

Race 2

by Oliver Beck

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1-Introduction

“To make a race car accelerate and achieve a higher top speed you need more power, less weight and less aerodynamic drag. And if that sounds like a simple set of goals, it probably would be if not for the troublesome mechanics of cornering” (Newey, 2017) This shows that understanding a cars aerodynamics will give a clear competitive advantage as not only will a good aerodynamic set up provide less drag it will also need to be set up to give as much downforce during cornering (Rowley, 2003). Throughout this report the MCR car which is a single seater racer that competes in the sports s2000 series will be run on the simulator around Pembrey with various different aerodynamic set ups, these results will be looked at using MoTec software with the results evaluating vehicle performance. For each different set up various different factors will be looked into such as the vehicles lateral and longitudinal G as this will be a factor of the grip that is available to the driver and the vehicle speeds achieved throughout the test to show how each set up effects acceleration and top speed. Through the use of Motec a series of different maths channels will be created to evaluate the data including the total aerodynamic lift coefficient, the total downforce at both the front and rear axle and the centre of pressure for each aero set up. Once all these elements have been plotted and evaluated the best set up for a dry race day is to be recommended with support of why.

2-Aerodynamics

For aerodynamics to be used to an advantage it must first fully be understood so quite simply what is aerodynamics, aerodynamics is the study of the flow through and around an object, air will interact by applying pressures perpendicular to the surface it acts on (Bertin, 2001). Aerodynamics was poorly used in early motorsport with the majority of vehicles through the 1940's and 1950's ignoring the uses of it as it was such a poorly researched area at this time, it was not until the 1960's where it was prominent in motorsport especially at Le Mans (Newey, 2017). Aeroplanes were the original thinking point for aerodynamics as they are capable of achieving lift so how can this be used and manipulated to create benefits for a race car. The principle of causing down force is creating negative lift in the vehicle, this will then be doing the opposite of how a plane works, this works by having air flow at different speeds across the two sides of the wing, with low pressure on the topside of the wing and high pressure on the other with the wing then moving in the direction of the low pressure creating the lift force (McBeath, 2011) this occurs in vehicles creating a reduction in in load on the tyres. This can then be reversed to create negative lift which is also known as downforce by having low pressure on the underside and high pressure on the top side (McBeath, 2011). Downforce is a highly sort under attribute in a race car, this is because downforce will create additional force and load to a vehicles cornering without adding weight to a vehicle (Newey, 2017),

this is a massive advantage to designers as it allows for additional grip without the negative effects in acceleration that will be caused by this additional weight (McBeath, 2011). Drag is another massive factor in aerodynamics as it is the resistive force in the opposite direction of motion, it is made up of 3 main elements including frontal pressure, rear vacuum and skin friction.

2.1-Calculating Aerodynamic Forces

The drag force will be determined by multiple different factors including the, Coefficient of drag which is how well the shape of a vehicle cuts through the air this is a figure between 0 and 1 with a saloon car being around 0.5 whilst a bus is around 0.7, the density of air is the next factor which for this report will be used as 1.223Kg/m^3 , the frontal area which is 1.2m^2 and finally the velocity at which the vehicle is travelling at. (Hall, 2015)

$$\text{Drag Force} = C_d \times \frac{1}{2} \rho V^2 \times A \text{ (Hall, 2015)}$$

The lift force uses the same principles but replaces coefficient of drag with coefficient of lift, this is

$$\text{Lift Force} = C_l \times \frac{1}{2} \rho V^2 \times A \text{ (Hall, 2015)}$$

3- Test plans 1

The first session will look at the affects that lift and drag have on a coast down test, this will involve using the simulator to measure these effects, the simulator will be used as it gives the same conditions for all runs these are because in aerodynamics factors such as temperature and wind speed can have a drastic effect. There will be 3 different wing angles that are used low, mid and high aero this will be used on both the front and the rear this will result in running 9 different aero set ups. Below will show the wing position for each run. The other factor that will be looked at is the ride height of the vehicle, this will then look at what it does to the drag and lift, the heights will be looked at in the same way as low, mid and max.

Front	Rear
Low	Low
Low	Mid
Low	High
Mid	Low
Mid	Mid
Mid	High

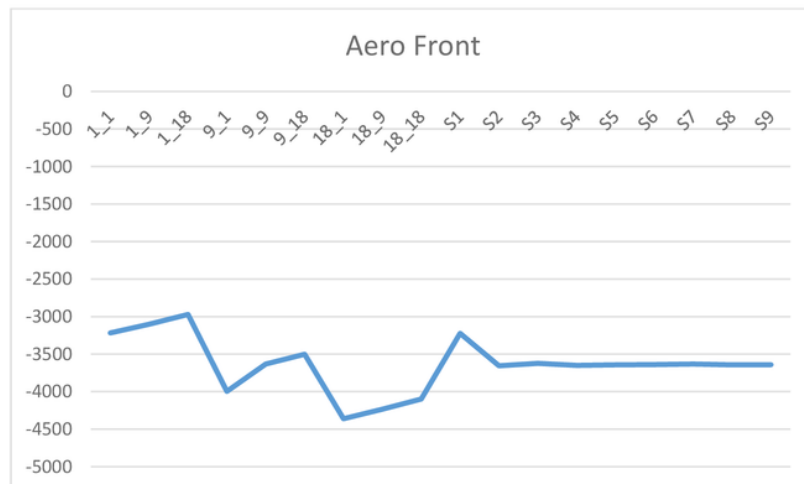
High	Low
High	Mid
High	High

The test will compose of the driver completing a loop of the skid pad before coming to a complete stop then accelerating to a speed of 220 kph before coming completely off both the accelerator and brake, the car will then come to a gradual stop, the test will not need to be completed to 0 every time as we are only looking at the aerodynamic drag at 2 different speeds on the coast down to see the drag created.

3.1 Test Plan 1 Results Aero Front

Once the data is available from the tests there are multiple factors that can now be calculated including the aero loads for both the front and the rear of the car then putting these gives the total aero loads. This is calculated from adding together the static loads from the front left and right then taking away the constant velocity loads on the wheels when the vehicle is at maximum velocity which will be near 220kph, this can be done for all 18 runs (Gowda, 2019). Figure 1 shows the range of the aero for the front across the different set ups.

Figure 1-Aero Front

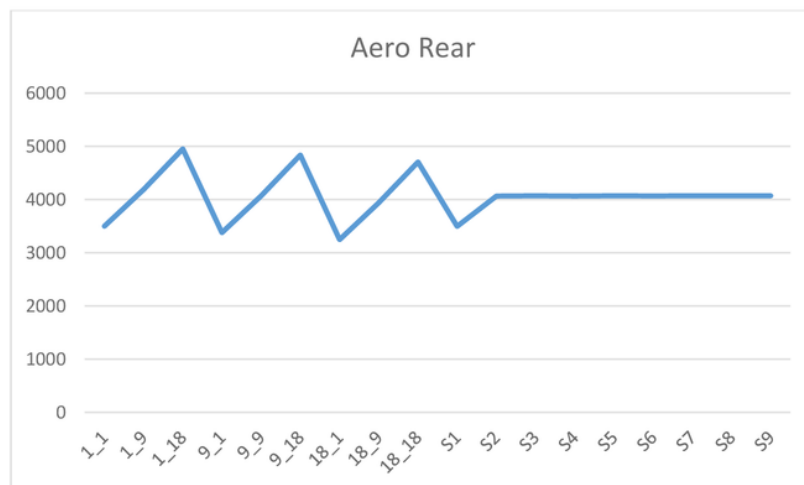


This shows that there is a massive difference in the aero forces occurring at the front of the car when the wing angles are changing yet when it comes to ride height it is very small adjustments with all being within 30 newtons of each other, whereas there's a range of 1500 newton's across the wing changes. The set up that gives the least are force at the front of the car is 1:18 wing angle, this is because it will be focusing putting the forces towards the rear of the car and will then prove to be unbalanced, this the shows in the opposite way as the most aero force is at the set up 18-1 as the forces will be focussed on the front.

3.2-Aero Rear

The aero on the rear will be calculated using the same method as the front but only by using the rear wheels this time. Figure 2 shows the change in aero to the rear across the set ups.

Figure 2-Aero Rear



This shows again small changes across the ride height changes where as big spikes in the wing set up changes. The lowest aero force is seen at the set up of 18-1 where there is maximum focus on the rear then the inverse of this causes the largest aero force at the rear whilst at 1-18.

3.3Aero Total

The total aero is simply 2 added together and is shown below in figure 3.

Figure 3-Aero Total

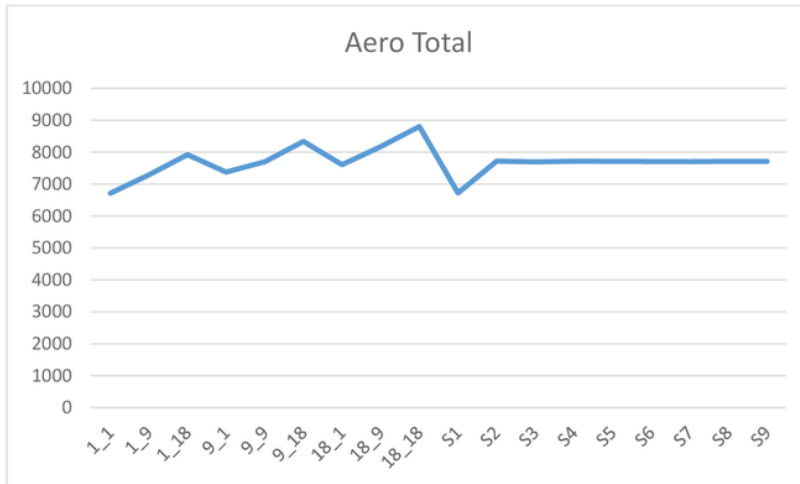
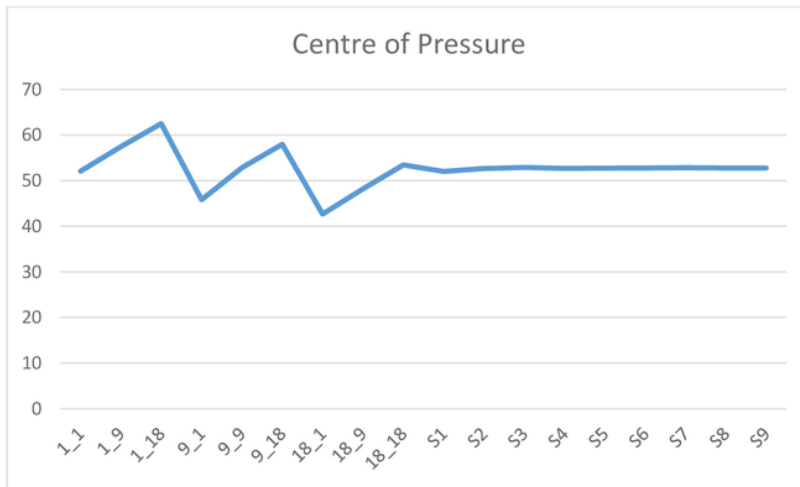


Figure 3 shows that the setup with the most aero force is at 18-18 this will be when there is the most amount of downforce being put into the vehicle this should then relate to the best cornering forces.

3.4-Centre of Pressure

The centre of pressure will be calculated by using the aero rear/aero total then multiplying this by then times by 100 to leave it as a percentage. The centre of pressure will affect the way the car handles, if the centre of pressure is in front of the of the centre of gravity there will be more load on the front wheels creating oversteer, and the reverse will then cause understeer. The main aim of the centre of pressure is to balance this with the centre of gravity of the vehicle to create a balanced ride. Figure 4 shows the centre of pressure across the runs.

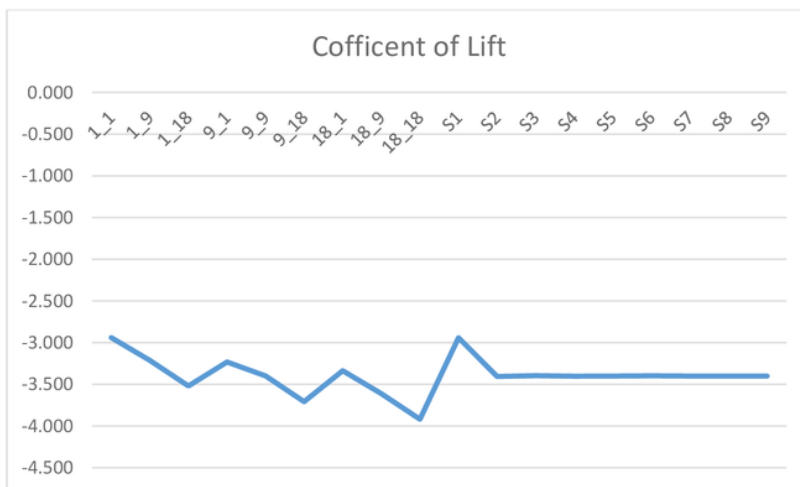
Figure 4-Centre of Pressure



3.5- Coefficient of Lift

The coefficient of lift on the front is calculated by using the formula $(2 \times \text{Aero Front}) / \text{density of air} \times \text{max velocity squared}$. The coefficient of lift will show the amount of downforce that the vehicle subjected to (Boretti, 2006). Figure 5 shows the variation in the coefficient of lift across the different set ups.

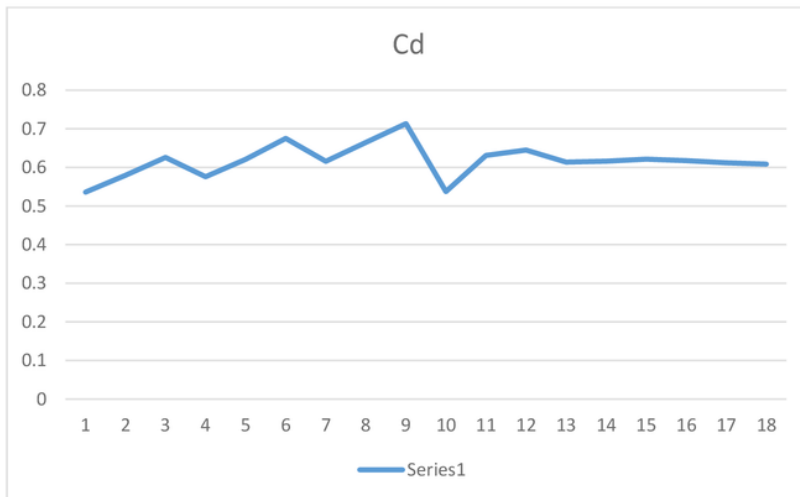
Figure 5-Coefficient of Lift



3.6-Cd

The coefficient of drag has been previously discussed in section 2.1, this changes greatly between the laps with the 18-18 achieving the biggest cd value. The formula used from the coast down data is $((\text{mass} \times \text{acceleration } 1) - (\text{rolling resistance})) / (0.5 \times 1.223 \times ((\text{velocity } 1 + \text{velocity } 2) / 2)^2) / 1.2$

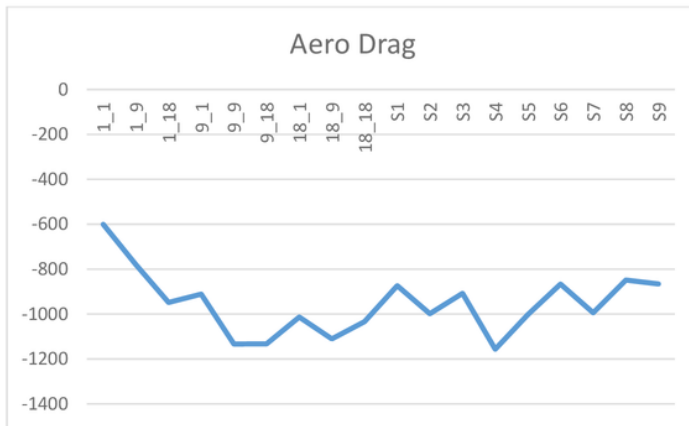
Figure 6-Coefficient of Drag



3.7-Aero Drag

The aero drag is calculated by using values from the coast down test, this will be done by taking the weight * the acceleration 1 on the coast down divided by the acceleration 2 * weight. The set up with the greatest aero drag was 9-9 but with a drop in ride height.

Figure 7-Aero Drag



4-Test Plan 2

The second test will look at the affect that aerodynamics has whilst cornering, in terms of grip available for the driver. The simulator will be used again with the same driver being used as in the coast down testing, the chosen track for this testing is Pembrey as it includes both high and low speed corners which will show the effect of aero at different speeds, Pembrey is also a very flat track which will be vital in this testing as a change in incline will impact the air flow and therefore the aero dynamics. The driver will be instructed to drive at a comfortable pace for each set up as it allows a more consistent result across the session compared to if he was to push to achieve greatest lap time. There will be 9 set ups runs including changes to the front and rear wings with ride height bring changed. Driver comments will be taken on each set up including a drivability rating out of 10.

Front	Rear	Driver Comments
Low	Low	6/10
Low	Mid	5/10
Low	High	5/10
Mid	Low	4/10
Mid	Mid	7/10
Mid	High	3/10
High	Low	1/10
High	Mid	9/10
High	High	9/10

4.1-Test Plan 2 Results

To look at the calculate the difference aero loads

To analyse the data several different constants will first have to be put into MoTec as constants these include:

-Static Load for the front left and right, rear right and left. This will be taken when the car is at 0m/s

-Mass which is given in the brief as 560 kg

-Gravity- 9.81m/s/s

-Wheelbase 2.73

-Centre of Gravity- 0.23m

-Cd- Will change on each run depends on the straight-line testing calculations

-Density Of Air 1.223Kg/m³

Maths Channel

-Speed (Corr Speed 1000/3600)

-Aero Front = (Tire Load Front left+ Tire Load Front Right)- (Static Load Front Left+ Static Load Front Right) + Weight Transfer Longitudinal

-Aero Rear = (Tire Load Rear left+ Tire Load Front Right)- (Static Load Rear Left+ Static Load Rear Right)- Weight Transfer Longitudinal

-Aero Total= Aero Rear + Aero Front

-Centre Of Pressure= (Aero Front/ Aero Total) *100

-Weight Transfer Longitudinal (Mass*G Force Long* 9.81* Centre of Gravity)/ Wheelbase

-Corner Radius (Speed²)/(G force Lateral *9.81)

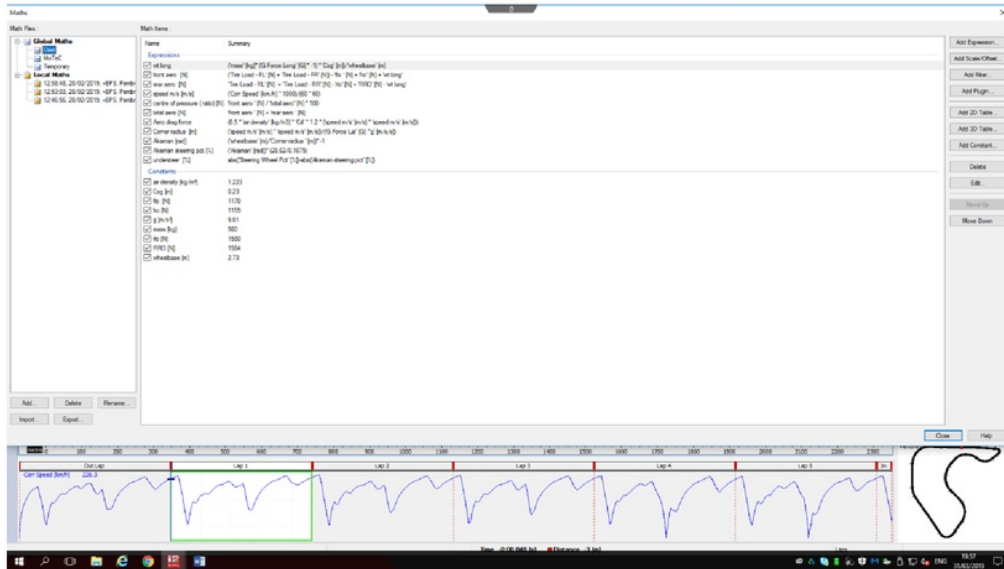
Akerman Steer= Wheelbase/ Corner Radius

Calibrated Ackerman Steer Pct+ Akerman Steer*Calibrated Factor

Understeer= Abs (Steering Wheel Pct)- Abs(Calibrated Ackerman Steer Pct)

These maths channels are shown below in figure 8.

Figure 8- Maths Channels



The 3 different set ups that will be analysed are low-low, mid-mid and max-max, they will be overlapped. The Red will show min-min black will show mid-mid and green will show max-max. The first maths channel that will be looked at is figure 8 which shows the total speed that is achieved throughout the lap against the total aero force created.

Figure 9- Speed against Aero



As shown in figure 8 above there is a direct correlation between the speed that is achieved throughout the lap and the aero that is created. This shows every time the car speeds up the amount of force the car is subjected to is also increasing, this is because the calculation for total aero will include the tire load meaning the vehicle is subjected to higher tire loads when at a higher speed (McBeath, 2011). All 3 Traces show the same pattern but will differ slightly with max-max obtaining the maximum downforce at any point, whilst it is followed by mid-mid then min-min having the least amount of aero force. The max-max has higher speeds through almost every corner showing that the driver is most comfortable in carrying his speed throughout this and this then shows as this is the fastest lap out of the 3.

Throughout the lap the driver will reach a range of different oversteers and understeers. There is far more understeer achieved throughout. Oversteer is when there is a loss of grip in the rear of the car, causing the front of the car to start to overtake to front of the car. Understeer is when there is a loss of grip to the front of the car and there is more steer applied than required for the corner. Figure 10 shows the understeer channel accompanied with the steering as well as the G force lat.

Figure 10-G force Lat/ Understeer/ Steering pct



This shows that all 3 set ups occur similar understeer throughout the lap as there is understeer in corner 1 with all 3 set ups with max-max occurring the least amount of understeer in the first corner whilst also being the only set up where oversteer didn't occur on the exit of the corner, this can also be shown in the steering trace as it's the only trace to not giving up steering early (Law, 2000). It can be shown understeer is present in corner 3 also with max-max occurring the most understeer but also shows that it also has the most grip available to the wheels as it has the highest lateral g at this point it can be shown that when a steering correction is applied the understeer is corrected. The only point that are large amounts of oversteer is present is during 6 and occurs differently for the different set ups and in mid-mid grip is lost early in the corner and is also accompanied with a spike in the g force lat. Understeer is present in turn 8 with it coming in mid-mid and max-max early on in the corner with a sudden drop off when the steering is completed and the wheel is returned to straight whereas min-min has a steering correction which then causes additional understeer.

The aero drag force will change throughout the lap and will change between the different set ups due to the change in cd between the 3 different set ups, this is because min-min has a cd of 0.638 whilst mid-mid has 0.621 and 0.713 for max-max. this shows the changes between the 3 in figure11.

Figure 11- Speed Against Aero Drag



This shows that the 2 traces are almost identical in terms of shape as the speed dictates the change in the graph as this is the only variable in the formula. The amount of drag will affect the top speed able from the vehicle although this contradicts this as the set up with the highest drag sees the highest speed but this is due to the grip available in the corners allowing the speed to be maintained (McBeath, 2011).

The centre of pressure will change throughout the course of the lap as shown in figure 12.

Figure 12-Centre of pressure/speed/total aero/weight transfer long



The centre of pressure changes depending on the balance at each point of the track. This shows that all 3 setups follow the same path with the centre of pressure moving forward at turn 1 as the speed drops and the brakes are applied this then does not rise again until turn 6 when the vehicle slows, this is accompanied with a transfer in weight longitudinally (Gowda, 2019).

Driver confidence is a big factor in the stability of the car, this is because a driver that is comfortable in the car will brake harder and be harder on the throttle creating a faster lap as shown in figure 13.

Figure 13-Throttle/brake/steering



These traces show that there is multiple different points at which min-min has a poor throttle trace has it is often on and off the throttle because of the instability in the vehicle. This can also be accompanied with brake being applied, this may be due to the imbalance that is taking place in the vehicle (Fey, 1993).

5-Conclusion

The set up that would be chosen for a lap around Pembrey would be max-max this is because of the high-speed corners that occur throughout the lap the extra down force that is created allows for additional grip meaning that corner speed is maintained allowing for a quicker lap time, this would also be applicable in the wet as it would help to apply additional force to the vehicle (Newey, 2017). If the track were to be changed it could affect the set up choice as a track with long straights will lose time with the additional drag that is created. If the test was to be repeated with longer time on the simulator smaller increments in wing changes could be used to find a better set up. Wing changes could also be accompanied with changes in ride height meaning that the ideal set up could include providing more rake to the vehicle whilst having different wing settings.

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