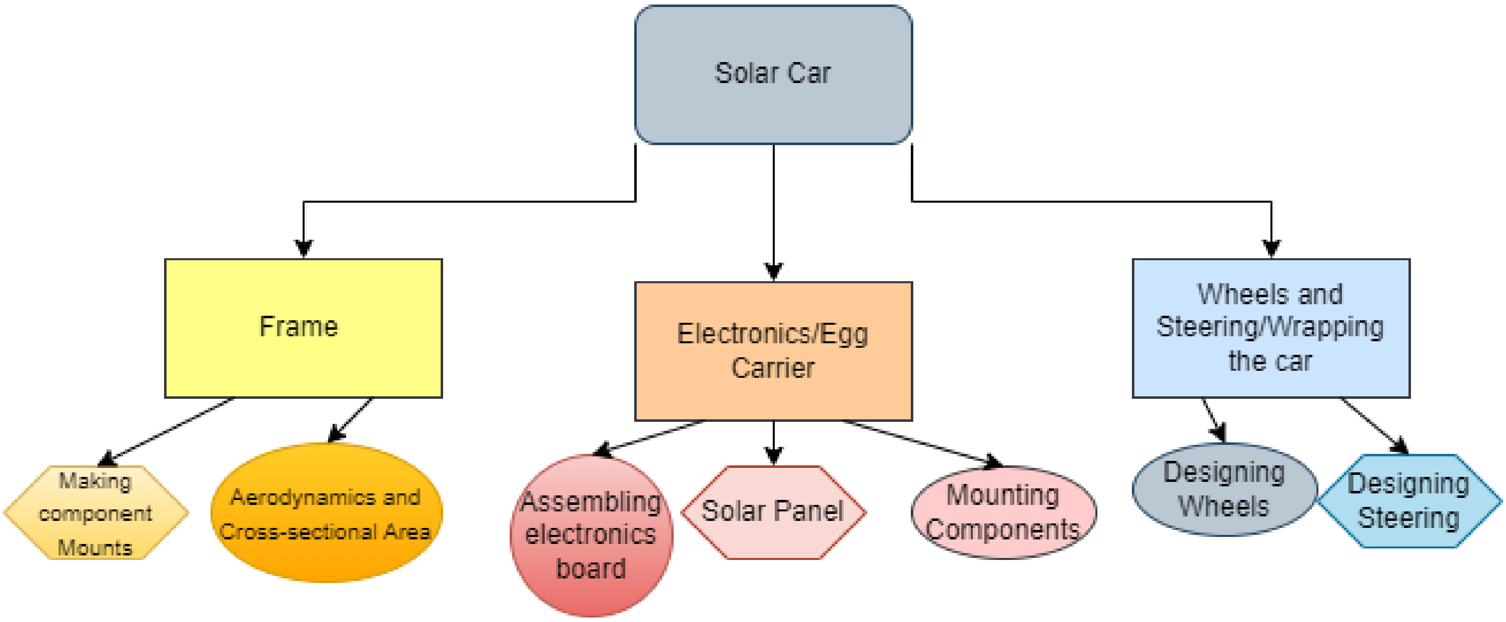


*Figure 2 shows the breakdown of tasks into areas of most relevance to the Frame, Electronics and egg carrier, and the Wheels, steering, and wrapping of the car.*

Tasks will be delegated based on personal strengths and previous experience with electronics, CAD software, and power tools. I was elected to construct the frame from my previous experience using computer aided design (CAD) software (Fusion 360 by Autodesk). Constructing the frame also includes ensuring that all components being produced would fit together and having mounting points inside the frame for the electronics, guide wheels, and motor for example. The build had specific size requirements as seen in figure 3. Following the AIMSC regulations which the car is being based on. A solar car must be constructed not exceeding 500mm long, 320mm wide, and 150mm high. The vehicle will require a guide system as the track has a guide rail to steer the vehicle.

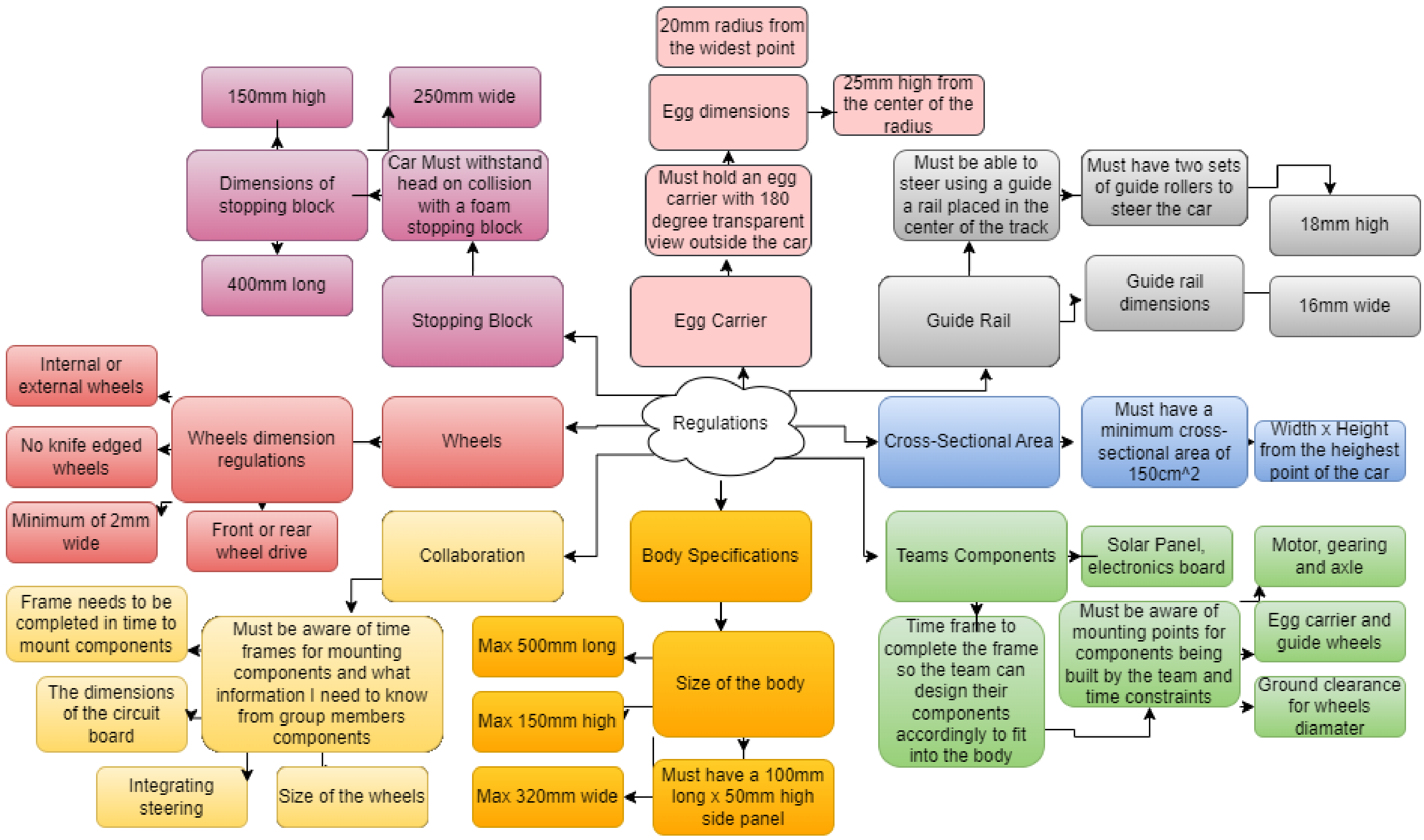


*Figure 3 Shows the frame/body specific deconstruction.*

**Controlled and Uncontrolled Variables**

Given the regulations in figure 3 must be met to 'qualify the vehicle', there are also other variables that affect the max speed. As the event is ultimately a race that the task is based off, then the goal is to make the fastest car as possible in the 6 weeks we have dedicated to construction and testing. Therefore, the variables involved in making a solar car as efficient and fast as possible were identified. These fixed variables being the solar panel, electronics, and the motor in terms of weight, efficiency of the components and the quality of the build. The solar panel has a fixed voltage output dependent on the sunlight provided and the motor constantly runs at 87% efficient, therefore the solar panel and motor are uncontrolled variables. Whereas the weight, quality of the vehicle build, and aerodynamics / cross-sectional area are controlled variables. Keeping the weight low, the cross-sectional area small and the build quality high the faster the vehicle should become in theory.

**Mass and Friction**

As the problem is based around efficiency the weight of the vehicle must be kept to a minimum. This is due to Isaac Newton's second law of motion "the acceleration of an object depends upon… the net force acting on the object and the mass of the object. (Byju) The relationship between these variables dictates that "the acceleration… is directly proportional to the net force acting on the body and inversely proportional to the mass of the body (Byju). Given that the force acting on the body in this case the vehicle is relative to the maximum power output of the motor, the force cannot be controlled. However, acceleration can be controlled by minimising the cars weight. As the mass decreases the acceleration increases, therefore a greater terminal velocity can be achieved, being the goal of the solar car. Having a greater mass also inhibits terminal velocity from secondary factors such as friction forces between the wheels of the vehicle and the surface of the track. This is due to the normal force which is equal to mass x gravity. As the mass increases as does the normal force, making them proportional. This affects friction as "frictional resistance force between two surfaces is proportional to the normal force pressing them together" (Nave)

**Internal Friction**

Internal friction of the vehicle will also be present, for example for motion to be transferred to the wheels an axle will be used to connect the motor and wheels. This will inherently require bearings to fit on the axle and will create a small amount of friction. However, if the build quality is poor then the bearings may turn in their socket (yet to be designed) and the wheels will lose power. This similarly may occur with the gearing from the motor to the axle and from the axle to the wheels, given that the gears and wheels do not have a sound friction fit onto the axle. This would result in the wheels and gears rotating at different speeds relative to the axle. This is a controlled factor that will need to be considered during the build.

**Quality of the Build**

The quality of the build may have a large impact on the terminal velocity of the vehicle. Should the solar car be built poorly with lots of vibration and movement in the body with parts moving around in their joints would absorb energy. For objects to move energy must be supplied to them, which would come from the propulsion of the motor. The optimal build quality for this not to occur would be for the car to be completely rigid and for all components being attached to the axle to have a tight friction fit and reinforced with a glue of some kind.

**Aerodynamics and Cross-Sectional Area**

The car will be designed to have the lowest cross-sectional area permitted by the regulations. Drag will be controlled by designing the body shape to have the lowest amount of drag possible. Based on background research into drag the most aerodynamic shape is a tear drop shape with a rounded front and a sharp-edged tail. This allows the air to split and travel along the surface of the body and then return together at the same point. This is due to drag being the result of a low-pressure area created at the back of the car from the air travelling around the body not meeting the same point. A large box or rectangle for example a trucks trailer has a large low-pressure pocket behind the trailer. This low pressure at the back of the vehicle along with high pressure at the front of the vehicle, then the car will have a force acting in the opposite direction to the vehicles motion.

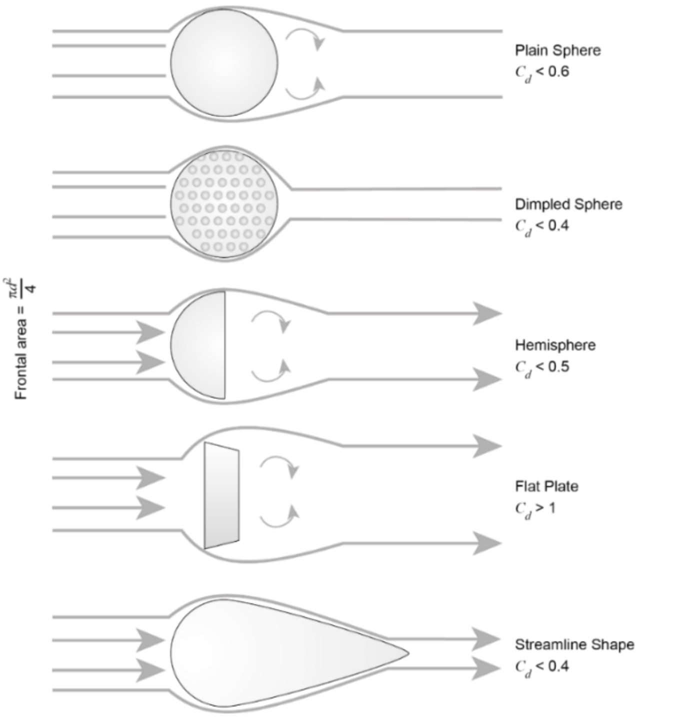


*Figure 6 shows how air moves around different shapes. Representing the advantages of a tear drop shape (streamline shape)*

*Figure 4 shows an Audi R8 in a wind tunnel showing how traces of wind move around the vehicle.*

*Figure 5 shows a Mini Cooper S in a wind tunnel showing how air moves around a more box like car compared to the Audi. It also shows a greater low-pressure area at the back of the car (The dark area where there's no air strands).*

**Planning and Timeline**

Following the groups individual deconstruction, a timeline was put together that involves all the group members tasks that need to be completed. A certain synergy is required to effectively make a solar car in a short amount of time where every group member knows when their work needs to be complete. This should assist in removing confusion

| Personal Time Frame for building the body | | | | | | | |
|---|---|---|---|---|---|---|---|
| **Week** | **Mon - Single** | **Tue - Single** | **Thu - Double** | **Fri - Single** | Agreed Team Progress for the Frame | Agreed Team Progress for electronics, gearing, and motor mount | Agreed Team Progress for wheels, steering, and guide rail. |
| **1** | Deconstruct the initial problem individually | Continue Deconstruction individually | Begin evaluating and testing possible materials | Journal the weeks work and progress | Complete individual Deconstruction by the end of week 1 | Complete individual Deconstruction by the end of week 1 | Complete individual Deconstruction by the end of week 1 |
| **2** | Develop Basic Shapes in fusion to put into CFD | Continue Developing Basic Shapes | Test Basic Shapes in CFD | Journal the weeks work and progress | Retrieve results from tested basic shapes in CFD | Finished soldering the electronics board | Design different sizes of wheels to be tested |
| **3** | Assemble components into CFD and finish sketches | Laser cut components | Laser cut and assemble components | Journal the weeks work and progress | Assemble cut out components | Design and print a motor mount | Print wheels and design guide rail to fit onto the frame |
| **4** | Attach the solar panel to the frame | Glue the frame together | Initial testing of the car getting some basic data | Journal the weeks work and progress | Glue components and attach the solar panel | Integration of electronic components into the frame | Develop and attach steering to the axles |
| **5** | Prepare the frame for wrapping | Any final work that needs to be complete | Testing the solar car out on the track | Journal the weeks work and progress | Testing the solar car estimated speed, volts, amps, power | Build and assemble an egg carrier plus skin the car before testing on Thursday | Help skin the car with Liam before testing on Thursday |
| **6** | Finish the Journal | Finish the Journal | **Sports Day** | **Pupil Free Day** | Complete the individual Journal | | |
| **7** | Evaluation | | | | | | |

*Figure 7 shows the 7-week timeline and plan for the solar car.*

and roadblocks for work as some components rely on another group members components being complete first. From this a six-week plan was produced outlining what should be happening and when for everyone's tasks and a lesson-by-lesson plan for what I would be doing, as seen in figure 7. We made agreed upon weekly goals for where we should be up to at the end of each week. This should be able to achieve the synergy desired to be able to meet the goal of building a solar car that meets all regulations. The main weekly goals that have been set for myself are to test basic shapes using CAD software computational fluid dynamics (CFD) a wind tunnel software, assemble laser cut frame components, glue components and attach the solar panel, and finally testing.

### Journal #2 Initial Design and Testing Phase

The initial sketches for the frame were based around the most aerodynamic design possible. Background research into aerodynamic shapes of vehicles suggested the use of a tear drop shape as previously discussed. Using the wellington Solar Car Event winners document the winning cars shown did not follow tear drop shapes rather aimed for the lowest cross-sectional area possible regulations permitting (150cm$^2$) and using light weight wood as seen in figure 8. These vehicles also had small wheels with external steering on the front wheels also small wheels. Using these concept ideas several different models of cars were produced in CAD to identify the aerodynamics of these vehicles. These models were placed into Autodesk (CFD) a wind tunnel software to see the results on the high- and low-pressure areas around the vehicle and how air particles will move around the car. CFD can also show the turbulence of air around and behind the vehicle along with the drag affect from the low pressure represented at the back of the model. As seen in figure 9 and 10 the screen shots taken from CFD displays the air flow around the basic shapes. As seen in figure 9 a solid block and a concave model was placed to see the effect of intuitively inefficient designs. The ellipse design and the ellipse

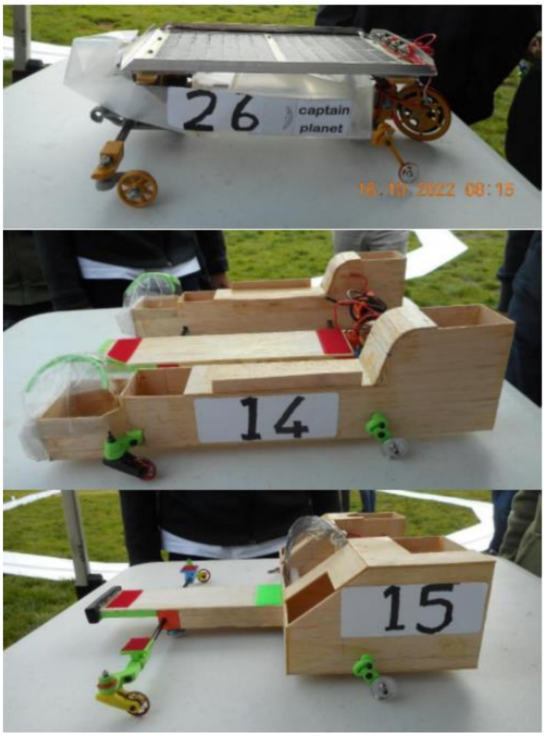


*Figure 8 shows the event winners from the Wellington Solar Car Event.*

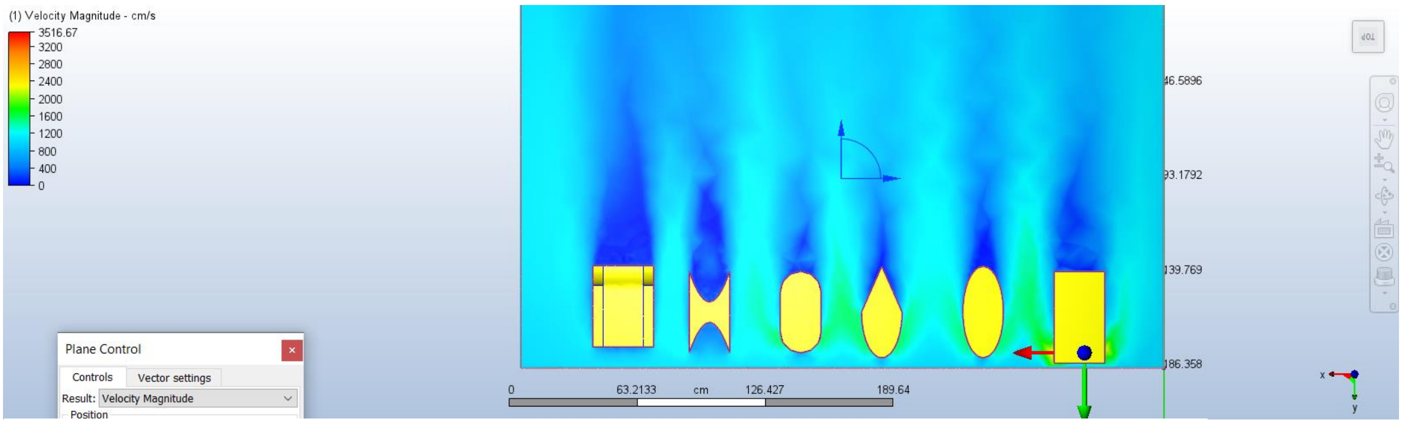


*Figure 9 Displays the top view of air pressure and turbulence of the basic shapes testing in CFD.*

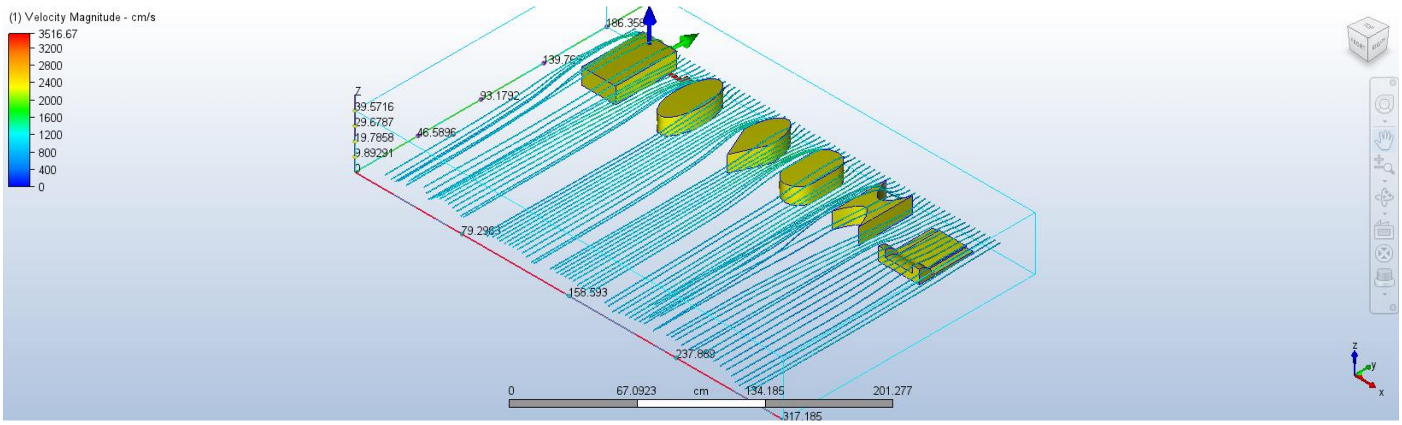


*Figure 10 Displays the back view of the basic shapes in CFD observing the path of particles moving around the models.*

design with a sharp tail appeared to perform the best with the lowest amount of low-pressure turbulent air behind the object. Whereas the solid block performed close to worst as it can be seen the dark blue low-pressure cloud does not abate at all unlike the ellipse shapes. The model on the far left of figure 9 was based off the winner for the international event in 2022 at Wellington and appeared to perform worse than the solid block. It has a clearly defined low pressure drag factor right behind the model which also doesn't abate for a long time when compared to other models being tested. However, when observing the movement of particles around the models in figure 10 the international winner designed appeared to have all the air particles travel over top of the model, this contradicts the pressure diagram in figure 9. The explanation for this may be that the international winners design was only 1/3 of the height of the other objects. The only model that consistently performed well in both models was the ellipse design

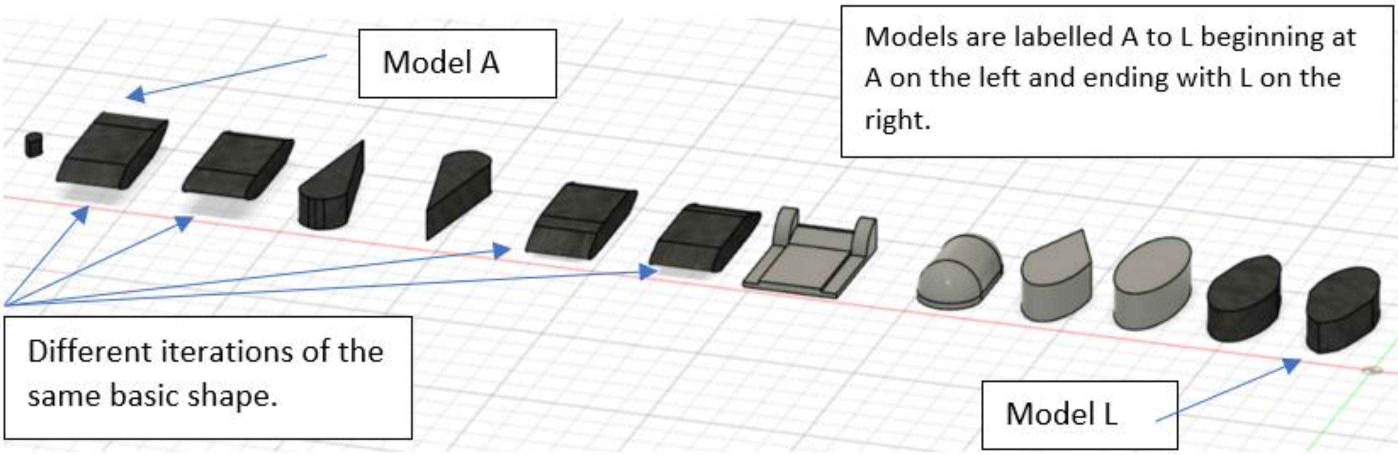


*Figure 11 Displays the second set of basic shapes designed in fusion to be tested in CFD.*

with a sharp tail. Using this data another set of basic shapes will be designed to place into CFD. The limitation of CFD is the experience of using the software where there may be more functions available that are unknown such as the drag coefficient acting on each object or adding a mass to each object. Using this information new models were developed in fusion 360. To model the designs that performed the best and made different iterations of them. For instance, in figure 11 there are four iterations of the same basic shape, there's the original model then back to front and then upside down original and back to front. This is due to that design being most practical for the final product

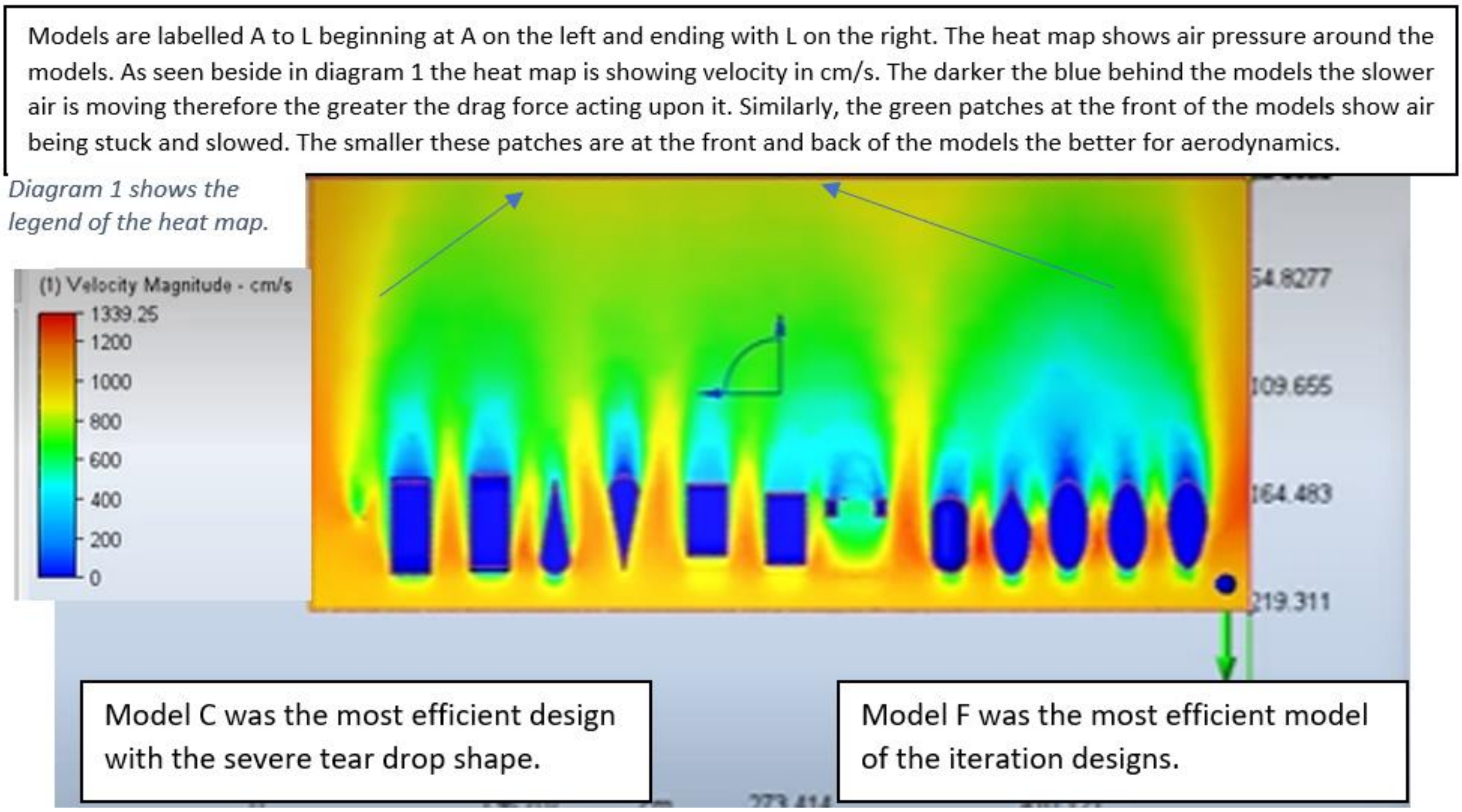


*Figure 12 displays the velocity heat map of the second set of basic shapes.*

in terms of mounting the solar panel and wheels into the body. It became a time concern that a body needed to be selected as two weeks had already passed without any physical assembly construction. The results from CFD showed

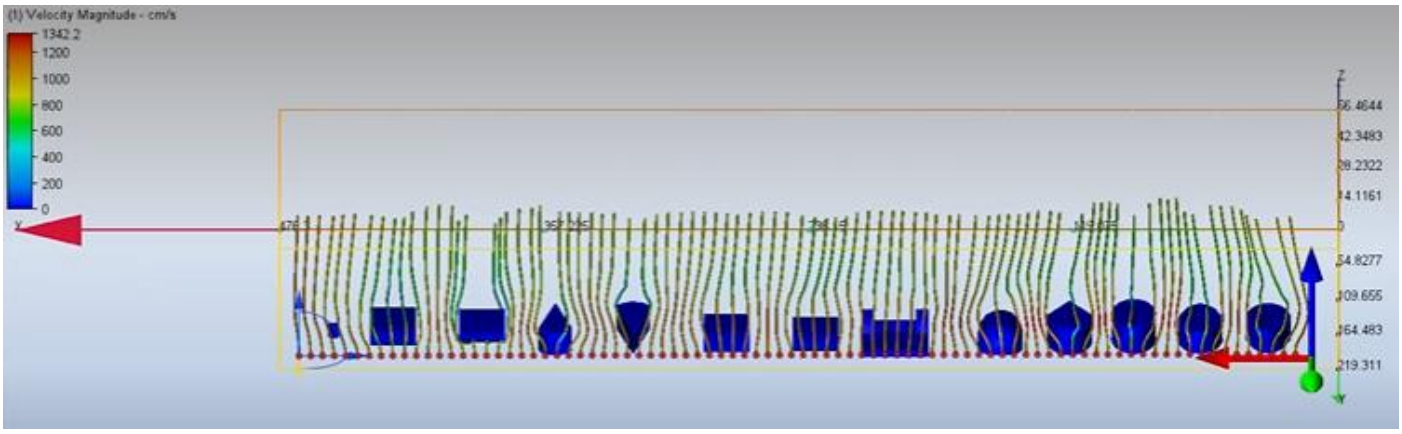


*Figure 13 displays the same set of basic shapes as figure 12 with the particle trace's function active.*

that the more severe tear drop shape object C performed by far the best, in figure 11. When using the particle traces as seen in figure 13 model C performed the best overall in the heat map and the particle traces. Although it came back to the practicality of mounting a big rectangle solar panel on the roof of the object which would negate the aerodynamic design of the tear drop shape. As it is currently week three and the results discussed in figures 11, 12, and 13 had not been retrieved yet and with the other group members waiting for me to begin the framework design so they could mount their components to the cars. Model A from the second set of basic body tests was used as the final car design and was decided upon in the necessity of time and before the results discussed were available. As seen model F is the upside-down version of model A. Making the decision to use model A over model F came down to what intuitively made sense, as an egg carrier is required to be mounted in the car and the general idea is to mount it in the back. Model A therefore offers an easier to manipulate design to mount the egg carrier. Using the side shape of the model some sketches were produced with the thought in mind of being able to assemble for additional rigidity and strength. Three of the same frame pieces would be designed to sit parallel to the front of the car and connect three

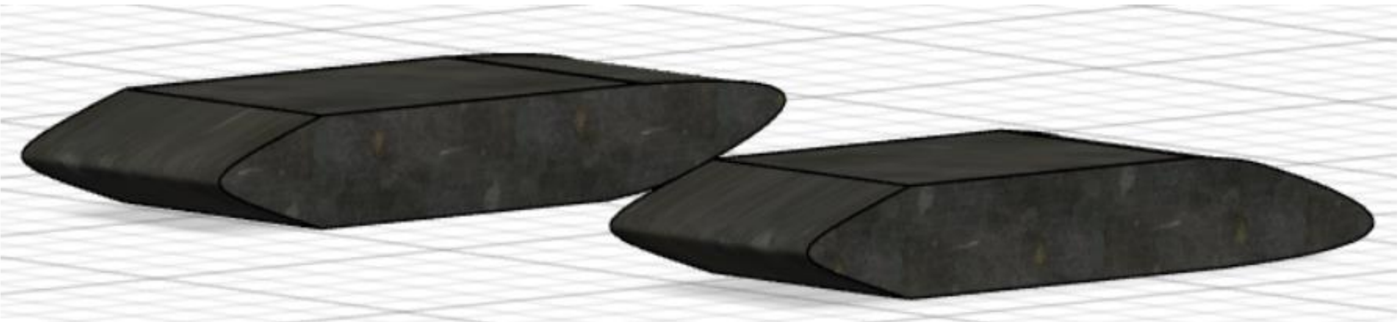

*Figure 14 displays model A and model F from figure 11. Model A was the selected model to be used and model F was the most efficient model of the iterations.*

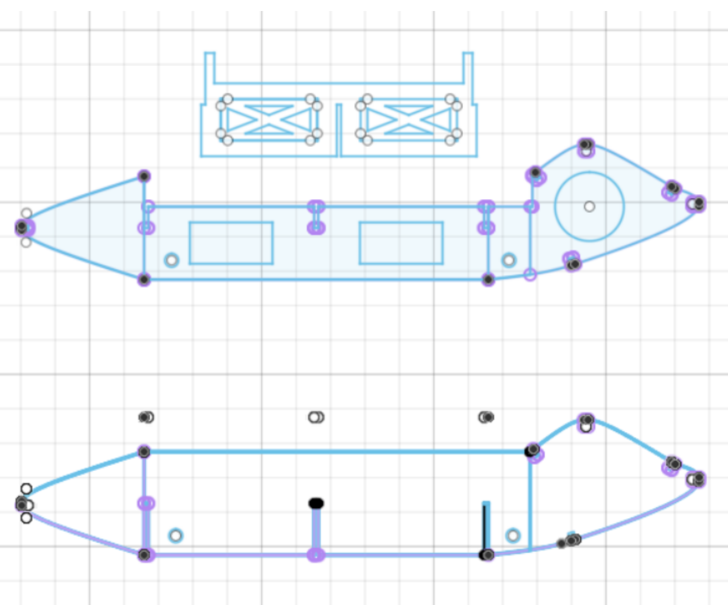

*Figure 15 shows the sketch of the model's frame.*

*Figure 16 Displays the components of the body assembled from a front view.*

different pieces going down the length of the car. Two of the pieces for the length of the car would be the side panels and the third would be an altered design to sit in the middle of the car with a solar panel resting on it. This can be seen assembled in figure 16. The sketch at the top of the image will sit the car and the bottom two will run down the length of the car. As seen in figure 15 there are cut outs on the sketch to fit the other pieces together. The current idea is to use Balsa wood, a lightweight hard wood that is flexible and 1/8$^{th}$ the weight of MDF, the next best material available for use.

### Journal #3 Initial Construction and Assembly

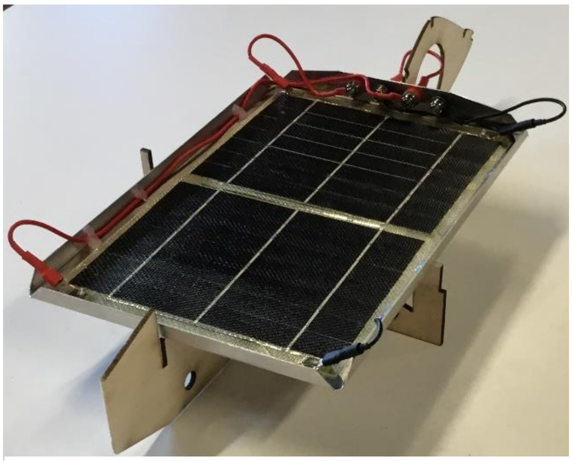

*Figure 17 shows the initial frame pieces being tested with the solar panel.*

With the CAD design completed initial pieces were cut out of balsa for its low weight to strength ratio. These pieces were placed together, and the solar panel placed in the middle for initial material testing. As seen in figure 17 on the right-hand side of the solar panel a piece has been snapped off due to the dimensions provided of the solar panel being slightly inaccurate. On the left-hand side of the solar panel a piece of balsa protrudes above the panel to keep it in place, the similar piece on the right-hand side is not seen. The group member who wired the solar panels measurement did not account for a slight angle in the side panels of the solar panel that increases the dimensions. That was the first issue of the strength of balsa being weaker than anticipated. The second was the rigidity of the material as the frame and panel connected as seen in figure 17 would wobble excessively. This would result in poor build quality should the final product shake and vibrate while driving. Power being supplied from the motor will be absorbed from the vehicles shaking rather than entirely going towards the vehicle's velocity. As the only place the energy is coming from to cause vibrations in the body will originate from the motor. This was the second draw back identified from using the balsa as the material for the frame. Finally, the measurements of the car relative to the pieces of balsa available did not match. Somewhere in the design the measurement of car became larger than expected. The pieces of balsa available are 400mm x 70mm, whereas the cars dimensions are 450mm x 90mm. This can be seen in figure 17 where the front of the vehicles nose frame appears to be cut off compared to the designs discussed in figures 14 to 16. From these issues it was agreed that balsa was not the best option for the frame. The material was then switched to MDF as it was sturdier although the issue with MDF is the additional weight. The design then added larger holes in the frame to take weight away from the body. All the pieces were then recut from the laser cut this time in 3mm MDF and assembled as displayed in figure 18 to test the new material. All the pieces fitted together as intended with greater rigidity then the balsa. However, it was found as seen in figure 18 that holes cut in the frame to fit the axle didn't line up. This rendered the middle frame completely useless given that without a straight axle the car could not function. This was then amended to fit the axle uniformly through the frame. It was further found that the frame could be more

*Figure 18 displays the initial assembled cuts of the MDF frame.*

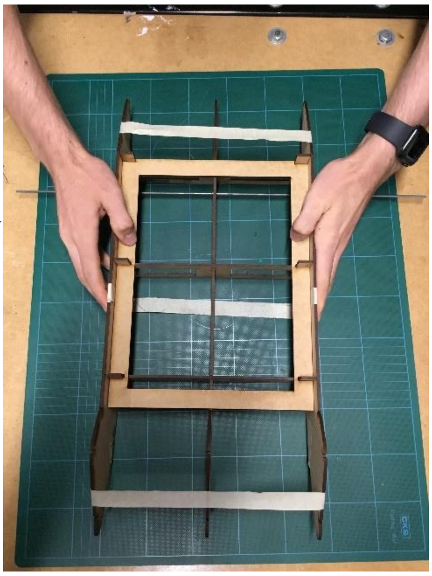

*Figure 19 shows the MDF bodies contortion.*

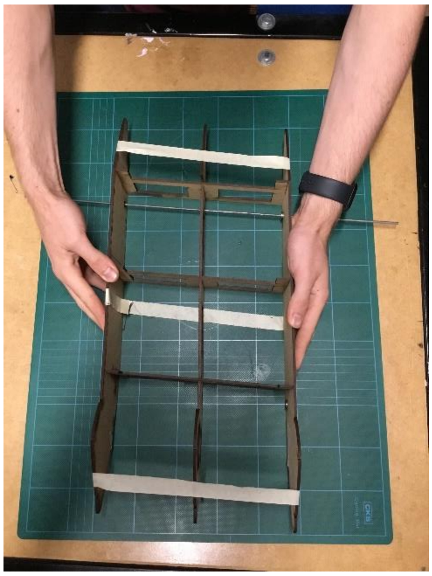

*Figure 20 shows the solar panel mount MDF piece removing the ability for contortion.*

rigid as seen in figure 19 the body would contort, this was solved from the solar panel mount as seen in figure 20. With the panels mount in place the body was firmly in place with no contortion. With the frame now complete the other group members could now clearly see where they could mount their components in the space available. The body was then handed over to the electronic group member who was looking at gear ratios to connect the motor to the axle via gearing. While this was happening the wheel size for the car was yet to be selected, using the guide rails dimensions and desired ride height the wheels diameter was decided to be 80mm. This provided approximately 1cm of ride height from the bottom of the frame relative to the guide rail. Given that the group member with the guide rail task was behind schedule and the end time frame looming I acquired the guide rail design and assembly. This allowed the possibility of steering to be achieved for the front wheels by allowing that group member to solely focus on that task. A simple guide wheels design was tested using blocks of balsa, bearings, bolts, and lock in nuts. Following the principle of the effect of weight on the vehicles velocity the guide rail was made with as little components as possible.

*Figure 21: The Balsa guide wheels. Image on the left shows the guide wheels veering to the left with the right wheel in contact with the rail. The image on the right shows the guide wheels when perfectly straight.*

Also, with it currently being week 4 and testing needed to be completed in week 5 the guide rails needed to be assembled quickly to allow for that testing. Using a rectangular block of balsa 6 different holes were drilled to allow for basic testing. This involved as seen in figure 21 the balsa block with two bolts going through the middle holes. The holes had approximately 5mm distance between them to have a 2cm total range when testing to get an idea of what movement the car should have. If the guide wheels distance is too small the wheels will constantly be on the rail creating friction and affecting the velocity. If the guide wheels are too great then the car will be almost 'tacking' like a sailboat moving back and forth from one side to the other, this similarly will have an adverse effect on the velocity as the total distance travelled will be greater than the actual track. The selected range came out to be approximately 5cm between the bolts, which gives just under a 1cm of range between the guide wheel and the rail. With the guide rails complete a decision was made that there was not enough time to develop steering front wheels rather the car will have all wheels fixed in place. Given that the track that the car is going to be tested on is straight with no corners, steering at this point is unnecessary. Wheels had already been developed as contingency given that the steering wasn't achieved, these were assembled onto the axle. The motor and gearing to the axle were also completed while the guide wheels were developed.

## Journal #4 Initial and Final Testing

After integrating all necessary components, the solar car was taken to the school basketball court for initial testing. Although no quantitative measures were taken at this stage, it was clear that the car was performing poorly, moving slower than a walking speed with a tail wind, and not moving at all against the wind. To understand why the solar car was performing so poorly, a Go Direct Energy Sensor was used to measure the voltage and current being pulled from

*Figure 22: The solar car being initially tested; no measures were being taken. The car performed extremely poor, if facing into the wind not moving at all.*

the solar panel. It was discovered that the solar panel was producing less than half of its maximum load, pulling only 3.5 volts from an 8-volt rated panel and 110 mA of current. This contrasted with another solar panel which pulled 7 volts and 220 mA of current. The panel could not have been wired incorrectly in terms of series or parallel, as the voltages and currents were both half that of the other solar panel. It was then found that the second part of the panel was not connected to the electronics, meaning that the car was only running off half a panel. With this amended, the car was retested and performed significantly better than in the first test. This involved the collective effort of the whole group to identify the problem while testing and communicate to the electronics specific group member who amended the problem. Effective communication was also needed to ensure all the parts were integrated in time for the initial testing prior to the final testing. This involved the sharing of CAD files and discussing the integration process, for example the earliest time the frame could be glued together dependent on the motor and gearing being integrated. With the body wrapped and egg carrier integrated all regulations were met, the solar car was then tested outside on a flat surface using the school cricket pitch, which had 19 panels of track, each 1.2m in length, giving the track a length of 22.8m. Wind was present during the test, providing a tail wind when the vehicle was heading towards the right of figure 23. The results were measured in terms of time, voltage, and current using an Energy Sensor. The car was run a total of four times, twice with and against the wind, providing an average velocity. The car showed fluctuations in voltage and current during the test. The results showed that just before two seconds into the trial, the solar panel reached peak voltage of approximately 8 volts and 270 mA after being exposed to the sun. The electronics aboard the solar car regulate the voltage and current directed to the motor, as shown by the

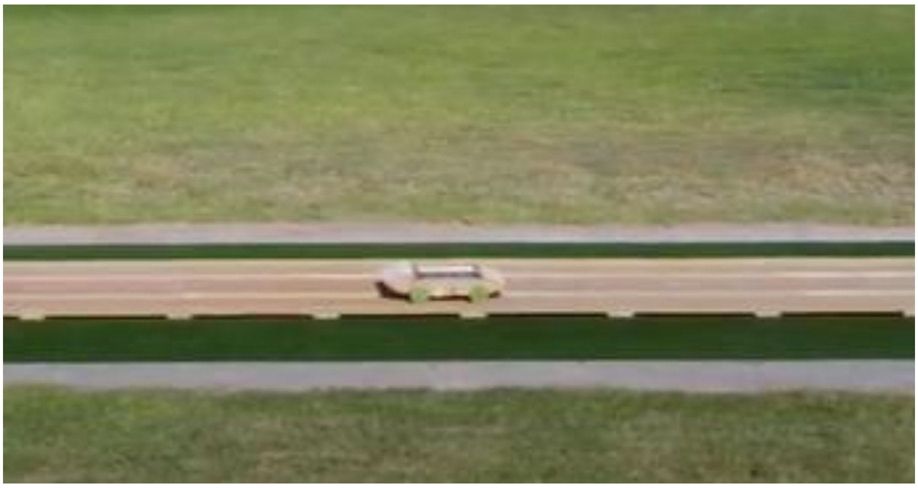

*Figure 23: The solar car being tested with a tail wind, image captured by drone footage.*

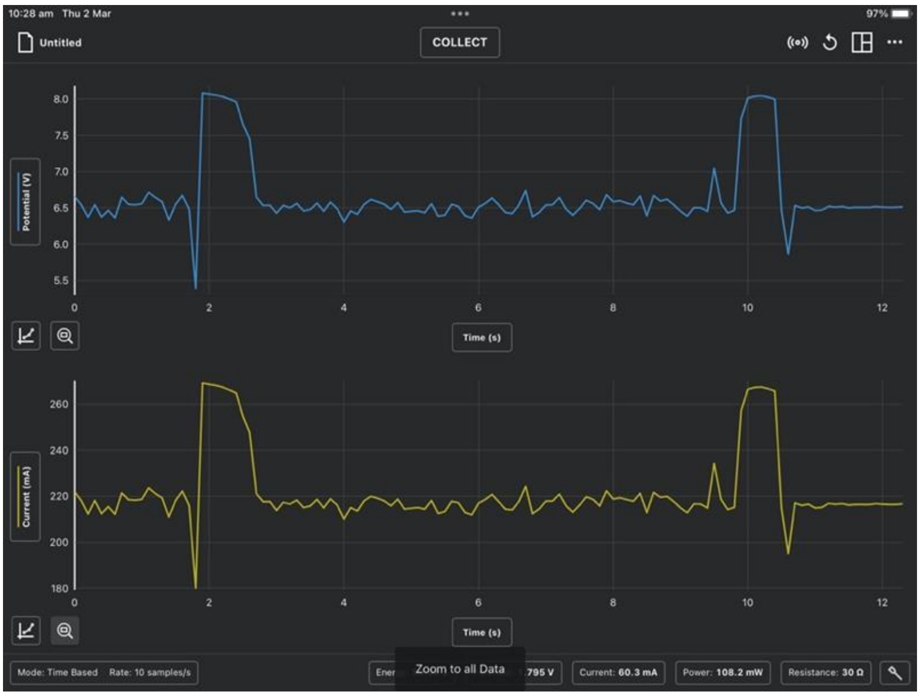


*Figure 24: The Voltage and Current results for Trial 1 with wind.*

peaks in figure 24. The first peak occurred when the solar panel was first exposed to the sun, while the car had no velocity, and the second occurred when the car collided with a stopping block and was no longer pulling load from the panel. The fluctuations in the middle of the results were due to the electronics pulling varying loads from the panel,

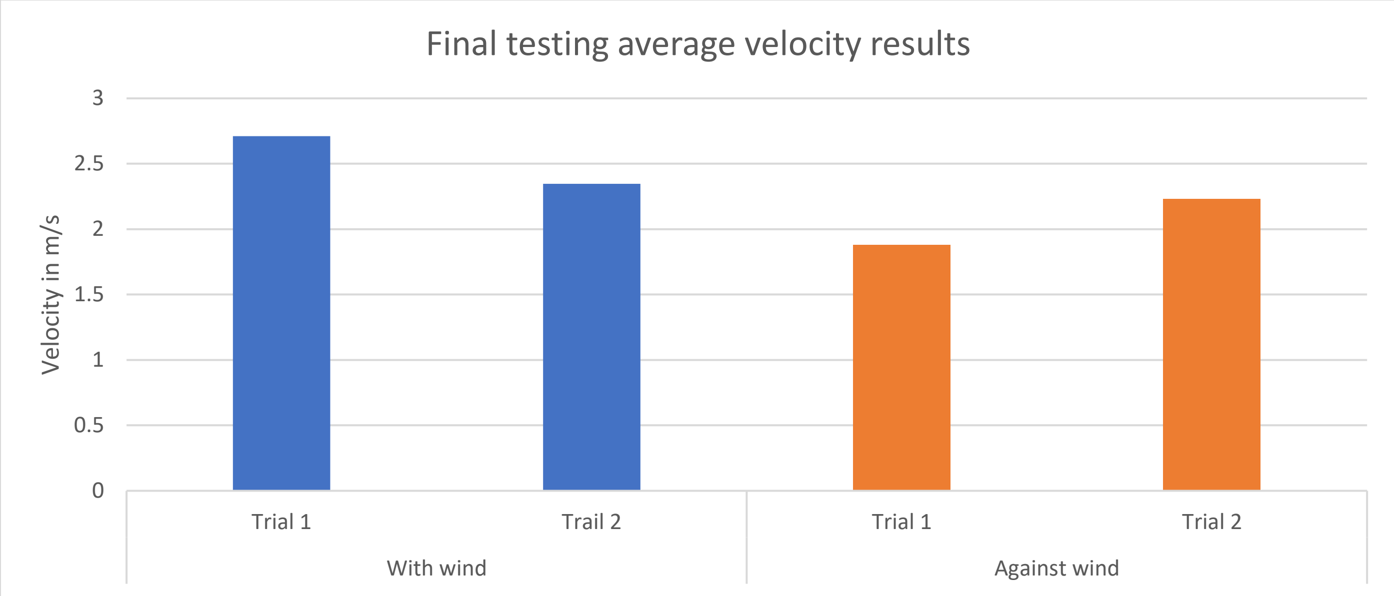


*Figure 25: Shows the bar graph of each trial's average velocity.*

as the Energy Sensor was wired from the solar panel's output, and the negative wire returned to the panel. From the times recorded with a stopwatch, the average velocities of the solar car were calculated using Excel. The calculations can be seen in figure 26. The maximum velocity attained was in trial 1 with a wind speed of 2.7ms$^{-1}$, which is approximately 9.7kmh$^{-1}$, about the speed of a slow jog. The car's velocity when going against the wind, as seen in

| | A | B | C | D |
|---|---|---|---|---|
| 1 | | S= | =19*1.2 | m |
| 2 | | With Wind | Avg Velocity | |
| 3 | | 8.41 | =C$1/B3 | m/s |
| 4 | | 9.72 | =C$1/B4 | m/s |
| 5 | | Against Wind | | |
| 6 | | 12.12 | =C$1/B6 | m/s |
| 7 | | 10.21 | =C$1/B7 | m/s |

*Figure 26: The calculations for each trial's average velocity.*

figure 25, was considerably lower than when being tested with a tail wind. However, the trials on the track were not as fast as the second test on the basketball court after the solar panel's wiring had been amended. The decrease in speed on the track may have been due to additional weight added to the car, such as the egg carrier and balsa wrap, which may have had an inverse effect on velocity. The friction between the wheels and the MDF track may also have been weaker than on the concrete basketball court. The friction between the wheels and the track is important as greater friction allows for more grip between the wheels and surface which assists in the car's acceleration. If the friction between the wheels and track was low, then the wheels are more likely to spin and can't reach the same velocities. The most prominent error was the guide wheels on the rail, the solar car appeared to veer towards the left, as shown in video 2. The increase in friction between the guide wheels and rail could have produced the results seen in figure 25 and videos 1, 2 and 3. Given the time frame the hypotheses were not tested to identify if the decrease in speed seen in the results compared to the initial testing were due to additional weight, friction between the wheels or the guide wheels. The project had limitations that impacted the build consisting of time restraints and the effectiveness of the collaboration. The limited timeline to complete the task restricted the ability to test an array of options regarding the initial car design and build. In most scenarios a decision had to be made based on a portion of data rather than conducting more in-depth research and making a more informed decision. Similarly, the time frame restricted the possibility of refining the vehicle further after the final testing to investigate the conjectures limiting the vehicles velocity. The collaboration also limited the results as communication was not overly effective in terms of explaining the properties that some components needed to be to match the vehicle. Also, the group timeline originally constructed was not matched by some group members that resulted in tasks being picked up by others and some 'luxury' functions of the car not met, such as the steering. Improvements regarding the collaboration could have been to set more realistic individual goals and had regular group meetings to boost communication. To conclude, a solar car was produced that met all requirements set by AIMSC and could reach near

10kmh$^{-1}$ speeds while testing and potentially more if more time was available to investigate the conjectures produced about the solar car's performance.

## Bibliography:

Byju. "Newton's Second Law of Motion - Derivation, Applications, Solved Examples and FAQs." *BYJUS*, byjus.com/physics/newtons-second-law-of-motion-and-momentum/#:~:text=Newton.

Jack. "Windtunnel Photos of Various Cars." *Miata Turbo Forum - Boost Cars, Acquire Cats.*, 7 July 2012, www.miataturbo.net/insert-bs-here-4/windtunnel-photos-various-cars-67417/. Accessed 11 Apr. 2023.

Nave, Rod. "Force." *Hyperphysics.phy-Astr.gsu.edu*, hyperphysics.phy-astr.gsu.edu/hbase/frict3.html#:~:text=Friction%20and%20Normal%20Force.