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Contents

1. Introduction	3
2. Literature Review	4
3. Methods.....	8
3.1. Computational Fluid Dynamics	8
3.2. Wind Tunnel.....	10
4. Results.....	11
5. Timescale	14
6. Evaluation	15
7. References	16
8. Appendix	19
8.1. Other Useful Regulations.....	19
8.2. Gurney Flaps	19
8.3. Flow Vis	19
8.4. Diffuser.....	19
 Figure 1 - Comparison between 1980s and 2000s LCR F2 Sidecar (LCR, 2021).....	4
Figure 2 - Wing Terminology (Kachare, 2017)	5
Figure 3 - RSR F1 Sidecar with Wing (Dmon Parts, 2020)	5
Figure 4 – Domain (Franck et al., 2009)	8
Figure 5 - Examples of Skew and Orthogonal Quality (Avraham, 2019).....	9
Figure 6 - Mercedes Flipping Le Mans 1999 (Haffenden, 2019)	11
Figure 7 - F2 Sidecar Side Wheel in the Air (LCR, 2021).....	12
Figure 8 - MoTeC Data to Calculate Drag and Rolling Resistance.....	13
 Table 1 - Regulation Sizes	6

1. Introduction

This report is a proposal for the authors MSC Masters project 'Aerodynamic Design of a F2 Sidecar with a Focus on the Isle of Man TT'. The purpose of the project is to investigate how current sidecar bodywork behaves aerodynamically, once this is done the main aim will be to reduce the drag that acts on the sidecar by modifying the bodywork design. This will be done as the sidecar being investigated is used on road circuits but primarily focuses on the Isle of Man TT. As a large portion of the lap is spent at full throttle reducing the drag will therefore increase the top speed and should allow the sidecar to achieve a quicker lap time.

As there is limited to no published data on sidecar aerodynamics this will mainly consist of new research.

2. Literature Review

Sidecars are raced both around short circuits and road circuits, they are purpose built racing vehicles. Teams running at the front of these competitions have an annual budget of over £100,000. (Holden, 2021). These teams are competing in these series and producing parts for these sidecars as a job not a hobby. While this project is focused on sidecars the skills and techniques being used throughout are transferable to any vehicle not only in the automotive world, but they could also be applied to planes or boats. This would mean the research and testing methods could be applied in many real world applications not just in motorsport but in many different industries.

Sidecar racing at a world level has been around since 1949. These were very rudimentary with the passenger section being attached a standard bike frame. It was not until 1979 that sidecars were designed specifically to race and were built from the ground up instead of modifying a standard bike to accommodate the passenger section.

The modern sidecar outfit as it is known now has been mainly unchanged since 1981.



Figure 1 - Comparison between 1980s and 2000s LCR F2 Sidecar (LCR, 2021)

Figure 1 shows a comparison between two f2 LCR sidecars. On the left is a sidecar from 1984 and the sidecar on the right is the modern LCR design. When comparing the two designs it can be seen that the main design of the bodywork is mostly unchanged. Main design changes have come from optimisation of the original bodywork design however, the original design has not had a major overhaul. This is why the author believes there are potential gains that could come from a major redesign of the original bodywork.

The most notable change between the two designs shown above occurs from the nose to the driver. The original design has a bulbous nose with no aerodynamics to push the air over or around the driver. The modern design has a greater point at the leading edge, this is the first point of contact between the air and an object. (Kumar, 2005). This new nose design leads into a lip directly in front of the driver. This should push the air over the drivers head in an attempt to reduce drag and also reduce the force acting on the drivers helmet.

The regulations state that no aerofoils or spoilers are allowed to be attached on any of the streamlining (bodywork). While this rule eliminates a large area where a wing or spoiler could be placed the rules do not state anything about a wing or spoiler being attached directly to the chassis. This is potentially a large area for improvement and from the authors research is an area not well explored. When testing wings a pre-existing aerofoil could be used or a custom one could be

designed depending on the application. The main criteria's when looking at an aerofoil are the chord, camber, and span of the wing. (College, 2013)

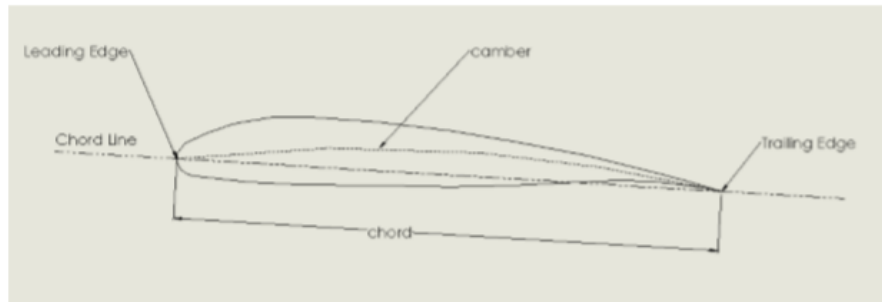


Figure 2 - Wing Terminology (Kachare, 2017)

The chord length is the distance between the leading edge and the trailing edge of the wing; the leading edge is the first point where air contacts the wing, and the trailing edge is technically the last point where air contacts the wing; but, due to separation, this might happen sooner. (Houghton and Carpenter, 2003).

The asymmetry of a wing's profile is explained by its camber. A wing's profile is more curved the more cambered it is. The camber on a symmetrical wing profile would be zero. (Abbott and Von Doenhoff, 1997). The span of a wing is the distance between one side and the other. The drag and downforce can vary as the span is changed so a bigger wing has a greater surface area, which increases drag. (Diasinos, Barber and Doig, 2017)

Figure 3 shows an RSR F1 sidecar with a wing attached in front of the passenger platform.



Figure 3 - RSR F1 Sidecar with Wing (Dmon Parts, 2020)

There are no reports or evidence to show why this wing is placed where it is and if it produced any benefits. One potential use of this wing is the traditional use of a wing producing downforce to help corner faster although, another potential use for this wing is to force the air to become turbulent before it hits the passenger. (Chalia and Bharti, 2017). This would put less stress on the passenger as they would feel the wind resistance less, reducing buffeting and allowing for easier movement around the sidecar. This design will not be tested as it would not comply to the regulations, but a similar device could be tested.

A monocoque design is forbidden by the rules which eliminates the option to have a bodywork design that is integrated with the chassis. (Wade, 1997)

Table 1 - Regulation Sizes

Area	Maximum (mm)
Width	1575
Wheelbase	1651
Height	800

Table 1 shows the maximum values allowed for each axis of the sidecar.(Paul Phillips, 2017). To ensure that the new bodywork design will comply with the regulations boxes will be drawn around the CAD model to demonstrate where the limits are to ensure that the new design will be legal. Two other important regulations with limits is the front of the bodywork must be within 400mm of the front wheel centre line and the rear of the bodywork must be within 400mm of the rear wheel centre line.

The minimum ride height is stated to be a minimum of 65mm at race weight (136.5kg) (Paul Phillips, 2017). The regulations state that no device can explicitly be there to lower the ride height below the minimum value however, there is no rule against a device with a main purpose that could lower the ride height as a by-product. Aerodynamic devices are known to reduce the ride height as more force begins to act downwards towards the road with the velocity increasing. (Bradford, Montomoli and D’Ammaro, 2014). Extreme ideas such as the fan car used in Formula 1 (Jenkins and Floyd, 2001) will not be tested as the time taken to test such a device would impede other research would be simpler to gain an advantage.

The use of aerodynamics has been around in the car world since the 1920s but started being properly explored towards the late 1960s. (Dimitriadis, 2005). Race cars began using aerodynamics as it was discovered that the use of wings similar to aeroplane wings being placed upside down on a car could produce downforce. This allowed the cars to corner quicker and lead to quicker lap times. The use of aerodynamics in race cars coincided with the automotive industry which began using aerodynamics as an attempt to reduce drag and therefore increase fuel economy due to the fuel crisis. (Strohl, 2013). Developments have continued throughout the years to achieve modern cars that are seen today. Formula 1 cars are known for their aerodynamic developments and currently can produce over 30,000N of force at 300kph which is the equivalent to three tonnes acting on the car at this speed. (Hinson, 2020). Features on these cars and also other race cars that produce downforce will be investigated as some of these ideas could be adapted to be placed on a sidecar.

As both the riders and passengers head is exposed to the air the helmet being used will have an effect on the aerodynamics of the vehicle overall. (Schuetz, 2018) By both looking at the 2019 TT highlights (TT Races Official, 2019) and talking to people within the paddock the most common helmet used is an Arai. When placing the driver and passenger onto the CAD model of the sidecar an attempt will be made to use an Arai helmet on them both to increase the accuracy of the results.

While producing a new bodywork design that would be faster around a lap of the TT is the main goal for this project there are other considerations to be made. As with every vehicle there are components on the sidecar that can overheat without sufficient cooling. (Clemens, 2017) The main two are the engine and the brakes. The engines used are 600cc bike engines from different manufacturers and are all water cooled. Placement of the radiator is important, if the radiator is not provided with enough clean air, it will not efficiently cool the engine which can lead to overheating issues. (Yadav and Singh, 2015). The actual placement of the radiator will not be investigated for this project although, the duct where the air will enter for the radiator will be explored. The same goes for the brakes cooling, the aim will be to have as much air going into the brake ducts as there is with the current design.

3. Methods

3.1. Computational Fluid Dynamics

The main method that will be used to gather results will be computational fluid dynamics (CFD). The package being used is Ansys which is a commonly used software in industry. (Lanfrit, 2005). Ansys is regarded as the "parent programme" for the different subsystems being used, which include Design Modeller for defining the domain, ICEM for defining the build grid (mesh), and Fluent for defining the fluid investigation.

There are four main areas inside the CFD package that will be used to investigate the sidecar aerodynamics. The first being the domain which is used to first optimise the model by simplifying the model or fixing any geometric issues with the model if they happen to occur. This area is also used to create the domain around the model, this can be used to simulate a model inside a wind tunnel if the outside edges are selected as wall or can be used to simulate the model in free air if the outside edges are selected as symmetry. It is important to find an appropriate size for the domain if the domain is too small it can affect the air flow around the model which will therefore effect the accuracy of the results. If the domain is too large it will increase the computational time and can again effect the results. This is because the computing power available is not effectively being used as the quality of the mesh around the model must be reduced to compensate for the extra domain size.

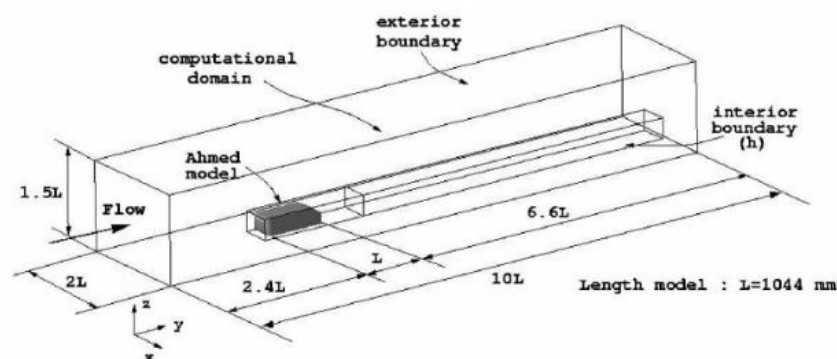


Figure 4 – Domain (Franck et al., 2009)

The next area is the mesher, ICEM is the mesher that will be used. This is where the domain and model are converted from solid models into a mesh. This mesh will be used when imported into the solver to calculate the air flow over and around the model. There are multiple settings that can be modified inside of ICEM to create and refine the mesh. These will need to be experimented with using both trial and error alongside previous experience. As there will not be any real world wind tunnel data to be used as a comparison initially the built in mesh quality checks will be used to assess the quality of the mesh produced. There are two main mesh qualities that will be checked when determining the quality of the mesh, these are skewness and orthogonal quality. Skewness is the 'difference between the shape of the cell and the shape of an equilateral cell of equivalent volume'. (ANSYS, 2009). The more skewed a cell is the more it had to modify its original shape to fit into the mesh. If there are lots of cells with a large skew value it can lead to inaccurate results when trying to solve. Since the calculations used to measure the outcomes presume the cells are equiangular, a large skew value will make the solution difficult to converge or yield incorrect results. (Aamir, 2017) Orthogonal quality is how much the cell has been modified which can increase the angle between the cell to the centre of the next cell. Too many cells with a low orthogonal can also lead to a poor mesh quality and therefore inaccurate results. This is because all the calculations start

at the centre point of the cell, so the software needs to compensate for the different angles of the cells.

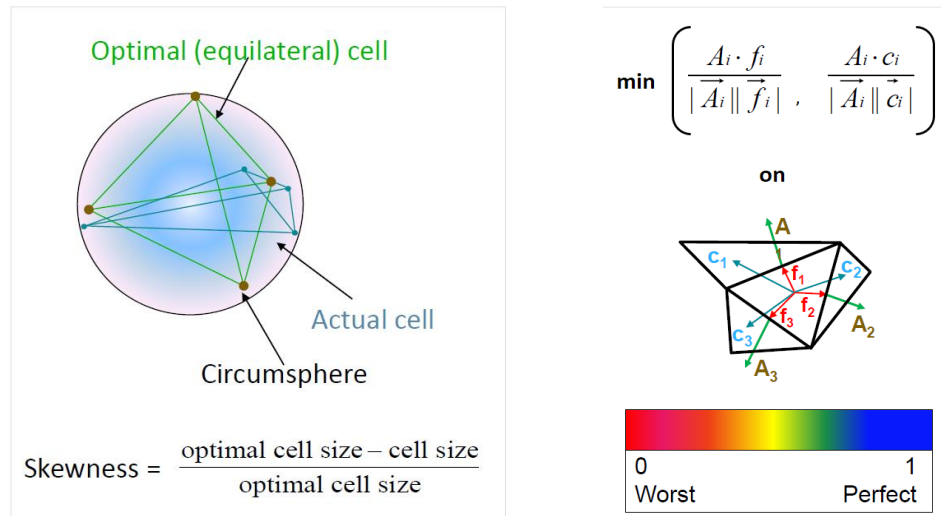


Figure 5 - Examples of Skew and Orthogonal Quality (Avraham, 2019)

The third area is the solver, Fluent will be used to solve all the meshes. As with the mesher there are multiple options inside fluent. Most of these have already been established through previous work however the turbulence model might have to be modified depending on the study being conducted. For most of the studies, a K-Epsilon model will be used. This model is good at modelling flow where there are small adverse pressure gradients. (Singh *et al.*, 1983). This means this model is good at modelling the flow structures that occur behind a model. This is important in road vehicle aerodynamics as it allows the wake being produced by the vehicle to be more accurately modelled, this can provide vital information to the user allowing them to have a full understanding what happens to the flow as it stops acting on the vehicle, this can allow the user to make changes to the design of the vehicle. If the study being conducted will have large adverse pressure gradients, then a K-Omega model could be required. K-Omega models are superior at modelling close to wall interactions, they are also superior at predicting the point where flow will separate. One example where this model could be used is a wing angle study as it will more accurately tell the user at what angle the flow will begin to separate which could decrease downforce and increase the drag therefore, the user will know not to use that angle or any greater angles with the current design as it will yield no benefits. For this model to work as intended the mesh close to walls will need to be more refined. If the mesh is not refined enough it can lead to the model over or underpredicting the point of separation. (Menter, 1992)

The final area is the post processor. This is the area used to visualise and analyse the results produced in the solver. (Toet, 2019). There are multiple ways to manipulate the data to analyse the results. The first is the use of contours, these can be applied to any surface to show pressure, velocity etc. This can help the user by showing them exactly what is happening on the surface, they will then be able to identify any issues or areas that could be improved. Another visual method that can be used is streamlines or vectors. These represent the magnitude and direction of flow occurring over and around the model. These can help the user see any blockage issues or areas where the flow is not acting as intended. Finally the post processor can be used to produce graphs such as pressure distribution over the surface of the model. These graphs can be useful to the user as it allows them to view the data in its purest form.

3.2. Wind Tunnel

Another method of collecting aerodynamic data is through the use of a wind tunnel. A wind tunnel is a room with a large fan where a model or object e.g. a car can be placed inside, the fan pushes air into the direction of the object at a constant velocity. Pressure sensors can be applied to the object to determine its coefficient of drag (c_d) and coefficient of lift (c_l). Wind tunnels come in different shapes and sizes ranging from full scale plane wind tunnels to ones that can be placed in most ordinary rooms. (Katz, 2006; Favier, 2010)

Ideally the real sidecar would be placed in a full scale wind tunnel, this would allow the CFD to be accurately validated and thus the results produced from the CFD in the future would become more trustworthy. It is unlikely due to both Covid-19 and financially that this will happen without external backing. As this option is unlikely the backup option would be to use the scale model wind tunnel located at the university. A 3D printed scale model of the sidecar would be printed and placed inside the wind tunnel. This would allow for the coefficient values to be obtained but could also allow for visual data to be gathered through the use of smoke and/or strings. These results would not be as accurate as a full scale wind tunnel but would still provide relevant data.

4. Results

Once a design has been created that design will have to be put through a series of virtual tests to ensure the results produced in the initial tests should translate into real world gains. The first of these tests will be a straight line test. This test will consist of the car straight towards the direction of flow as if the car is travelling in a straight line. The passenger will be placed in three different positions, tucked in, hanging off to the left and hanging off to the right. Next crosswinds will be added, this will consist of adding a velocity in the z direction simulating a crosswind acting on the sidecar. This is important as it will provide more information about vehicle stability and cooling in this scenario. The average wind speed on the Isle of Man during the TT is 20kph (Weathers Park, 2020), this will be considered when investigating crosswinds.

The next test will consist of seeing how the sidecar behaves in the air. During the lap around the Isle of Man the sidecar leaves the ground at multiple points. Each of these points and the velocity the sidecar is travelling at will be found through the use of MoTeC data. The sidecar will be tested will be tested both initially as the front wheel leaves the ground and also when the sidecar is at its maximum height above the road. This test is important in both understanding how the sidecar behaves in the air but more importantly for safety. It has been known for cars to flip in the air after the front wheels leave the ground. These can be seen in figure 6.



Figure 6 - Mercedes Flipping Le Mans 1999 (Haffenden, 2019)

This phenomenon occurs when the front of the car is sucked too close to the ground creating a blockage and reducing the downforce acting at the front of the car. This reduction of downforce causes the car to bounce. Air became trapped under the front of the car, lifting the front and causing it to flip. This is more likely to occur if the road surface is uneven as it is at the TT. (Canada, 2012)

After that, the next test is to look at the sidecar with yaw. This test is designed to simulate the sidecar during a corner. By completing this test it ensures that the new design is beneficial not only on the straight line but also has better performance around corners. To ensure real world relevance the maximum and average yaw of the sidecar will be calculated through the MoTeC data. Sweeps will be run from 0° of yaw to the maximum yaw angle. By running these tests it should hopefully reveal any potential issues that could occur from the air not hitting the leading edge of the nose. One possible issue that could occur is that points of stall could occur during cornering as the bodywork is initially designed with the sidecar travelling in a straight line. If these points of stall were

to occur it could make the sidecar more unstable during cornering thus making it harder to drive. (Roberts *et al.*, 2015)

One characteristic of sidecar driving is lifting up the passenger side wheel during cornering as seen in figure 7. This allows the sidecar to turn sharper so the driver can instigate this action around certain corners. (Ward, 2021) Virtual testing will be done with the passenger side wheel off the ground to ensure that there are no negative aerodynamic effects by lifting up the wheel. If it is discovered that there are negative impacts a redesign will be considered to alter the affected areas and attempt to improve them. Consideration will be taken about the sidecar lifting more than it should as with the off the ground model. If that were to occur at full speed in a real life scenario it could be fatal for the driver and/or passenger.



Figure 7 - F2 Sidecar Side Wheel in the Air (LCR, 2021)

When travelling behind another vehicle the drag acting on the following car is reduced. This is because the first vehicle has already disturbed the air meaning the following sidecar is travelling through turbulent air which has less resistance. (Mit, 2012). A formula 1 car loses from 23% to 62% downforce when following another car. (Guerrero and Castilla, 2020). While these cars would be less sensitive to disturbed air than a formula 1 car there would still be positive and negative effects that should be tested. It would be expected that there would be a reduction in drag as there is less resistance acting against the acceleration of the sidecar. The main use of the test is to explore if there are any potential stability issues.

Another use for this test is cooling. While the original tests should ensure that the sidecar is getting sufficient airflow to both the radiator and brakes, this test will show if being stuck behind another sidecar has an impact on the cooling. While it will be expected that there will be some decrease in performance the bigger question is how much the turbulent air will impact the cooling. (Siitonen, 2011). If it is found that cooling could become a potential issue, then a redesign of the radiator or duct positions will be considered.

Another potential way to gain real world data is through the use of pressure taps. Pressure taps work by measuring the ambient air pressure against the air pressure acting on the surface of the

vehicle at speed.(Kuester, Borgoltzy and Devenportz, 2016)(Butterfield, 1988). This data can be used to calculate the pressure distribution across the pressure taps and also the CL of the vehicle. The CD of the vehicle could also be calculated at the same test through the use of data and a coastdown test. To do this the sidecar would need to accelerate to a known velocity and remain there for around 10 seconds, the driver would then place the sidecar into neutral, letting it coast to a stop while keeping the steering as straight as possible. By taking two measurements of velocity with a gap of 1 second just after the driver places the sidecar into neutral the CD can be calculated. The rolling resistance of the sidecar can also be calculated by repeating the same process just before the sidecar reaches a stop.

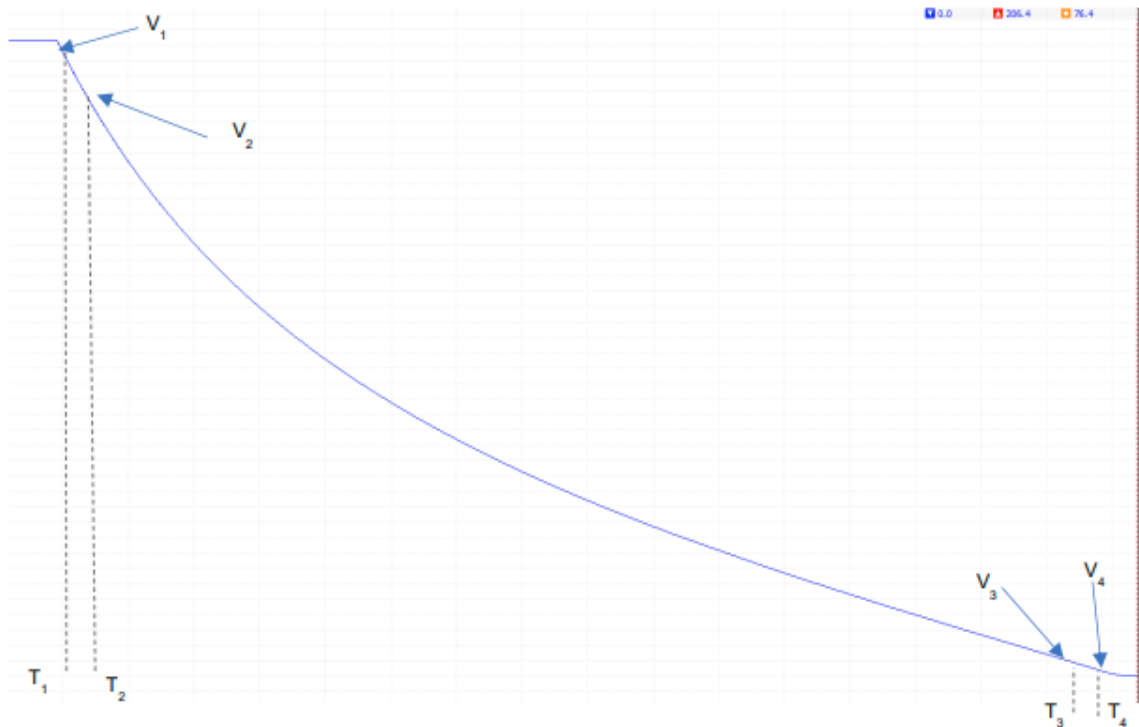


Figure 8 - MoTeC Data to Calculate Drag and Rolling Resistance

Figure 8 shows how the drag and rolling resistance can be calculated.

Confidential MoTeC data has been provided to the author by a top team at the Isle of Man TT. This data will be used throughout the project as it will enable the author to find exact real world values that will make the virtual testing more accurate. The main use of this data will be finding exact velocities around the track, including maximum and average velocities. Suspension potentiometers will also be used to find the points on the track where the sidecar leaves the ground.

5. Timescale

The timescale for this project will be dependent on the amount of resources that can be gathered prior to the start. If no CAD model can be obtained, then the initial step of the project will be to create a CAD model either from measurements taken from a real sidecar or by using high quality images.

The next step would be to establish baseline settings and results in CFD. This will allow the author to have initial results to compare future changes to and these results can be investigated to see where the best and worst areas of the initial design are. The worst areas of the initial design can then be modified, and the iterative stage of the project can begin.

The iterative stage of the project will consist of constant small changes to the design of the bodywork. A set area will be chosen e.g. the floor, nose etc, initially using the baseline results. Small changes will be made to the selected area with different modifications being made to the bodywork. These changes will all be tested with the use of CFD to see how the results are affected by the changes. This iterative stage will take place throughout the majority of the project, since there is no date for manufacture or required date to have a completed model by changes can be made until a few weeks before the dissertation deadline.

6. Evaluation

This report has hopefully shown why the proposed project is a worthwhile undertaking. With the topic being mainly unexplored with limited published data exploring a new topic will generate new research which not only will further engineering for sidecars but will involve new research for aerodynamics as a general topic. The option to involve real world testing whether it is involving the real sidecar or a scale model in the wind tunnel will assist in the accuracy of the project and provide more real world relevance to the project.

One potential issue with the project could be the lack of CAD model being provided. If the author has to produce their own CAD model it could push back the timing of the project and reduce the amount of testing that can be completed. Another potential issue could be the lack of a full scale wind tunnel test at the start of the project as this would provide accurate data to be used as a comparison for the CFD runs. The use of the scale model would still be a good alternative as it would provide some data even though it would be less reliable compared with a full scale test.

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8. Appendix

8.1. Other Useful Regulations

- Streamlining must detach for scrutineering.
- Must always be 20mm between handlebars end, steering mechanism, front wheel, and bodywork.
- Passenger platform min dimensions 800x300mm measured 150mm above the platform.
- Every part of the driver should be visible from top down perspective except for arms, legs, and feet.
- Underfloor must detach.
- Monocoque forbidden.
- Suspension min travel 20mm
- Composite construction forbidden except for passenger platform.
- Min weight 136.5kg without fuel

8.2. Gurney Flaps

A gurney flap is a right-angled strip attached to the trailing edge of a wing's high-pressure side. The basic concept behind a gurney flap is to provide an area for air to hit, resulting in counter rotating vortices at the trailing edge of a wing. These vortices would cancel out each other's effects, lowering drag. (McBeath, 2006). At the trailing edge, the gurney flap changes the kutta condition. When there is a sharp trailing edge, the air tries to bleed around it and makes a vortex in this area, which is known as the kutta condition. It seeks to keep this from happening by attaching a gurney flap. (Jang, Ross and Cummings, 1998; Mohebbi, Evans and Sellier, 2019)

8.3. Flow Vis

Flow vis is another method of real world testing that can be used to compare against the CFD results. Flow vis is made up of fluorescent paint powder mixed with paraffin, which is sprayed onto the vehicle with a spray bottle, liberally covering the areas to be examined. The paint dries onto the vehicle as the paraffin evaporates, revealing the flow systems that are formed on the surface. (Smedley, 2019)

8.4. Diffuser

The airflow under the car's body is accelerated by a diffuser. This accelerated air is then returned to ambient pressure slowly and seamlessly. The idea behind extending the diffuser is that as the air takes longer to return to ambient, an adverse pressure gradient forms beneath the vehicle, sucking it to the ground and creating downforce. (Mohankumar, Hudson and Daniel, 2015). From the kick point to the trailing edge, a diffuser's continuous curve indicates that the air is continuously changing direction, which accelerates the air and keeps it attached to the diffuser. Due to the adverse pressure gradient, if the angle of the diffuser becomes too large, the air will begin to separate. (Cooper *et al.*, 1998)