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Flexi wings: An innovative approach for the future of material science with an aerodynamic influence in motorsport engineering

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Abstract: In motorsports engineering, the influence of aerodynamics on the vehicle's body is of great significance. They are needed for generating downforce efficiently for better traction & high-speed cornering. That's where the concept of aerofoil comes into play, commonly known as wings. To get optimal steer at higher speeds from a formula car without changing the wing design, Flexible wings can be used. These flexi wings can tilt or bend about its vertical axis due to the effect of g-forces, generated due to cornering of the car at high speeds and hence preventing understeer or oversteer, in a very effective way. It'll reduce the ailerons' dependency or use of excessive manual adjustments to the wings, to get distinguished steering capabilities at high speed.

Keywords: Aerofoil, wings, motorsports, aerodynamic influence, Flexi wings, formula one, drag, aeroelasticity

1. Introduction

In motorsports especially in formula 1, where victory must be evaluated in milliseconds, every little change in design, every little gram of weight and perfectly calibrated components play a vital role.

That's why aerodynamics plays an important role. The design and the behavior of the body under influence of high- & low-pressure air constantly, results in its aerodynamic characteristics. It also proves beneficial in the elimination of undesired lift, wind noise emissions and minimizes any other type of aerodynamic instability at high speeds, especially **DRAG**. Reduction of drag is very necessary. As we can see from the drag equation below, drag force experienced by the car is directly proportional to the square of its velocity.

$$F_d = \frac{1}{2} \rho u^2 c_d A \qquad (1)$$

Where,

F_d = drag force

A = area

ρ = mass density of fluid

u = velocity of flow

c_d = coefficient of drag

Therefore, as the speed of the car increases, the force pulling increases exponentially. Apart from above, factors like weight of the vehicle, frame material, suspension and tires also affect the speed of the car, including lift forces and aerodynamic drag. The aerofoil structures (also called wings in motorsports) are constructed & modified in accordance with the track the car must race and that's where the concept of flexi wings comes into play.

Due to constant innovations in aerodynamics structure, Flexi wings have become an integral part of professional racing since its initial days. As the figure shows the measurement pointer for wing flex seeking. If the distance or dots perspective gets distorted, it means wings are in flex harmonic motions.

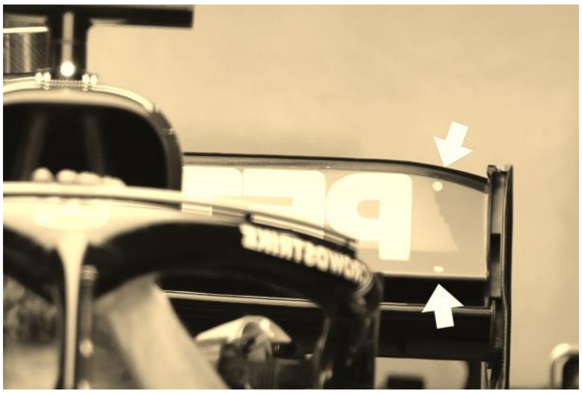

Fig. 1 Rear wing flex *check* points implemented by FIA for each team.

Flexi wings are distinctive because they provide drivers with optimal steering control, reduced drag & downforce on long straights, mainly at high speeds, without sacrificing maneuverability at corners. All this with no major add-ons in the wing design. They're also able to perform better than other wing modifications in F1 when it comes to maneuvering at various cornering situations, simultaneously improving acceleration in straights.

2. History

In 1999, Several F1 teams were trying to develop a tilting effect in the rear wings of their cars which would benefit them on both, long straights, and fast corners. The concept was that during high velocities, an impact force of high magnitude generated on the rear wing would cause it to bend & decrease the angle of attack of wings, thus reducing drag & downforce on straights allowing the car to achieve greater top speed. Now as soon as the car would slow down on corner entry, the load on the wing would unload, allowing the wing to retract back to its original position, thus producing necessary downforce, sucking the car into the road. This way the flexi wings can serve two purposes with their same basic design.

But it wasn't until racing seasons of 2005 & 2006 that [7] FIA noticed the cars are noticeably faster by unknown factors on straights, which made it clear that teams have begun to use aeroelasticity in F1 cars again and were exploiting the rules.

Now due to this unpredictable downforce impact and movement of the wings, accidents began to happen. After analyzing the main root cause of these high-profile accidents, FIA (Fédération Internationale de l'Automobile) introduced several stringent load tests and banned the use of active aerodynamics.

3. The Concept of Flexibility

A material science approach

The concept of aeroelasticity has been used in shear deformation of wings that are currently used in f1 by some teams. In the 2010 season of F1, [7] FIA calculations estimated that the deflection of some wings went up to 21mm.

Some literature searches estimated that deflection in wings happens due to change in orientation of fiber plies (as shown in figure 2 in carbon fiber composites. However, research of the Aerospace Engineering Department from Bristol University explains that elastic coupling properties can be achieved using "Laminated composites materials”. The adaptive changes with respect to physical properties of body & surroundings, it exhibits elastic properties, such as shear deformation on normal load experiences.

The application of bend-twist coupling, results in lower drag as angle of attack decreases depending upon the velocity.

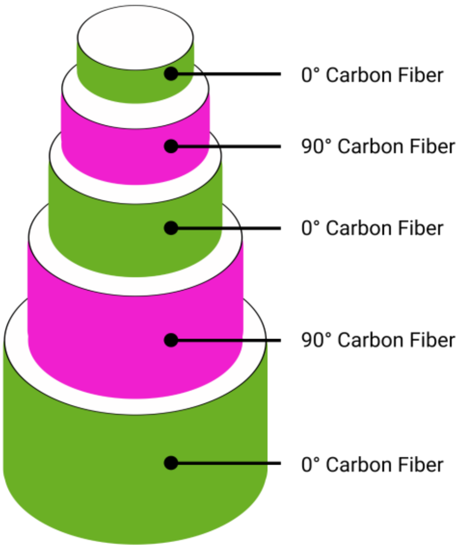

Fig. 2 Carbon pliers’ arrangement

4. Aerodynamic approach behind flexi wings

Flexi wings is a revolutionary technology in formula one. In simple terms, it exerts more downforce on the rear of the car whilst at lower speeds, and less downforce when at higher speeds. This means a car can run with a significantly lower drag than ever. On high-speed circuits (with long straights like MONZA) where downforce is less important, these wings equate to allowing a car to run with less drag and therefore be significantly faster down the straights. On low-speed tracks (with fast & tight corners like MONACO) where straight line speed is less important, this equates to producing much more downforce over the whole car enabling it to enter & exit the corners faster than before.

As the basic nature of materials, they need to bend, otherwise they’ll overbend & break as soon as a sudden heavy load is applied. It is not possible to achieve infinite stiffness in any material. Taking the above into consideration, Flexi wings will bend on higher velocities and without any failure. This bending results in a change in relative angle between flaps and main wing plane, further increasing the downforce & reducing angle of attack. Also, the backwards tilting of the wing reduces the frontal area, which is in contact with air, thus lowering the drag coefficient. This also helps reduce drag because as per the mathematical equation of drag, exponential increase in the speed is being compensated by reduction in area and coefficient of drag.

On deceleration, the wings will then return to their original position as they get unloaded, thus inducing the required downforce again, which is needed in high-speed sharp corners. Hence, we can say the use of flexible wings creates an optimum balance between speed and stability.

5. Construction & Wing arrangement

In the present day, the wings of all cars in formula1 are made from carbon fiber having a low-density core(foam) to impart further rigidity. Several plies of carbon fiber are added to induce rigidity to the wing to pass the FIA load tests and fulfill certain requirements stated in the rule book. Below Figure 3 shows the rear parts related to formula one car

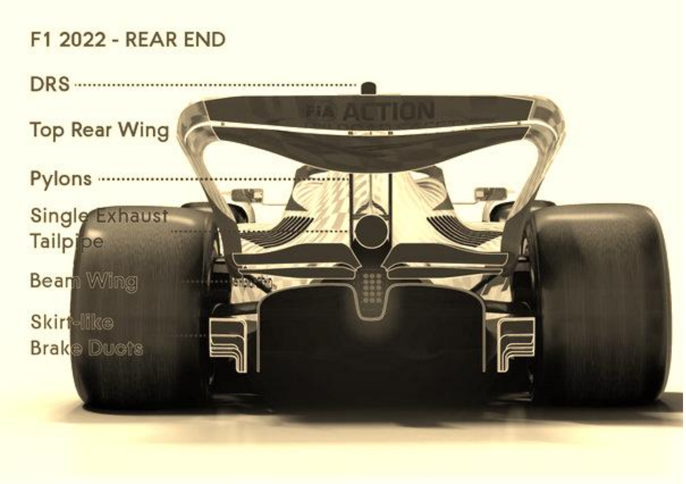

Fig. 3 Rear view of F1 car representing different components

The two main types of possible construction of flexible wings are-

- **Flexible flaps**

In this type of arrangement, the rear wing is divided into 2 parts - a lower flap which is fixed and an upper flap which can pivot about an axis. There is a certain gap between them allowing air to pass through between them. The pivoting flap movement i.e., the slot gap in the rear wing changes dynamically depending upon the speed of the car i.e., the speed of incoming air. (As shown in figure (4 & 5), due to high angle of attack or high downforce condition on maximum velocity, the wing tends to fall back backwards, or we can say that, it shows the properties of flex)

They remain fixed up to a certain load exerted on them due to acceleration, but as soon as load exceeds i.e. The car is pushed/accelerated hard, the above pivoting flap moves down and closes the slot gap between both the flaps. Now due to this, the suction side flow does not remain energized anymore, & becomes too weak to stick to the lower surface. Thus, flow separation occurs, resulting in lesser downforce and drag.

But due to this constant separation and adjunct of the flow, several problems arise, such as fluttering of the wing, which could even damage the flap at high speeds, since the g-forces rise way too much.

It was this reason that **in 2007,** FIA banned its use and introduced strict regulations like using slot gap separators (are solid rigid metal plates built into the rear wing to ensure that slot gap must never go below 10mm) to stop the teams from taking advantage from the varying slot gaps. Also, the minimum gap allowed in between two slot gap separators was 510mm.

However, these separators, on the contrary, proved beneficial as they created an additional boundary layer & also a V- Shaped separation helping in minimizing the dead area which made the wings more rigid.

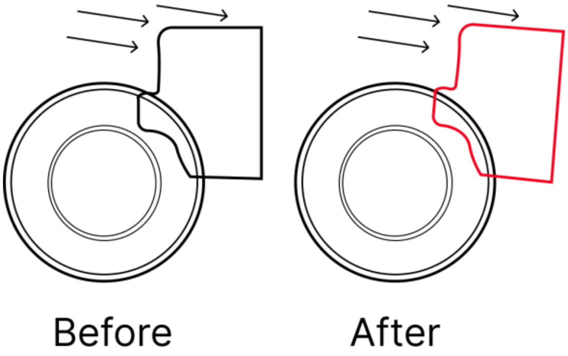

Fig. 4: Observation of wings flexing under load

But teams again researched and found ways of arranging these separators as per their advantage without breaking any rules. There were two possible arrangements of these separators -

- ➔ Two separators on the whole rear wing, one either side of the wing halfway through the profile.
- ➔ Three separators, one in the middle, and other two on either side of the wing.

However, this slot gap had the effect of **stalling** (strong vortex generation due to wings, shedding from edge of the wings and travels back slightly above the wings) the rear wing, since air could not circulate around the wing, thus reducing its efficiency.

- **Flexible wing assembly**

In this arrangement, the whole wing assembly tends to tilt at higher speeds which results in reduced angle of attack and as the car slows down, the wing corrects itself by getting back to its original position. But because of no attachment & re-attachment of flow, this method turns out to be more reliable than the slot gap method we previously discussed. However, the overall effect produced is comparatively less.

This assembly can be designed for both front & rear wings but due to wider & higher rear wings, it is easier to design than the complicated structure of the front wing.

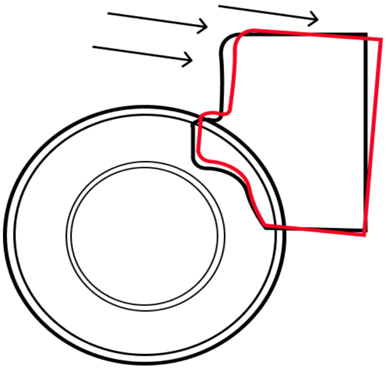

Fig. 5: Flexible wing assembly

6. Advantages of Flexi-Wings

One cannot derive and use all the maximum power generated by the drivetrain to develop high speed on straights and that too in such a small amount of time. Hence, the use of flexible wings can give several advantages when positioned [13] exactly as per the requirements of environment & track conditions. Some of these benefits are-

- Flexible front wings will improve underfloor and diffuser performance since just before the rear tyre, low pressure air gets directed into the underfloor making it flex downwards thus improving downforce and sucking the car down into the track.

- They will dynamically change the angle of attack of the wings, without the aid of any actuators or linkage mechanism i.e., no complex setup will be needed.
- They may also reduce the *porpoising* effect, which can be seen a lot in the 2022 F1 cars.
- They also can act as a replacement for DRS in case FIA discontinues its use in future.
- Flexible front wing will reduce the front wing's angle of attack, dynamically shifting the center of pressure rearwards for high-speed corners, which will help in reducing understeer in the slower corners since wings will tend to move forward as the car slows down.
- They will make it easier for drivers to get the desired results out of their race cars without having to rely on other settings (like ailerons) or making excessive manual adjustments during races—which is important when every second counts during competition.
- The flexi wings are made of carbon fiber and are lighter in weight. So, they will reduce strain on the monocoque and aerodynamics.
- Flexible wings will also help the driver in overtaking after slipstreaming. This is because as soon as the car behind begins to overtake, it moves from the wake of the front car where there was a minimum drag and downforce onto the clear track, so it faces a lot of high-speed incoming air resistance which acts as a parachute for the airfoils attached on the car which dissipates the overtaking speed which was the main advantage of slipstreaming. But when flexi wings are used, they will bend as soon as the driver overtakes and high-speed incoming air will hit them, thus reducing the air resistance (drag) and downforce, thus allowing for better overtaking acceleration for the rear car.
- Bending of the wing will reduce its face's surface area, consequently reducing drag as well as increasing potential V-max (low maximum velocity), thus allowing the car to run with a higher wing setting without getting penalized in a straight line.

7. Shortcomings of Flexi-Wings

Although possessing several advantages, the current technology and development of flexi wings still lacks behind, leaving room for several drawbacks [10] due to which they haven't been able to be put to practice on a large scale.

Some of these drawbacks are-

- The structure and construction of flexible wings would only be successful if engineers manage to create a balance between the rigidity and weight of the wing. Since for any material, torsional strength is directly proportional to its weight.
- The greater the number of plies of carbon fiber, the higher the [15] rigidity and so the weight, and increased weight will counter all the aerodynamic advantage created by the flexi wing.
- Now if the wing is kept too light, it loses its strength and so it can break, crack or tear either because of contact with another car or due to aeroelastic effects. (Like fluttering)
- Fluttering is a harmonic phenomenon (oscillating mass motion) of a wing that causes it to produce very unpredictable downforce. Now while driving, if the driver steers a car with such unpredictable downforce, instances of braking failure may occur during cornering, leading to a crash since the car cannot stop in time.
- Also in extreme conditions, the wing can even tear apart and collide with the car behind, or broken pieces may create debris on the track.

8. 2021 Technical Regulation (Load Test) for F1 by FIA of Flexibility in body

8.1

➔ Body work shouldn't flex or deflect more than 15mm under 1000N of applied vertical load. (Figure 6 shows how the FIA conducts the wing bending)

- Load point will be 700mm vertically, 895mm from the center and1000mm in forward direction.
- Measurement of deflection will be done along the axis of load

Table 1

Max Flex	Load
15mm	1000N

8.2

- Body work shouldn't flex or deflect more than 8mm under 500N of applied vertical load.
- Application of load will be in downward direction with the help of a ram (50mm diameter) and its adapter

Table 2

Max Flex	Load
8mm	500N

8.3

- Body work shouldn't flex or deflect more than a degree on the application of 1000N.

Table 3

Max Flex	Load
1°	1000N

8.4

- Body work shouldn't flex or deflect more than 3mm on the application of 500N load.
- Direction of load will be downward.

Table 4

Max Flex	Load
3mm	500N

8.5

- Body work shouldn't flex or deflect more than 5mm on the application of 4000N load.
- Application of load will be at three different points (Center or 100mm side of it).

Table 5

Max Flex	Load
5mm	4000N

8.6

➔ Topmost airfoil element of the rear wing shouldn't flex or deflect more than 7mm horizontally on the load of 500N.

Table 6

Max Flex	Load
7mm	500N

8.7

➔ Most forward airfoil on rear wing, shouldn't flex or deflect more than 2mm on the application of load 200N

Table 7

Max Flex	Load
2mm	200N

8.8

➔ Trailing edge of the front wing shouldn't flex or deflect more than 4mm on the application of load 60N, in the normal direction of flap.

Table 8

Max Flex	Load
4mm	60N

For new upcoming test [11]

Fig. 6: FIA test for rear wing

Conclusion

The concept of flexi wings is unique & innovative because they provide drivers with optimum steering control at high speeds, without maneuverability at corners. Hence, they are a much better option to implement than other wing modifications. They are light in weight but rigid in construction, giving a weight reduction advantage. In addition, flexi wings can bend downwards and upwards to adjust the air flow direction with more precision and control by rapid speed changes. The use of actuators can also be used in this concept, further improving its capabilities and efficiency. But still, it all comes down to the development of such materials capable of exhibiting such aeroelastic properties.

This is going to change the perspective of use of material science in future. Racing Sports engineering is going to use this concept a lot to unlock the maximum potential of drag reduction to win the races. Thus, the research and development in this sector has a great scope ahead.

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