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The Aerodynamics and Engineering behind Formula One

Abstract

With 20 Grand Prix in 20 different countries every year, Formula 1 displays some of the world's most technologically advanced cars racing lap after lap for the winning positions. While many enjoy it for the racing factor, what really interests me is how cars so fast, powerful and sophisticated are developed, and what makes the champion car different from the rest. This report goes through some of the different aspects that make a top F1 (Formula 1) car, including aerodynamics and how the power is accumulated, but also adaptations to the racing style which has brought it forward to the modern day.

Introduction

Formula 1 is arguably the most prestigious racing series across the globe. After all, what's not to like about some of the world's most impressive inventions, purely engineered for speed, winding around circuits at speeds that aircraft take off at? The cars on show demonstrate F1's leading platform as the forefront of design and technology, and I find it fascinating how some of the world's top engineers have come together to make this possible. In this report I hope to share my admiration of the breath-taking engineering and innovation that goes into these super-speed cars.

Figure 1

Engine [1]

Engines provide the main source of power for all cars, and F1 cars demands a lot of it! You may expect huge engines to be used which can drive the cars forward at monstrous forces, but in reality they're smaller than many family cars, with most of the engines being of 2.4L. As the technology in Formula 1 has advanced, design engineers have learned that when creating champion F1 cars, precision needs to be focussed on rather than brute force. Even though the engines are smaller, the precision which is achieved allows the components to move at speeds which will destroy the conventional engines used on the road. This idea first came from developments in artillery, something completely detached from motorsport.

It's common knowledge that conventional car engines are powered by fuel, which is combusted so that energy can be released, however how this energy is used to get the car moving is less well-known. The fuel is ignited so that an explosion takes place in a small gap between a piston and the cylinder it is held in. With the gap being of very small volume, the explosion creates lots of pressure, based on a theory called Boyle's Law (it explains how the characteristics of a force depend on the pressure and volume of the space it is exerted in). This pressure is more than enough to thrust the piston downwards, across its cylinder to the other end. This is when lots of things start going on all at once, all providing bits of power which build up and eventually move the car. The bottom of our piston is connected to a shaft, which is connected to another piston, but in a different position to the first one; if the first piston is at the top of its cylinder, the connected piston will be at the bottom of the next one. This positioning is really important in ensuring that the efficiency of the engine is maximised and the most useful energy can be gotten out of the explosions. As the first piston is forced downwards, down its cylinder, it rotates the shaft to push the second piston upwards, so that when the first piston reaches the bottom of its cylinder, the second has reached the top. At this point, another explosion takes place at the top of the second cylinder, in the small gap between the piston and the top of the cylinder. The second piston is then pushed downwards, so that it reaches the bottom it its cylinder, and has pushed the first cylinder back to its original position at the top. This process then repeats.

The movement of these pistons lead to the shaft being rotated, which in a more technical way is done by transferring the chemical energy of the fuel into kinetic energy. In cars, this shaft is connected to an axle in which the wheels are attached to, so when the shaft rotates, the axle does and so do the wheels, allowing the car to move. But all this doesn't just work for cars! This structure is used in so many machines, that actually this has become the conventional prototype that all machinery is made from.

You can get more powerful engines which can rotate the shaft at faster speeds by adding more cylinders. Each cylinder, with its piston, provides a pathway in which chemical energy can be transferred to kinetic, so adds a bit more power which is used to rotate the shaft. Having more cylinders means that more kinetic energy can be collected at any point, directly leading to the shaft, and connected parts, rotating at greater speeds. Although, when designing engines, engineers need to keep in mind that a more powerful engine, with more cylinders, uses up fuel at a faster rate and contributes to a greater overall mass of the machine, which will lead to a lower efficiency.

In some ways, the classic cannon and modern internal combustion engines work similarly; they both use energy from explosions to drive the movement of a propellant (convert chemical energy into kinetic energy), regardless of whether that be a piston or cannonball. Older artillery required a windage gap to be installed, which was an air gap between the propellant and barrel, acting as a safety feature against the propellant getting stuck. Although, this safety precaution meant that artillery couldn't work to their full capability; the air gap provided an escape for some of the pressure, building up behind the propellant, ready to be used to drive it away. This lowered the efficiency of many artilleries, and acted as a limitation to its development during the 17th and 18th centuries.

This was until an industrialist called John Wilkinson (better known as *Iron-Mad Wilkinson* in his day) came up with a solution. In the late 1700s, he designed an advanced cannon-boring machine which allowed for safer and more accurate cannons to be made. This precision machining meant gunners no longer needed to allow for windage, increasing the efficiency of new artillery. This discovery was so useful that it started to spread and become a key advancement in which the industrial revolution built upon. Wilkinson's invention supported the advancement of steam engines, which could now use precisely bored cylinders as their pistons and have no need for a windage gap. Machines, in particular engines, now had the ability to become more and more finely tuned to maximise efficiency, not having to be held back by safety measures getting in the way.

Nowadays, F1 engines are so tight, precise and finely tuned that it cannot be started when cold, without being damaged – the pistons and so tightly packed in their cylinders that they need the right conditions, so that they expand to the right volume before being able to function. Engineers have gone about this by using water heaters, sometimes on timers overnight, just to start these cars, without thinking about the implications of reaching up to 12,000 revolutions per minute (rpm) in order to challenge for the podium positions!

Aeroparts (aerodynamic devices) [1]

The power being generated by the engine is great for the speed factor of races, however a major problem when it comes to corners. As seen in the 1980 Formula 2 (2nd division of Formula 1 series)

German Grand Prix, where Manfred Winkelhock was involved in a *flying car* accident (Click me to check it out for yourself!), aerodynamics is a major part of any racing car and in some ways even more important than the engine. As bizarre as it sounds, when going fast enough, F1 cars can behave in a similar way to aircraft – the speed at which air passes underneath the car can create sufficient force to lift it off the ground! The aerodynamic shape of these cars has subsequently been designed so that it prevents them from *taking off*, and so play a vital part in ensuring the car, and driver, pass the finish line in a quick time but also in one piece.

Figure 2

The term aeroparts is short for aerodynamic devices, which is what we call any component of a car which contributes towards its aerodynamic function. Nowadays it is deeply embedded into the style of F1 cars, but was first devised by Iranian wind sailors. The sailors found that it is much harder to sail against the direction of the wind compared to sailing in the same direction as it. But the Iranians came up with a solution, and it was through shaping their wing more like a triangle. This shape acted more as a *wing*, creating low air pressure region to one side of it, and a high pressure region to the other. The boat was naturally pulled into the low pressure area, and by using a flat keel on its base, the sailors could easily control which way the boat moved.

The invention of the aerodynamic wing provides F1 engineers with the ideal solution to prevent the straights of the race track turning into runways in which their cars take off on. They are used all around the car to push it downwards into the track, not only countering the tendency for the car to lift off, but also giving the tyres more grip on the track. This force pushing the car downwards is known as either negative lift or more simply as downforce, and plays an important role in providing F1 cars with enough grip to go around a corner quickly. I'll get into the nits and grits about how exactly all this works later on.

An alternative to this was to increase the mass of the car, which would proportionally increase the weight. Whist this did work to increase the resistive force against the car lifting off so the chances of it happening were reduced, the extra mass would also eat into the speed of the vehicle, increasing the drag acting on the car. This is down to Newton and his 3rd law of motion, in our context stating that if our car exerts a stronger force on the air, the air will also exert a stronger force back on the car. This force applied on the car from the air acts against the cars motion, so can be a real problem when trying to achieve top speeds. Newton's Laws can get very complicated very quickly, so in a nutshell, a heavier car experiences more drag than its lighter competitors, meaning that if the same power is used to accelerate the car, the heavier car will come out with slower speeds and so a lower position in the standings. Due to this, the option of making a heavier car was off the table. The engineers were looking for a solution which provided maximum downforce, yet minimum drag.

Wings match these criteria almost perfectly, especially with the new DRS technology which can change the ratio between downforce and drag depending on the car's needs. But all these aeroparts still have some mass, albeit it be little! They therefore still contribute to drag, and engineers need to choose carefully how much of these they want. Having too many would lead to too much additional mass, which creates too much drag, but having too little means that less downforce can be created, making it more likely that the car will have less grip, have longer lap times and potentially rise off the track. Engineers want the aeroparts to be light, but also strong enough so that it is cost effective and can make it through a race. One way of going about this is by using the right material, which can have a huge impact on the overall mass added by the aeroparts.

Carbon Fibre [1]

Choosing the right material to make your car from can give you the perfect advantage over your rivals, so F1 engineers need to choose carefully when deciding on this. Like the aeroparts, the material needs to be light so that the car is kept as light as possible, having the minimum weight and drag acting on it. But things have been changing recently, with an ever-increasing concern for the drivers' safety, creating a fine line between competition and safety. The material needs to be strong and rigid enough so that it can protect the driver but also the car parts – engineers need to ensure that their cars can carry on and complete the race if they take a bump, but also ensure that the more dangerous components such as the fuel tank don't present a risk of danger. The importance of this was seen at the 2020 Bahrain Grand Prix, where the driver for the Haas team, Romain Grosjean crashed into the track-side barriers at around 140mph. The impact saw the car split into 2, pulling apart the fuel tank and leading to the whole car, with Grosjean inside, setting on fire (Want to see it for yourself? Click me!)! The infamous driver, Niki Lauda was also involved in a similar fireball accident when driving for Ferrari at the 1976 German Grand Prix (Here's a video including the official footage from the race. Click me!). Fortunately, both drivers survived, and the incidents lead to a widespread concern for safety in motorsport.

The choice of materials can also affect the performance of the cars, especially at corners. Stiff, rigid bodies prevent the car twisting as it goes round the bends at high speeds and under great force. If a car does twist, it can commonly lead to at least one of the tyres losing contact with the track, and subsequently reducing the overall grip the car has on the track. Having a rigid body avoids this twisting, keeping the tyres in contact with the track and so maintaining the high levels of grip needed when cornering. This allows it to go through the bends at even faster speeds, without any additional risks of danger. Lighter cars can accelerate and brake more quickly, having weaker inertial forces to deal with. There are so many ways in which the material of a racing car can affect its performance, and vulnerability to danger, so it is essential that engineers get the material choice right.

Figure 3

In the early 1980s, Rolls Royce started using carbon fibre in their jet engines, but many people had their doubts about this new, synthetic material. It originally takes the form of string, woven into cloth or straightened so that it is at high levels of stress and on the point of deforming. It is then baked in industrial pressure cookers, and this is when it becomes useful. The heat and pressure the string is exposed to transforms it from being floppy and flexible to lightweight and exceptionally tough: exactly what F1 engineers were looking for. It is much lighter and stronger than its predecessor in Formula 1, steel, and therefore has had a huge impact in advancing motorsports and the world's technology and engineering capability. Being very expensive to produce, carbon fibre has only really been seen in the elite road cars and modern race cars, although huge investments in manufacturing is opening up it up, little by little, to everyday cars. The BMW i3 and i8 models all have carbon fibre frames, and it is projected that this material is going to be used in more and more future road cars.

Carbon fibre is so useful to engineers due to its ability to withhold massive amount of torque (turning/twisting force), whilst being ultralight and having insanely high melting points. As a result, many motorsport teams have chosen to make their braking equipment out of this.

Carbon fibre has been revolutionary in advancing the design but also the safety of Formula 1 cars. The main body of the car is known as the monocoque (or single shell), and contains the cockpit, which is what the driver sits in. The use of carbon fibre for this component has majorly improved the drivers' safety when whizzing around circuits; the increased strength of the monocoque body means that it can endure a much greater force, so much that there is no longer a need for an internal frame, further reducing the overall mass of the car. The introduction of this ground-breaking material has allowed Formula 1 to enter a whole new level of design and technology.

Figure 4

Aerodynamics – The Basic Principles [2]

Aerodynamics is all about how we can control and affect that way that air moves around, and it is arguably the single-most fundamental aspect of an F1 car. Even with the best engines, perfect materials and most skilled driver, the aerodynamics are critical in bringing all these aspects together and allowing the car to cut through the air in the most useful way. Almost every component of these cars is engineered to have the perfect aerodynamic shape, not just improving the speed of the car but also its functionality. For example, some aeroparts allow different streams of air to be channelled separately around the car, supplying the engine with enough air to be used in combustion and providing the brake pads with enough air to cool them down.

Starting at the basics, a large part of all aerodynamics builds off the principles of pressure. Air pressure is the total momentum of the air molecules contained in a given volume of space, and when these molecules collide with other particles, they exert a force. Due to this, some people refer to pressure as the resultant force exerted per unit of volume, but in many cases they are the same thing. At a higher pressure, the overall momentum of the air molecules will be greater, so each molecule will have a greater momentum. As the molecules don't change mass, the momentum is directly proportional to the velocity (speed with direction) at which the molecules are moving at. This means that each molecule will take a shorter time to move across the balloon, and so collide with the walls of the balloon much more frequently. On the whole, this exerts a greater force onto the walls of the balloon, fulfilling the other definition of pressure.

For instance, when you blow up a balloon, it starts inflating and expanding. Whilst this goes on, you are pumping air molecules inside of the balloon – this is changing the air pressure inside the balloon. As you keep blowing, more air molecules are entering the balloon, quicker than it is expanding. This means that there are an increasing number of molecules in the space inside of the balloon at one instant, so there are more molecules which add up to a greater total momentum of air molecules inside the balloon. This results in a greater, or higher air pressure inside the balloon.

Although, the important point is that it's the relationship between the different pressures which causes most effects. As well as the air inside of the balloon, there is ambient air surrounding it from the outside, with its own pressure. To keep things simple, we can assume the surrounding air isn't being blown around, and its volume or temperate isn't changing. This means that the pressure of this ambient air remains fairly constant, so as the air is pumped into the balloon, the air pressure inside rises and eventually becomes greater than the pressure outside of the balloon. At this point, there will be more collisions taking place between the air molecules inside the balloon and the balloon walls than between the molecules outside of the balloon and the walls. Therefore, the air inside the balloon will exert a greater outwards force on the balloon than the inward force applied by the surrounding air, creating a resultant force outwards. This allows the balloon to expand, so that the volume in which the air inside the balloon is contained in grows. By both definitions of pressure, this reduces the pressure inside of the balloon, so it becomes of lower pressure, but the expansion of the balloon can only take place while the internal pressure is greater than the external pressure. Ultimately, the pressure will even out and the process will repeat again, where more air needs to be pumped into the balloon for more expansion to take place. As you can see, it's not directly the pressure which causes the effects, but its balance with other pressures.

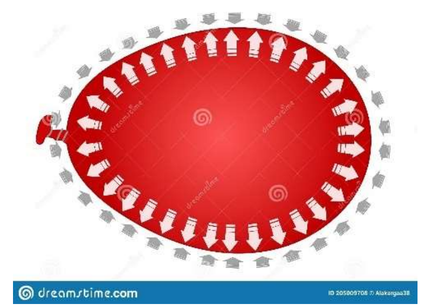

Figure 5

Once the balloon has inflated enough and you let go of it, it will go flying off as the air rushes out of it. This is partly due to rubber balloons being an elastic material, but also the tendency air has to move from higher pressure to lower pressure regions. Inside the balloon will be of higher air pressure, so that the balloon could expand in the first place, compared to the pressure outside. This higher pressure is pushing harder to escape the fixed space of the balloon than the lower pressure, having more momentum and exerting a stronger force. Therefore, when the air is free to move, the net air movement is by the higher pressure air outwards, towards the lower pressure regions. The lower pressure air also moves, but at a slower rate due to having less momentum to do so with. The air will then settle, becoming one entity with a single pressure equal to the mean pressure of the 2 different regions beforehand. In other words, the air pressures have been resolved.

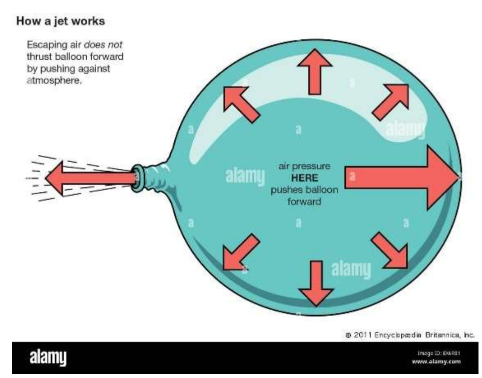

Figure 6

When you let go of a balloon, you are also allowing the Venturi Effect to come into play. This effect takes place when an airflow, which is a moving stream of air, is forced through a tight gap. When this happens, the air become more compact, with the molecules moving closer together. This creates the same result as if the volume decreases; there will be more molecules in the space that the airflow is being forced through, meaning there is a larger total momentum in this space and so a higher pressure.

The Venturi Effect describes that the smaller the region you force air through, the faster the air will flow through it. This also explains how an aerosol can works, having a small puncture in which the vapour leaves the can from, and why you get a faster water flow when you squeeze the end of the hose.

We can use pressure to deliberately move air in the way we want it to go. By creating differences in air pressure, the air will always naturally try and move from the higher pressure to lower pressure regions, aiming to rebalance the differences. This is the basic principle of aerodynamics, and it is being used all around is, all the time – even on birthdays! When you go to blow out your candles, you make a small gap between your lips which you blow out of. But in depth, what you are actually doing is setting up the Venturi Effect to take place between your lips. The high pressure air inside your mouth will speed up as it passes between your lips, creating a fast and controlled airflow as it leaves the lips, towards the low pressure region and the candles.

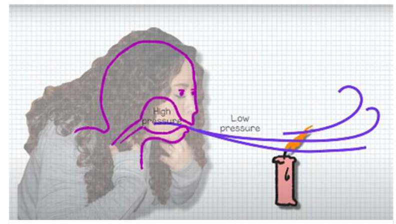

Figure 7

Another important principle is Newton's 3rd Law of Motion, which explains that all forces come in pairs, all across the Universe. These forces are identical, however act in opposite directions, with one acting on each object. Applying this to racing, if a car hits the trackside barriers, the car exerts a contact force onto the barrier; at the same time, the barrier will exert an equal, yet opposite force back onto the car. This explains why in some high-intensity, high impulse collisions with the barriers, cars are seen to ricochet back onto the track.

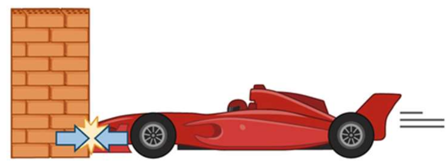
Figure 8

Aerodynamics – The Rear Wing [2]

Having explained that, we can now delve deeper and apply these principles to F1 cars, starting with the wings. These are perhaps the most distinctive parts of an F1 car, and are found at either the front or rear of the car, hence there is a front wing and rear wing. These control the airflow arriving at and leaving the car, to maximise downforce while minimising drag. They shape the whole airflow around the car, and therefore have a huge influence on its aerodynamic structure.

The rear wing uses Newton's 3rd Law to provide enough downforce and grip to allow the car to turn corners quickly. It is designed to force the airflow upwards, and by doing so exert an upwards force on the air molecules passing over it. Due to this principle of motion, the air molecules will exert an equal force back onto the wing, however in the opposite direction, so downwards. This downwards force is known as *negative lift* or *downforce,* and is primarily used to push the car into the track, increasing the grip of the tires.

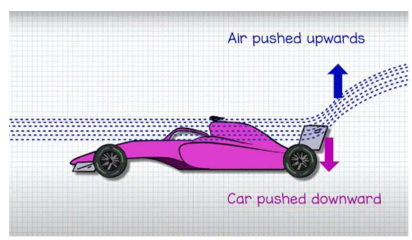

Figure 9

Let's now use a wing profile of a rear wing (its side profile; Figure 10) to explain how this downforce is actually generated. We can assume the car is receiving clean air, which rushes towards the car and rear wing in homogenous, straight horizontal layers. This airflow is generated as a result of the car moving through the air so fast – in reality, it's actually the car that's moving and not the air, however whilst we're focussing on the car we can imagine the air is moving instead.

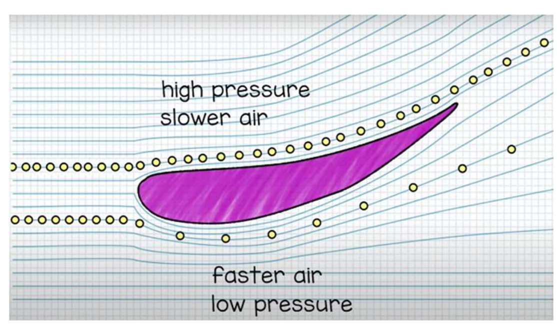

Figure 10

When the airflow reaches the curved edge of the wing, it can either flow above or below it. It's just like lanes on a straight road; it doesn't matter which lane is taken as both flows reach the same destination, but both lanes vary in direction and length. The easier option would be to flow above the wing and exit out of the back, higher up compared to when it first came into contact with the wing. This is much less obtrusive and therefore the airflow doesn't need to change its path and direction as much. Although not all parts of the airflow are able to flow this way, and each layers path in fact depends on its position relative to the wing. Only the air closer to the top of the wing will be able to take this route, and the air further towards the bottom will be forced underneath by the large curve blocking its path straight forward.

While all this is going on, the rest of the oncoming airflow, in which the wing doesn't get in the way of, carries on as normal; the unaffected paths of the airflow will still be horizonal, clean but most importantly fast moving. Meanwhile, the diverted air will have slowed down as a result of colliding with the wing and needing to change direction. The difference in speed means that the different airflows cannot mix easily, and this is really useful for engineers wanting to maximise downforce. By forcing the airflow underneath the wing, it is being squeezed into a confined, smaller area between the wing and the fast moving, unaffected air – the Venturi Effect is set up!

As we now know, the Venturi Effect will mean that the air underneath the wing will be travelling faster than the airflow above, and as the airflow has been separated at the front of the wing, this effect will go on to create pressure differences. As the airflow speeds up when it begins to flow underneath the wing, the separation distances between the molecules will be extended. In other words, as the stream speeds up, the molecules will spread out. This is the same effect as you've probably seen on a racetrack – the separation distances between cars are always given in terms of time rather than the actual distance, which will vary depending on the speed both cars are going. If both cars are travelling at the same speed when they pass any point on the track, the time separation would not change. However, in the time it takes for the following car to reach the point the leading car was at, the leading car could have sped up. The time separation would still stay the same assuming the following car also speeds up after passing this point, although this speeding up would have extended the physical distance between the cars. This effect is usually most noticeable when the cars are leaving a corner and entering a straight.

Going back to the rear wing, the faster airflow underneath would have larger, physical separation distances between the air molecules. But in the flow above the wing, the Venturi Effect isn't active, as the airflow isn't being forced into a smaller space, so it isn't speeding up. This would lead to no change in the physical separation distances between the molecules. A good thing to remember is that the difference in separation distances is due to the speed difference between the streams, and there will be no differences in these distances if they were measured in terms of time.

We can now say that the faster stream is of lower pressure, and the airflow above the wing is of higher pressure. To visualise this a bit better, imagine we had a box of a given volume, and we could measure the pressure of the airflow inside it. If a snippet of the airflow above the wing was caught in the box, more molecules would be able to fit into it, having shorter separation distances between them, so a higher pressure would be measured. However, if the airflow underneath the wing was caught, the separation distances would be greater, and therefore less molecules would be able to fit into the space. This means that a lower pressure would be measured.

We know that higher pressures exert a greater force than lower pressures, and this idea is what directly generates the downforce. The higher pressure is deliberately generated above the wing, and likewise the lower pressure is generated below, so that the resultant force exerted on the wing, from just these 2 airflows, will be downwards – the higher pressure airflow would exert a stronger downwards force onto the overside of the wing, and the lower pressure airflow would exert a weaker upwards force onto the underside. This net downforce is an essential component any F1 car needs in order to have enough grip to go round corners quickly but also safety. Nowadays, the downforce generated in F1 is so strong that it is theoretically possible for some of the cars to travel through the Monte-Carlo Tunnel (on Monaco Grand Prix racetrack), upside down! [1]

Aerodynamics – Angle of Attack [3]

By generating downforce, the overall airflow is being slowed down, even with the Venturi Effect in action, so that it can be redirected around the wing. This means that the wing applies a frictional force against the flow of the air, and due to Newton's 3rd Law of motion, the air molecules, being slowed down, will exert an equal force back onto the car, in the opposite direction. As the motion of the airflow and car are in opposite directions, slowing down the airflow will also slow down the car – both of the forces are exerted in the negative direction relative to the motion of the body experiencing it. The deflection of the airflow therefore applies a resistive force, known as drag, against the cars motion, and this is not wanted as it leads to a weaker resultant driving force, and subsequently lower acceleration.

Given that, downforce comes with drag, which isn't always wanted; the additional drag isn't always needed, such as when a car is travelling down a straight section of the track. Engineers have come up with a way to solve this problem, and it includes changing the tilt of the wing. Tilting it at an angle further against the direction of airflow would increase both downforce and drag, forcing the airflow even further upwards and take a larger deflection. This can be particularly useful at corners, where the extra grip is needed in order to turn through the corner, and speed capability of the car isn't as important. This is known as increasing the angle of attack. Decreasing this angle would mean that the wing redirects the air by a shorter distance, leading to the airflow being slowed down by a smaller amount. This reduces the downforce and drag experienced by the car, which is useful at straight sections of the track where top speeds need to be reached and grip isn't needed. The angle of attack can be decided before each race, taking into account the speeds which car go around the track at and the grip which would be needed across it. All the minor changes to the car between races, such as this one, are part of what is known as the setup of the car. The setup can be altered to allow the modifications on the car to be a perfect match for the style of the upcoming race. The Drag-Reduction System (DRS) decreases the angle of attack even further, so allows even faster speeds to be reached.

Although, changing the angle of attack too much can cause more problems than it solves, so engineers need to make sure they don't get over-excited by the whole idea. The phrase *viscosity* relates to the strength of the attraction, or friction, between layers of a substance, and it is one of the aerodynamic components that account for drag. The closest layer of air to the surface of the wing is known as the *static layer*, and it can be thought of as being *stuck* onto the wing by strong molecular forces. These molecular forces act between all molecules, so between the static layer and wing, but also between the layers within the airflow. As a result, the static layer has a *knock-on* effect on the layers next to it, which altogether contribute towards a drag force being present.

Due to these molecular forces, the static layer pulls back the next layer of air, slowing it down as it moves across the wing. This layer is now travelling slower than the one next to it, so the forces between them pull the faster layer back, and this process repeats. The molecular forces aren't strong enough to replicate this effect every time, so the process leads to each layer further from the static layer going a bit faster than the one before it. A point is reached where a layer isn't slowed down at all, so is moving at full speed, unaffected by the static layer. The region where the layers are slowed down, so that they're not moving at full speed, is known as the *boundary layer*.

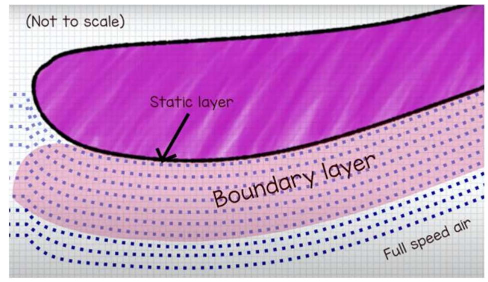

Figure 11

Airflows have the natural inertial tendency to resist a change in motion and continue in the same way, rather than taking a turn, slowing down or speeding up. pressure stream travelling underneath the rear wing. After the large curve at the front, the edge of the wing bends upwards, however if the airflow is travelling fast enough, with enough of this inertial tendency, it may resist the bend in its path to follow the wing upwards, and instead continues in a straight, horizontal direction.

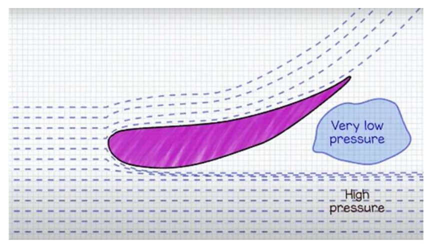

Figure 12

Engineers need a way of the keeping the airflow following the wing, so that it can be raised upwards and generate downforce. If the inertial tendencies get too high, the airflow can easily move away from the wing to create a very low pressure in the region where the airflow should be going. This pressure would be lower than the pressure of the airflow, mainly due to of the lack of supply of air going into the space, being blocked by the wing; as explained previously, air flows from regions of higher pressure to regions of lower pressure, and this comes in handy. It would be perfect if this movement to resolve pressure differences would overcome the inertial tendencies all the time, for the airflow to naturally bend upwards into the low pressure region and follow the edge of the wing, but unfortunately this isn't always the case.

This outcome only really happens when the airflow is moving at relatively slow speeds, so that the inertial tendencies can be easily overcome; this is down to inertia being proportional to momentum, so the inertial tendencies of the air molecules will be lower when they are travelling at lower velocities, holding a lower momentum. This means that if the air is going fast enough, the momentum and so inertial tendencies may be stronger than the pull due to the pressure differences, meaning that the airflow cannot be pulled upwards to follow the edge of the wing. The air would only be deflected slightly, so that the airflows above and below the wing become separated, even after the wing as cut through it. This is known as airflow separation or airflow detachment.

Airflow separation is a serious problem as it means on average, the airflow has been raised by a shorter distance, as if less of an upwards force has acted on it. As a result, less downforce is generated, and this is something engineers don't want to lose! When the angle of attack is changed in specific ways, the proportions of air moving below and above the wing is altered. This means that the amount of air being fed into the Venturi Effect is also changed, so the pressure and speed of the airflow underneath the wing is changed. Using too aggressive angles can mean that the speed and so momentum of the airflow underneath the wing is too strong, leading to airflow separation.

Airflow detachment can also amplify the pressure differences a car leaves behind after cutting through the airflow, due to this very low pressure region being created. It can lead to turbulent airflow leaving the car as air rushes in all directions to resolve the pressure differences, which can have dangerous effects if it is fed into the aerodynamics of a following car, especially if going at high speed or round a corner.

Almost all F1 aeroparts are designed for laminar flow (straight, layered and undisrupted), so if turbulent air is fed into these, they wouldn't be able to work as efficiently and so be able to generate as much downforce. This could disastrously impact the grip of cars and increase the risk of a crash happening – as a result, the FIA (governing body of F1) are introducing stricter restrictions year by year to regulate the amount of turbulent air the cars are producing. DRS has also been brought in to combat issues around stalling, which happens when the turbulent air reduces the downforce being generated whilst drag continues to increase.

Aerodynamics – Vortices [3]

A vortex is a spiral of air, spinning in a *corkscrew* shape along airflows; vortices can be used to solve the issues which arise when the angle of attack is raised too much, and therefore they have a key role in maintaining top speeds. Air flow detachment can be overcome by using a vortex which pulls the high speed, laminar airflow which had been deflected back towards the wing and its associated boundary layer (even though this area is of very low pressure, it is still occupied by a small number of air molecules which naturally form a weak boundary layer away from the wing). By using this, the separated layers can be reattached so that the disruption caused by the wing is smoothed out and no longer created a turbulent airflow. Vortices therefore provide a solution to extreme angles of attack, preventing airflow separation from taking place and so allowing downforce to continue to increase.

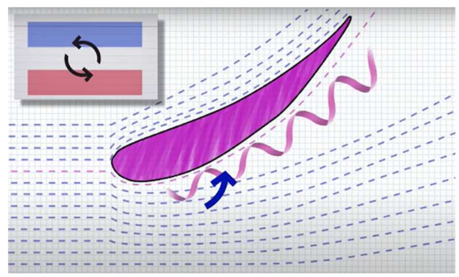

Figure 13

Vortices aren't only used at the rear wing – in fact, they're used all over the car and have a large influence on the navigation of the different airflows around the chassis (skeletal framework of car) and body. Many components of an F1 car need a good supply of clean, laminar air in order to function properly and efficiently; this includes the aeroparts but also the air intakes, in which many are designed to either cool down the engine or provide oxygen to be used in the combustion. Airflows also need to be directed so that the rear wing received a good, laminar airflow, which would otherwise be blocked by the driver or monocoque in front.

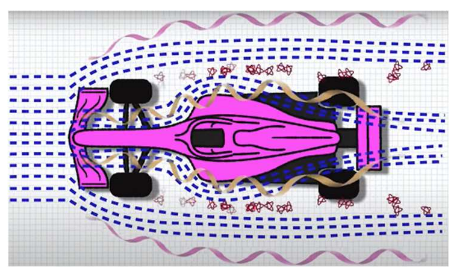

Figure 14

On the whole, the whole shape of an F1 car acts as its own large wing, especially when travelling at very fast speeds. Therefore, when going fast enough, airflow detachment can take place around the body of the car – the airflow underneath it will be flowing so fast that its momentum is stronger than its natural tendency to follow the rear of the car upwards. This would create a region of very low air pressure, likely to be of lower pressure than the airflow in front of the car.

This means that the air will have a natural tendency to move from the higher pressure to the lower pressure region, which is against the direction the overall airflow is moving in. An additional frictional force would be applied to the airflows around the car as a result, slowing them down and therefore contributing towards a larger total drag being experienced by the car. Vortices are used to pull this underside airflow upwards so that it follows the body of the car and prevents a very low pressure region from forming behind the car. These will be designed by the engineers so that the vortices don't only ensure the airflows are attached and together when leaving the car, but also reduce the overall drag exerted against its motion. The vortices work in conjunction with another component called the diffuser, which we'll get into later on.

Aerodynamics – The Front Wing [3]

The front wing is used similarly to the rear wing to generate downforce, but also has a huge role in structuring the airflows around the car, which is done using vortices. Being the first interaction for a large part of the airflow reaching the car, the front wing needs to be able to build these vortices perfectly in order to direct and control the airflow around the car. For example, many of the vortices come together to build distinct channels around the car, so that the different airflows can take different paths around it. This keeps the dirty, turbulent air coming from the tyres away from the clean, laminar flow which is supplying the aeroparts, meaning that the aerodynamic functionality of the car can be maintained.

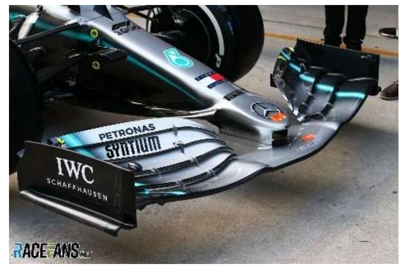

Figure 15

Modern front wings are built with a number of thin flaps, giving a stair-like structure to the overall wing; whilst these do look nice and fancy, they work really well in creating strong and structured vortices. Each flap acts as its own small wing, meaning that when encountered by an approaching airflow, high pressure will be directed above the wing, and low pressure below. With the flaps being so thin and narrow, it is much easier for the air to escape its designated path and flow around the wing to settle the pressure differences. This takes place the most at the pointy ends of the wing, where it is narrowest and therefore easiest to change paths. It creates a corkscrew-like airflow at the end of the flap, which then grows and moves across the wing so that a full vortex is formed – by the time the airflow reaches the other end of the wing, the momentum is strong enough is keep the corkscrew motion going around the rest of the car.

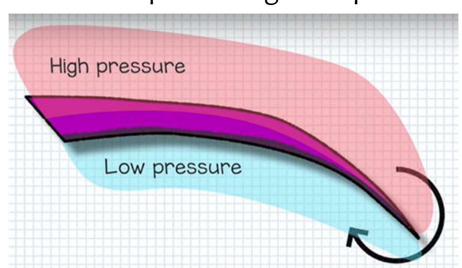

Figure 16

Although, it is important to note that however useful vortices are, we don't want too many of them. Vortices add to drag: the airflow takes a less direct route by flowing in a spiralling path, meaning that it takes longer to cover a given horizontal distance than a nice, straight laminar flow. This means that on average, the airflow in vortices is being slowed down from its motion in a natural laminar flow, and therefore by Newton's 3rd Law the air will slow down the car too. It is vital that engineers find the right balance between using too little and too much vortices, and when they do, they can start thinking about using some cool aeroparts!

Aerodynamics – louvres and cut outs [4]

Figure 17

Going back to the rear wing, we can now pick out some cool details which use vortices to increase speeds. On each side of the rear wing there is an endplate, which are the vertical boards and somewhat *box off* the wing. Without these, big vortices will be generated around the wing in a similar way to how they are generated at the front wing. These vortices really irritate engineers as they get in the way of the beautiful aerodynamics around the rear of the car, used to improve the cars performance. These endplates are put on each side of the wing so that any of the vortices generated are blocked and eliminated before they can interfere with anything important. But it's not problem solved yet – by placing these endplates on the car, the air needs to flow around it, and therefore even the endplates need to be designed so that the airflow around it is as smooth and *anti-drag* as possible.

All vortices are produced from pressure differences, and therefore in order to combat this problem engineers need to look at the pressure differences around the rear wing. The rear wing is designed so that a higher pressure airflow is channelled above it, so that downforce can be generated, but this also sets up a perfect scenario for vortices to be created; the high pressure air can easily escape from its designated channel in order to resolve the pressure differences and in the process form a vortex. Meanwhile, lower pressure airflow is streamed around the other side of the endplates, meaning that there is a strong pressure difference between each side. This strong pressure difference is what creates the really strong and dangerous vortices which need to be dealt with.

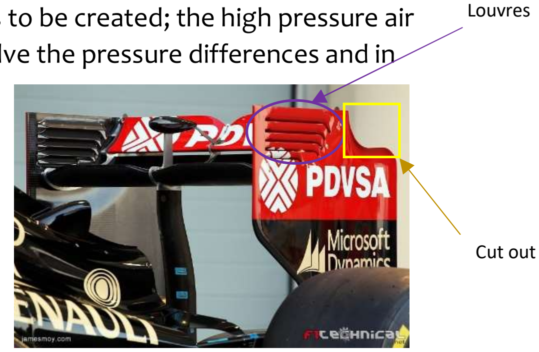

Figure 18

Engineers have started to cut a number of slits into the top of the endplates, and they call these features louvres. It allows the higher pressure air flowing above the wing to move across to the lower pressure region and reduce the pressure differences. By doing so, the problematic vortices will have a lower pressure difference to form off and therefore be weaker, meaning that less interference is likely to happen. Engineers have also added cut outs at the top end corners of the endplates. These provide a space for wingtip vortices to form, which acts like a barrier between the high pressure and low pressure airflows. This prevents the high and low pressure air mixing, which would create turbulent, dirty air in which even more large vortices can be produced from.

Louvres and cut outs can also help to create opposite vortices to the ones created around the wing; when both vortices meet, they cancel out and disappear, meaning that the aerodynamic structure around the rear of the car is well protected.

Aerodynamics – Diffuser [4]

Figure 19

Another really important aerodynamic component of F1 cars is the diffuser. This is the scoop-shaped base of the car at its rear, and it helps put the Venturi Effect into action. The oncoming airflow is directed either above or below the front wing in a way in which downforce can be generated. By doing so, a stream of low pressure air is directed along the underside of the wing and then underneath the car, so that it emerges at the diffuser at the point where the airflow is about to leave the car's vicinity. This forces the low pressure air into the tight space between the track and underside of the car, and hence the Venturi Effect is being set up; by squeezing the airflow into this smaller space it will speed up and so become of even lower pressure, meaning that downforce is increased. This is great for the grip of the car, however creates a new problem about the trail of air left behind.

The curved shape of the diffuser helps to shape the whole F1 like a wing, so that downforce generation can be maximised in a way that drag is kept to a minimum. This technique works so well that it has acquired the name *the ground effect*. As a result of the Venturi Effect, the low pressure stream will reach the end of the car moving at a very fast speed and therefore having a lot of momentum. This means that it is takes plenty of effort and energy to keep the airflow directed around the edge of the car, and due to this it is more likely that airflow detachment will take place between the streams flowing above and below the car. Airflow detachment can be really costly in motorsport as on average the airflow around the car is being raised by a shorter distance. This means that the average upwards force exerted on the air by the car would be weaker, and by Newton's 3rd Law the corresponding downwards force exerted back on car by the air would be weaker too. In short, it can heavily reduce the downforce being generated and therefore have huge effects on the grip the car has. This is where the diffuser comes in handy; it sucks the low pressure airflow upwards, into the very low pressure void between the detached airflows, resolving the pressure differences but more importantly fixing up the airflow detachment that had formed.

The curved shape of the diffuser also smooths out the airflow as it as it enters the ambient air behind the car, probably of a different pressure. Often the whole car is tilted upwards about the front wheel to help towards this, and this is known as increasing the rake of the car. With a higher rake, as the low pressure airflow approaches the diffuser and end of the car, the space between the track and underside of the car begins to increase. This means that the airflow isn't being squeezed as much into a smaller space, and therefore less of a Venturi Effect is active. This slows down the airflow as it reaches the end of the car, increasing its pressure so that by the time it needs to integrate into the ambient air behind the car, the pressure difference will be much smaller. This can lead to less turbulent air forming behind the car, but comes at the cost of downforce – the pressure is being increased as the airflow reaches the end of the car, so there will be more of an upwards force opposing the net downwards force. This leads to a weaker resultant downwards force and so downforce being generated.

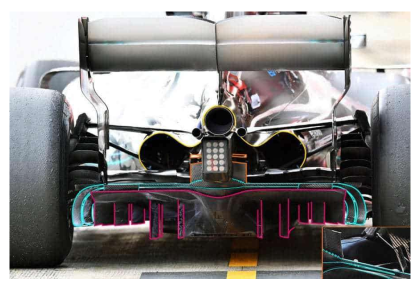

Figure 20

A popular alternative to increasing the rake is to add vertical straights to the diffuser. This helps to guide the air as it leaves the car, so that it mixes with the ambient air in a more controlled way. This can also reduce the turbulence of the encompassing air behind the car. Although, the rake of the car is used for more than just downforce, and allows the ratio between turbulence, drag and downforce to be easily adjusted, so engineers need to consider if they can afford losing these functionalities when thinking about alternatives.

Aerodynamics – bargeboards and s-ducts [4]

Bargeboards are simply pieces of bodywork, but have a fundamental role in maintaining the aerodynamic structure of the cars. Their shape allows them to deflect or even shape the paths of airflows, with some creating their own vortices to channel different air streams. This is seen around the edge of the underside of the car; the vortices created by bargeboards seal in the low pressure airflow flowing underneath the car towards the diffuser, stopping it from leaking out so that pressure differences can be resolved. This allows for the maximum Venturi Effect and ground effect possible, as a result maximising the downforce generated. Before this was discovered, the Lotus F1 team used physical beams known as skirts, which act in the same way; although, these were banned due to the downforce generated being too strong, and likewise bargeboards are no longer being used from the 2022 season onwards.

Figure 21

The s duct is another piece of bodywork, and provides a solution to the problems created by the nose of the car. The front of the nose has a very similar shape to the front of the wing profile, and therefore parts of the oncoming airflow can be significantly deflected around the nose. When the airflow meets the front of the nose, the air molecules collide with it and transfer energy away from the molecules to the nose. This leaves the air molecules with less kinetic energy, which can only support motion at a slower velocity. As a result, the airflow slows down when being deflected around the wing, in the same way as if there was a resistive force acting against its motion - by Newton's 3rd Law this adds to the aerodynamic drag exerted on the car.

Larger deflections can lead to more drag as the airflow needs to take an even longer detour around the wing, driven by a stronger resistive force. This means that the boundary layer between the static layer and the high-speed airflow, responsible for drag, grows. If a larger resistive force is acting against the motion of the airflow, the speed difference between each stream of air in the boundary layer would be smaller. This would mean that it would take more streams, and hence a thicker boundary layer, in order for the speed to gradually increase and meet that of the high speed airflow. In short, more drag means thicker boundary layers, and this is where the big problem lies.

As said above, downforce comes with drag, and some of the aeroparts designed for downforce generation, such as the front wing, and even the ground effect can create large levels of drag. This can cause the difference in lap times between the 1st and 2nd place car, so it's a big deal for engineers! As a result of lots of drag being created under the front of the car, the boundary layer can build up and sometimes contribute to even more drag being formed. This works a bit like a traffic jam – if 1 car (the air at the front wing) slows down for long enough, there's not much of an effect until the car behind, in this case the approaching airflow, meets the 1st car and slows down, so that the 3rd car eventually slows down and repeats the process. If the deflection is large enough so that the '1st car' slows down for long enough, it can result in a growing 'traffic jam' where a growing area of air is being slowed down. A larger area would be experiencing the effects of a resistive force, leading to an increased resultant resistive force on the airflow.

The s duct is a tunnel or pathway between the bottom and top of the nose, and allows some of the slow-moving boundary layer to escape from the underside of the nose, emerging above it instead. Consequently, it can relieve the build up of the boundary layer and prevent the drag force from increasing.

What makes the s duct really great is that it solves another problem at the same time! As said before, the overall shape of an F1 car is similar to that of a wing profile, so maximum downforce can be generated, however there are little tweaks here and there which don't match the overall pattern. One of these is when the nose levels off to make room for the cockpit, and it can cause serious issues. Especially when the car is travelling at high speeds, the momentum of the high pressure stream travelling over the nose is much greater than its natural tendency to keep with the static layer and level off when the nose does. Therefore, airflow separation takes place, and while being in quite a central location, it is difficult to produce vortices which don't interfere with something else.

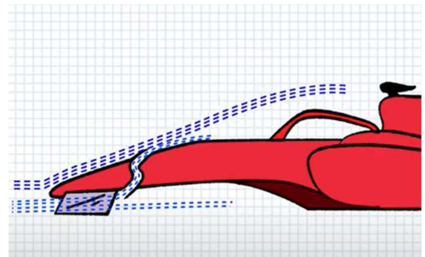

Figure 22

Engineers have deliberately set up the s duct so that the low pressure stream emerges on top of the nose at the point where the high pressure airflow levels off, so that there are now 2 separate streams travelling at different angles. With one being of very low pressure and the other being of very high pressure, there is another tendency for the streams to come together than resolve the pressure differences, and this happens to be stronger than the tendency to follow the static layer. As air always moves from high pressure to low pressure regions, the separated high pressure airflow is pulled back down to follow the shape of the nose.

This double-purpose is really clever of the engineers, and it isn't finished yet! Once the high pressure band is brought down to follow the nose and resolve the pressure differences, there is only one band of relatively average pressure left, flowing at average speeds. This reduces the drag experienced over the topside of the car; knowing that high pressure airflows are flowing at slower speeds and therefore are creating drag, combining it to produce an average pressure airflow means that the airflow is being slowed down less, creating less drag. In technical terms, the emergence of the high-energy, low pressure stream allows the boundary layer above the nose to be energised, increasing the speed difference between its layers and reducing its size on the whole. This gets the best of both worlds regarding downforce and drag – there's still enough downforce generated to keep the car glued to the track, and drag is kept down so that it doesn't cut into top speeds. And that's it for the s duct; who would have thought such an important component is so hard to notice?

Figure 23

Aerodynamics – drag reduction system [5]

DRS (drag reduction system) is one of those things that you hear all the time when watching F1, yet how it actually works is rarely explained. It is an influential aspect of modern motorsport, although has mixed views on whether it gets in the way of the traditional racing style many love. The FIA have responded to this by bringing in lots of rules and regulations around where and how DRS can be used, and it doesn't look like DRS will be leaving the sport anytime soon.

DRS is a movable flap on the rear wing prominently but also on the front wing, and was initially introduced to make overtaking easier, amid various advancements increasing top speeds and narrowing the competition between teams. Opening this flap can reduce drag and by doing so make accelerating easier, however this isn't always wanted.

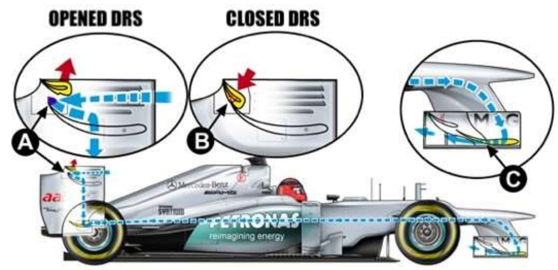

Figure 24

The FIA have set strict rules around the use of DRS, emphasising the fact that it should not be used for defence. DRS can only be used when a car, irrelevant of its position in the standings, is within one second of the car ahead when entering a specified DRS zone. These zones tend to be on the largest straights of each track with offer the best overtaking opportunities, and usually end with a corner or bend in which the car needs to slow down for; the flap closes when the brakes are applied, meaning that whilst there is a set point at which the DRS zone starts, the end point depends on the point at which the driver starts to brake at. However, DRS cannot be used in the 1st 2 laps after a race start, restart or safety car deployment (safety cars are deployed to set a slow speed and tone down a race, especially after an incident has occurred).

Figure 25

That's enough about the rules of DRS – let's get into the details about how it works! When DRS is activated, the flaps are pushed upwards to create big holes in the middle of the wings. The overall DRS is most significant at the rear wing, and due to this I'm going to base the explanation around that; however, it is the same mechanism at the front wing and so everything still applies to it! This open gap created by the flap allows all the air in line with it to pass straight through, so doesn't need to be deflected around the wing and be slowed down by doing so. Overall, this means that less of the whole airflow is slowed down, so on average the speed of the airflow is increased, as if less of a resistive force is acting on it. Following Newton's 3rd Law, this reduces drag, and at the same time reduces the downforce generation. By avoiding slowing the airflow down, the engineers are avoiding deflecting it upwards and over the wing. This means that less of an upwards force is acting on the airflow altogether, so also by Newton's 3rd Law, less of a downwards force will be exerted on the car.

Aerodynamics – slipstream [7], [8]. [9]

As effective DRS is at reducing drag and increasing speeds, many F1 fans aren't best pleased with it having such a central role in races. The thought that DRS contributes towards a more artificial feel of racing has been gaining support over the last couple of years, where people think that it discourages natural racing which involves overtaking anywhere, including outside of the DRS zones. Many teams take full advantage of the DRS zones, so plan their best moves inside this area, and as a result many fans have found races with DRS more boring and predictable. They are calling for a smarter and more traditional way for DRS to be used, and it is a hard task for the FIA to deal with.

The secret to having near-perfect lap times is focussed around maintaining high speeds in corners as well as maximising them in the straights, and to do this there needs to be a balance between generating downforce and minimising drag. A lot of fans want to see cars of similar ability, battling and overtaking each other naturally lap by lap, without the help of DRS, yet this is almost impossible! It could be said that DRS actually solves this problem more than it causes it, and it is the best option we have for now.

This whole idea ties in nicely with slipstreaming, which is another thing F1 fans hear lots of, but usually don't get the chance to understand how it works. Most people think that it is a great thing which helps the cars go faster, and in some places it is, but in others it is something drivers want to avoid. As we've previously covered, the wings on an F1 car generate downforce by deflecting the airflow upwards, and by doing so push the car into the ground. This is wanted as it increases the cars grip on the track, allowing it to go through corners at a much faster speed – without this grip, the drivers would need to slow down so that they have the enough time to turn around the corner, where if they don't they will face the risk of going wide and potentially off the track. Therefore, the grip a car has when going round corners really affects its lap times and consequently its success in races, so it is essential that engineers get enough of this without creating too much drag which may cut into the top speeds.

When a car goes round a corner with insufficient grip, there are 2 possible outcomes: understeering and oversteering, and both can be really detrimental to a team's performance. They are the main causes of crashes, especially at the later stages of a race where tire wear is at a high, so there a great deal of pressure on the engineers not just to keep lap times low but also protect the driver.

Understeering takes place when the car doesn't have enough grip going into the corner, meaning that it cannot turn enough to manoeuvre through it in the quickest way possible. It results in the car running wide, taking a longer path around the corner which will naturally take longer (assuming the speed of the car remains constant in both scenarios). In a nutshell, understeering happens when the car doesn't have enough grip to turn enough, and this is the completely different to oversteering, which has the effect as if the car steers too much. Oversteering is a bit more noticeable than understeering, and usually takes the form of the car sliding around its back, which some people call *fishtailing.* When this is happening, the back wheels spin, but don't have enough grip to pull the car round the corner. It is very difficult for drivers to control the car after it starts oversteering, and generally ends up with the car either *drifting* through the corner, or *fishtailing* and spinning around its back so that it is no longer facing the direction the driver wants to go in. The most extreme example of this is probably when cars do doughnuts, which is where they spin about their front wheels. However, drivers can pull off controlling oversteering, and it looks very impressive!

Figure 26

Now knowing this, we can look deeper into slipstream to see where it is good and bad. The wings on an F1 car, in particular the rear, work really well at generating downforce, and on the whole, this pushes the oncoming airflow upwards. By doing so, the car leaves a small region of lower pressure air behind it, in which the car is blocking any of the airflow from reaching. This is the cars slipstream, and its possible for a following car to get into it if they are close enough behind.

Being of lower pressure, the slipstream region will contain a smaller number air molecules per given volume. This means that there are less molecules around for the car to slow down, and subsequently there are less to exert a resistive force against the cars motion. This leads to a weaker drag being experienced by a car in a slipstream, which is great when it is on a straight. Having less drag against the cars motion means that more of the power produced by the engine can go towards its acceleration, where less of it is needed to counteract the resistive forces. This greater aero-efficiency makes it easier to accelerate, as a weaker driving force would be needed to provide the same level of acceleration. We can now understand why F1 cars are seen to overtake cars in front so late. The slipstream is only a small area in the shadow of a car, and drivers want to maximise the time spent in it. When going at the immense speeds seen down some straights, lots of drag can be created, so any slipstreaming opportunities definitely pays off. It allows for more acceleration, with produces faster speeds, increasing the chances of a successful overtake.

Slipstream is therefore something drivers want to get into when on a straight, although at corners drivers don't want to be anywhere near it! One of the most important aspects of downforce is that it comes with drag. It brings in a balance which can strongly influence the cars performance and provide variability between teams. In order to quickly pass through a corner, the car needs to obtain sufficient grip by the means of downforce, and to do this the air needs to be pushed upwards by the car. The intervention by the car, which causes this deflection also generates drag, so it could be said that downforce is a special element of drag, limited to a few scenarios. If a car is in a slipstream, the lack of pressure means that less drag is being exerted on the car, and downforce cannot be created without drag. In the slipstream there are less air molecules for the wings to deflect upwards and slow down. Therefore, there are less molecules in which an upwards force can be exerted on, and likewise there are less molecules to exert a downwards force back on the car. This means that the slipstream greatly reduces the levels of downforce obtained, and increases the chances of understeering or oversteering occurring, but the problem doesn't end there.

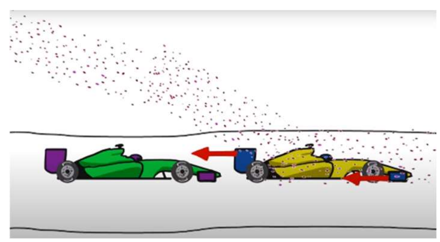

Figure 27

After a previously laminar airflow of homogenous, horizontal layers have pass around an F1 car, it will have been deflected and shaped and accelerated in so many different ways to allow the driver and team to get the most out it. This gives the driver more than a fighting chance to reach top speeds while having the sufficient grip to go round corners quickly and safely, but disadvantages all the cars travelling fairly closely behind it. Once the airflow has left the car, it will be so untidy and chaotic that it becomes incredibly turbulent and hard to work with for following car. This form of turbulent air is known as dirty air, and contrastingly the nice, laminar airflow that we want is called clean air. To make matters worse, all of the aeroparts on all F1 cars are designed for nice, smooth laminar airflows, which is what the cars will be receiving most of the time. All this results in the modifications and adaptations made to the following car becoming much more inefficient, with the aeroparts only really working to their full potential with the little pockets of laminar flow still left. It leaves the car without the benefits that usually come with the aerodynamic devices, in particular increased downforce and stability. It makes it almost impossible for the following car to continue competing for the leading spot, forcing them to drop back until clear of both the slipstream and dirty air – if the car continues at the same high speed and approaches the corner, it will not have

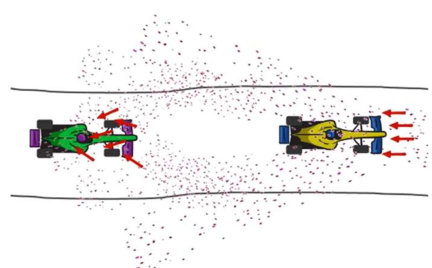

Figure 28

the sufficient grip to go round it and therefore result in understeering or oversteering, which is even slower than dropping back.

Some teams have started playing it strategically and using the dirty air to their advantage. By designing their cars so that the airflow leaves it, having been thrown around in all directions, with horrible vortices and large pressure differences, it makes it much harder for the following car to overtake. Even with strict restrictions being added by the FIA year after year, this is still a big problem, and at the minute DRS is our only solution. Without it, there will be no way for the following car to continue its competition with the car in front – it will be continuously forced backwards and out of the slipstream on the corners, increasing the distance between the 2 cars, ruining any overtaking opportunity the following car can get and closing the battle between them. The DRS zones gives the following car an advantage over the leading car, and in the sense that it eliminates the disadvantage the following car has through the corners, it makes the race much fairer and allows the individual battles to be longer-lived.

The debate around DRS [7]

The exciting thing about DRS is that it is something that can change so easily, and if it is changed it can really spice up a race. In preparation of the 2022 F1 season, lots of changes were made to the freedom teams had to change up their cars, including the introduction of a completely new car for the teams to start with. It meant that some aeroparts such as bargeboards would no longer be available to use, meaning that during the winter break the teams needed to think of worthwhile and creative replacements.

Figure 29

One of the most noticeable changes seen on the new car was its shape, which has become increasingly rounded and curved, in particular the wings and forward components. The rounded shape of the rear wing is much better at cleaning up the air when it leaves the car, collecting up all the dirty air and dumping it in front of the diffuser. This pushes the dirty air upwards and over the slipstream, being driven by the low pressure stream being pulled up by the diffuser. This relocates the dirty air away from the slipstream and following cars vicinity, lessening the disadvantage following cars have when going round corners. The exposure of dirty air to the following car also affected its tyre and engine cooling process, which also worked most effective with a nice, clean laminar flow. For a while now, ERS has been in use, and it has been successful in combatting this problem. ERS harnesses all the dissipated heat from these components, which would be otherwise be wasted, and stores it in a battery. This energy can then be used to propel the car forward and add to its acceleration. It is a similar system to KERS, which can be classed as the ERS specifically for the brakes.

The changes to dirty air generation reduces the disadvantage following cars have when in a slipstream, and therefore can possibly suggest that there is less of a need for DRS, which eliminates this disadvantage. The increased wing sizes which come with the new car also amplify the effect that DRS brings, causing more of a difference in drag, leading to a more distinct change in aero-efficiency and the car's ability to accelerate. The new and improved DRS, which is arguably needed less, has led to some fans speculating about a coming change to the how DRS is used, and what this might involve.

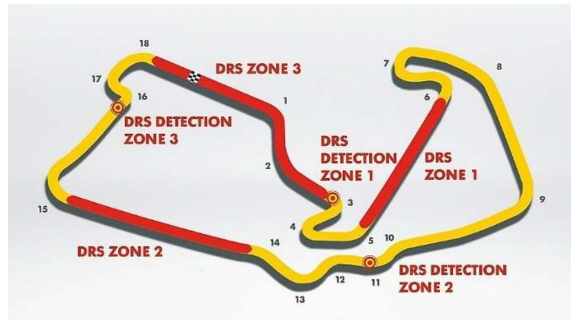

Figure 30

The most popular idea is that the DRS zones will be shortened, in response its reduced demand and increased effect. This will leave less space for teams to plan their moves in, encouraging overtaking all across the track. This would create much more unpredictable and exciting races, which is wanted by almost all fans. There are some more abstract concepts in addition to this, with one being that DRS will be available to use across the whole track, in any circumstance. Some fans like this as it means that no artificial advantage is given to only a few of the cars, and in some sense can create a fairer system, where all cars have the same advantages and abilities on track. Although, others argue it defeats the purpose of DRS, which was brought in to allow the following cars to continue battling for the overtake, amid the disadvantages it received by being in the slipstream; if both cars can use DRS, it just increases speeds, rather than taking into account the weaknesses the following car endures.

Others want to see DRS be used in a similar way to KERS, which is explained the next chapter. This will encompass DRS only being available to use for a certain time period every lap. It makes its use more strategic, which could take away its artificial feeling and add excitement and unpredictability. However, most teams will quickly recognise that DRS is most effective on the straights, meaning that this approach could easily lead to the same effect as if DRS could be used wherever, whenever. Shorter DRS zones with a stronger DRS effect is another idea, and it becoming has become more popular following the recent changes made for the 2022 season. The shorter length of these zones could mean that they can be moved further from the corners, leaving some room on the straight for natural overtaking and fighting for the leading spot.

There's a big debate around the use and possible changes to DRS, and its likely to grow as the aerodynamics in the sport advance and new regulations get applied. Although, what many fans don't realise is that it is a fundamental part of modern, exciting racing, and it cannot be removed without a suitable replacement; until this is found, DRS is the best option we have.

Kinetic energy recovery system [6]

The introduction of hybrid engines into F1 has been a catalyst in moving the sport forwards to the modern age; the kinetic energy recovery system (KERS) came about as engineers started to think about other ways to increase speed. So far, all speed-related modifications have been made to reduce drag, consequently allowing the car to accelerate, but speeds can also be increased by giving the engine more power to work with – this is exactly what KERS does to some extent, and so using both KERS and DRS when overtaking would maximise acceleration and lead to the best possible chances of overtaking.

Every time a car brakes, work needs to be done by the brakes to actually slow the car down. This involves the brakes transferring energy from the kinetic store (responsible for movement) to other stores which tend to be much less useful, such as heat and sound. This is why the brakes of cars tend to heat up and *screech* when the driver brakes hard, so in the context of F1 it is critical that the braking system gets a good air supply and can efficiently cool down. It is really bad when brakes overheat, as they are unable to provide a good, strong braking force which is needed to slow the car down; some of the braking equipment used in F1 cars have been seen to even set on fire when being overheated, so engineers need to make sure the temperature of the brakes are well monitored all the time, and in the case that they do overheat it doesn't cause a safety risk to the driver.

Every time an F1 car brakes, KERS *catches* the energy being transferred by the brakes, and directs it towards an electrical motor instead of being dissipated to useless energy stores. This allows the energy to then be converted into electrical energy, which is much more useful as it can power the electrical component of the engine, providing even more horsepower (a measure of power) for the car to accelerate with. Remember fuel adds a significant weight to the car, which would not only add to drag but also mean that a larger driving force is required for the same acceleration (this last part is Newton's 2nd Law of motion, and both are due to the inertial forces of the car). Given that, the less fuel carried by the car, the easier it is to accelerate and maintain the top speeds; having KERS means that the overall combustion of the fuel is a much more efficient process, and therefore less fuel would be needed, reducing the weight of the car.

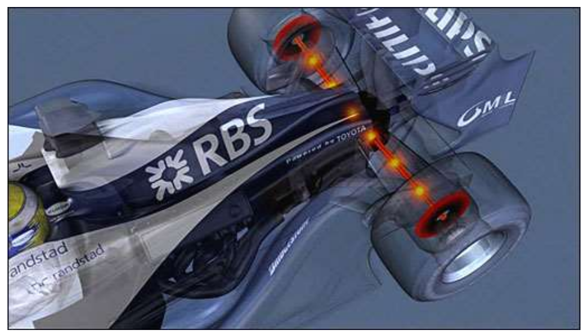

Figure 31

KERS can be used whenever in a race, but is not unlimited like DRS: the battery which stores the electrical energy can only be recharged when the car brakes. For example, if a driver uses all the capacity of the battery in one straight, such as to overtake the car in front, he/she will need to wait until the car has braked enough so that the battery has been somewhat recharged and there's enough energy in the bank to use KERS again. However, unlike DRS, KERS can be used defensively as well as offensively, and in a more strategic way. Most drivers save KERS for when it can really pay off, such as when overtaking or in a battle with another car for the best position, but some chip into the energy stored little by little to cut a bit of time off each lap. Nowadays KERS is mainly seen as a defensive attribute, with the FIA only allowing it to be active for up to 12 seconds per lap, but it can be really exciting when a driver uses it offensively to challenge the driver ahead! KERS systems used today can provide up to 120 KW of power, which is around 10 times the power required to run a whole house.

Conclusion

That's everything I'm going to cover in this report, and while it might seem like a lot, it is only a snippet of what technology and engineering in Formula 1 has to offer. What really excites me about it is that it has no end: things are always changing, or new things are being discovered, or teams are using components in ways that have never been seen before. There's always something else to look at and analyse, and this is what engineers need to do in order to win the competition between the teams and produce the champion car; They need to think out of the box and come up with new ideas that other engineers may not think of. This competition is great at bringing about technological advances, and is one of the main reasons Formula 1 is so highly spoken of today. Even with the prospect of big changes round every corner, one thing we do know is that there's always more to come!

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