Cause and Analysis of 2022 Formula 1 'Porpoising'

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Abstract. With the development of industrial technology, sports events have gradually drawn people's attention. In motorsports, which is the experiment of advanced automotive technology, fluid mechanics analysis has been applied to their design and competition. Fluid mechanics cannot only reduce the air resistance on the vehicle surface but also play an essential role in stabilizing the vehicle in racing, especially in the corners. Therefore, the application of fluid mechanics has become more prevalent in recent years with plenty of performant aerodynamic designs. This article describes the 'porpoising', the aerodynamic oscillation phenomenon of the Venturi effect newly designed for the 2022 Formula 1. Moreover, there will be an explanation of the causes and effects of this phenomenon through fluid mechanics. The explanation will be based on analyzing the information from mechanics, team, and FIA. A geometric model and mathematical method will be applied to analyze the Venturi effect. Also, SolidWorks CFD computation for a simple Venturi tunnel model is a persuasive verification for aerodynamic oscillation. In addition, the development of the team and the rules of the FIA will be introduced. This information will be a great help for the FIA to improve the regulations and for the teams to design new vehicles.

Keywords: Fluid mechanics; Aerodynamic oscillation phenomenon; Grand Prix.

1. Introduction

When civilization passed into the 21st century, the automobile industry and economy started a rapid development stage. The automobile companies have a huge budget to develop their Formula 1 team, which shows the highest automobile design and industry level. Each team spends a lot to develop their race cars' performance before 2021. That made FIA, the association to regulate Formula 1, design the whole brand-new race car in 2022. This new type of Formula 1 car utilized the Venturi Tunnel system under the chassis to improve the downforce [1]. The Venturi Tunnel design of a racing car can significantly improve the vehicle's aerodynamic performance [2].

However, during the winter test and the first Grand Prix, FIA and each team noticed that the Venturi Tunnel system would cause the car to have weird oscillation on the high-speed straight lane on the track. People call this phenomenon 'porpoising'. This word is made by Formula 1 engineers and fans, which means the aerodynamic oscillation happened at high-speed zones. Aerodynamic oscillation is a negative behavior for the car that affects the speed, grip, and even the driver's health. The FIA and teams dedicate to research eliminating this negative effect of the Venturi Tunnel. So, with SolidWorks modeling and description, this article will focus on characterizing the aerodynamic oscillation, or 'porpoising'. In addition, there will be some tips at the end of the article [3].

2. Description and effect

2.1. Description of 'Porpoising'

'Porpoising' is a new word for the 2022 Formula 1 aerodynamic oscillation when driving at high speed. The 2022 Formula 1 car introduces the new floor regulations, marking ground-effect cars' return. The front of the floor includes fences that protrude forward to adjust the angle of the air to pull them under the car. The floor has a curvature to produce a low-pressure venturi zone [4].

However, the ground effect will push the car extremely close to the ground when the car gets into a high-speed zone. The high downforce will push the lowest point of the Venturi Tunnel to become almost vacuum [5]. Then the ground effect will disappear shortly. However, the suspension will take the car back to its original height, which will cause the Venturi Tunnel to reopen. It can generate downforce again [6]. These steps now become a loop, and the car will bounce up and down in a short period. This phenomenon looks like a dolphin bouncing out of the water and getting the buzzword: ‘porpoising’.

2.2. Effect of ‘porpoising’

2.2.1. Effect to the performance of the car.

Aerodynamic oscillation ‘porpoising’ will cause high-speed trouble for the race car. It can directly lead to grip performance loss in high-speed situations. Also, it may lead to reliability issues for the car. Firstly, as mentioned before, the ‘porpoising’ is caused by the Venturi Tunnel block by smaller tunnel size. The downforce will suddenly lose in this situation. So, in this case, if the car turns at high-speed corners, it will lose downforce and grip. Then the driver will be hard to get enough speed in these corners and waste time in the race. If this situation is horrible, the car may crash or spin with a loss of downforce and grip. The ‘porpoising’ will also lead to similar trouble for the car in a straight line. The car will lose downforce at the end of a straight line and will be easily overtaken by opponents or crash the car. The impact on the driver and the car is negative [7].

Furthermore, of course, the extreme amount of oscillation will cause damage to the vehicle. The most direct damage happens on the suspension systems. The suspension will endure much impact when the car bumps at a high-speed region. If the suspension is not designed correctly or has some quality issues, some parts will be damaged, like struts [8]. It will cause the car to crash and cannot finish the race. Also, the impact may sometimes cause some parts to be damaged or lost inside. Engine parts or DRS systems may be affected by the bouncing vehicle.

2.2.2. Effect to the driver.

The ‘porpoising’ not only affects the race car's speed but also harms drivers’ health. The driver can lose the Grand Prix, but their health will suffer a fatal threat. FIA has received a medical review about ‘porpoising’ recently. It shows that this kind of oscillation risks brain damage for the drivers [9].

Thirty-seven-year-old Formula 1 driver, Lewis Hamilton, is now at years of competition well. Nevertheless, he suffered a headache during the race. When accepting the interview, he mentioned he was shorter during the racing weeks, and his discs were not at their best. Lewis also pointed out that this negative competition state is unsuitable for season-long racing. The Grand Prix is not necessary to give racers long-term injuries. The bruising in the racers’ bodies after the race weekends will require them to take more than a week to recover their body. It’s not acceptable for their age, and the bruising will be highly severe to them.

Also, the Figure 1 came from a scene in the Grand Prix, it’s clear that Lewis Hamilton is suffering from the ‘porpoising’ during the race. He felt very uncomfortable because of the headache and spine pain. Lewis was even hard to get off the vehicle. It’s not friendly to drivers, especially those of higher age [10].

Fig 1. Lewis Hamilton was hard to get out of the vehicle
with spine pain. He was serious suffered from the ‘poising’ [11].

3. Cause of 'Porpoising'

3.1. Brief Introduction about Venturi Effect Formula 1 Chassis

3.1.1. Diagram for Venturi Effect Formula 1 Chassis.

Figure 2 is a 2022 FIA's Formula 1 model car diagram. It is very significant with the benefit of the blue mark, which is the Venturi Tunnel under the chassis. Moreover, the fluid will flow through the white arrow direction. The air tunnel will get limited in the mid of the car. It will get faster speed and less compression under this section.

Fig 2. 2022 FIA Formula 1 model car [12].

3.1.2. Word description.

The Venturi effect reduces fluid pressure when the fluid flows through a choked pipe. This effect was named after its discoverer, Italian physicist Giovanni Battista Venturi, at the 18th century. It has applications in many fields of engineering. This year, the Formula 1 race car uses the Venturi effect for increased downforce and grip. A simple model of the Venturi Tunnel will be designed to analyze the effect which is Figure 3 [3].

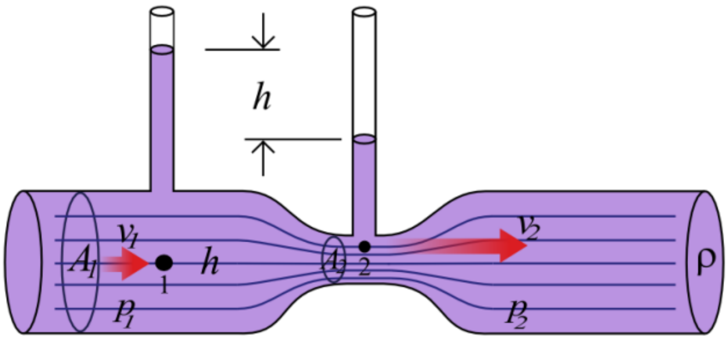

Fig 3. Simplified Venturi Tunnel Model [13].

In the model, it is very significant that the pipe's inlet and outlet are larger than the middle part. Assume that the flow inside the pipe is non-uniform and steady; we assign (A_1) for the inlet area. Furthermore, the choked section's area will be assigned as (A_2). (ρ) Will be the air density in the tunnel, which is assumed to be unchanged. (V_1) is the air speed at the inlet, and (V_2) is the middle section's airspeed. The formula for Q_1 and Q_2 will be written as following:

$$Q_1 = A_1 \times V_1 \tag{1}$$

$$Q_2 = A_2 \times V_2 \tag{2}$$

Since the fluid flow is steady inside the pipe, the Q_1 should equals Q_2

$$Q_2 = Q_1 \tag{3}$$

The equation will be compiled together as:

$$A_1 \times V_1 = A_2 \times V_2 \tag{4}$$

As description, the A_2 should be less than A_1.

$$A_2 > A_1 \tag{5}$$

So, in this case, V_2 should be larger than V_1.

$$V_2 < V_1 \tag{6}$$

Now we can apply Bernoulli's equation, which is presented as following:

$$P_1 + ½\, \rho\, V_1\text{^}2 + \rho\, g\, V_1 = P_2 + ½\, \rho\, V_2\text{^}2 + \rho\, g\, V_2 \tag{7}$$

If the air's density (ρ) is constant under the car, the P_1 should be larger than P_2.

$$P_1 > P_2 \tag{8}$$

This relationship can also be observed in Figure 3 that the liquid level in the inlet's tube is higher than in the outlet's tube.

Basically, the Formula 1 is applying upper half of this model, but the theory is same here. Now we assume the pressure of air on the car is similar from front to rear, the middle section of the car with choke part will have difference of the air pressure. The car will achieve negative lift, or we call it downforce under this situation.

So, this is the description of the Venturi effect of 2022 Formula 1 car. This is the theory about how the car gain downforce. But this theory is also the cause of bouncing car.

3.2. Comprehensive description of the reason for 'porpoising'

As the explanation came from FIA's official report, the 'porpoising' is a phenomenon of aerodynamic oscillations. As mentioned before, this phenomenon happened because of the Venturi effect of the car's design. The aerodynamic oscillations can date back to the 1970s. At that time, the Venturi effect chassis firstly appeared in several teams' cars. At that time, the Venturi effect car was advanced and faster than other racing cars. The 'porpoising' also happened during that era.

Firstly, as the Venturi effect's theory said, the race car's downforce is caused by low air pressure through the narrow section of the tunnel. When the car runs, the airflow is through the front wheel and then the chassis. The beginning and end of the tunnel are vast, and the fluid flows narrower than them. However, the narrower section at the bottom of the car has a faster flow rate. It means that the pressure is higher at the beginning and the end. Moreover, the pressure is lower in the middle section.

However, the flow rate will increase when the car is at a high-speed section of the track, such as a straight line or high-speed corners. The downforce will achieve the maximum point and cause the car to drop close to the ground. This dropping can shut off the narrower section of the Venturi tunnel. Then the car will suddenly lose downforce without the support of the Venturi effect.

In this case, the car will go back to its original height because of the suspension system's rebounding. The Venturi tunnel will reopen, and the air will flow through the tunnel without blocking. The new Venturi effect builds and makes the car drop again. These four sequences will build a circle and operate in less than a second. During the race, the car will pass through the high-speed zones in several seconds. Therefore, the car will oscillate in the circle several times. It makes the car looks like bouncing.

So, this is a deep description of the 'porpoising' phenomenon of 2022 Formula 1. This aerodynamic oscillation phenomenon is simple and easy to understand. However, it is still a puzzle for Formula 1 teams, including the last year's champion, Mercedes.

3.3. SolidWorks model and CFD analysis

3.3.1. SolidWorks model.

Figure 4 is a produced SolidWorks model, a simplified Venturi Tunnel model with a wide inlet and outlet with a narrow middle section. The design production is: Sketch the shape on the front side; apply the 'extrude' function in SolidWorks; the 'shell' function support to get the tunnel model. Then the CFD analysis will be applied to this model to excavate the pressure difference.

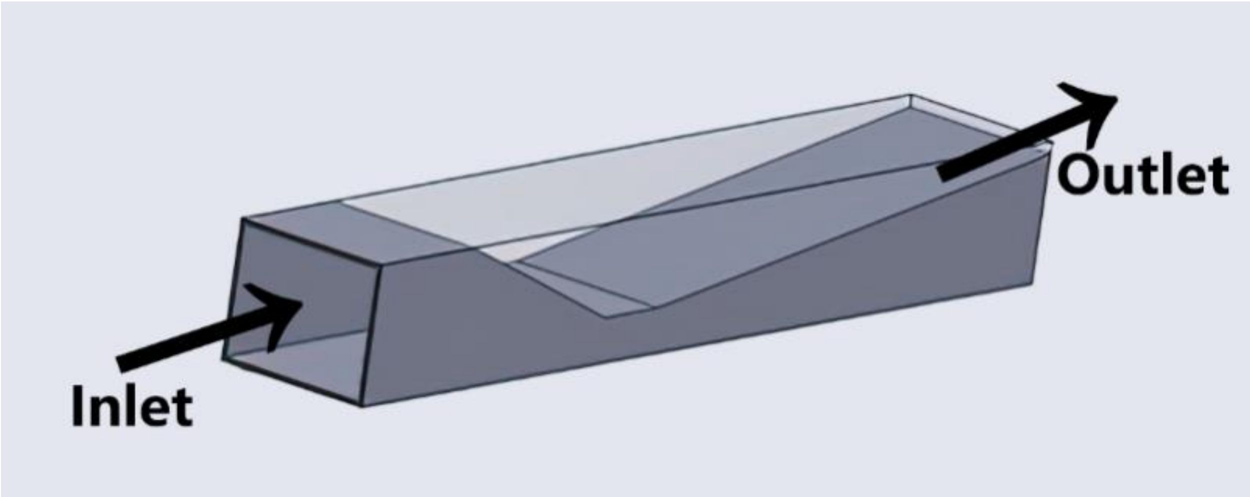

Fig 4. SolidWorks model of venturi tunnel.

3.3.2. CFD analysis by SolidWorks.

After setting the airflow parameters in the CFD's Wizard, start the analysis on SolidWorks can by setting the boundary conditions. The front end of the tunnel will be set as the airspeed. The following steps will be setting the mesh and running the computation. After the CFD's computation and analysis have been completed, the surface plot can present the scale pattern of the pressure and the data.

Figure 5 shows the car's pressure plot at 180km/h, scaled into 50m/s on SolidWorks. This speed is a car at corners or middle-speed areas. The pressure difference is not huge enough to cause the oscillation.

Figure 6 shows the car's pressure plot at 288 km/h, scaled into 80 m/s on SolidWorks. This speed is a car at fast corners or straight lines. The pressure difference is vast, which may cause oscillation in the vehicle.

Figure 7 shows the car's pressure plot at 320 km/h, scaled into 89 m/s on SolidWorks. A car is at a fast speed on straight lines, such as Monza's straight line. The aerodynamic oscillation will be more severe because of the increasing enormous pressure difference.

Note: The Surface Parameters in the Figures are very small. The data will be listed in the data analysis part.

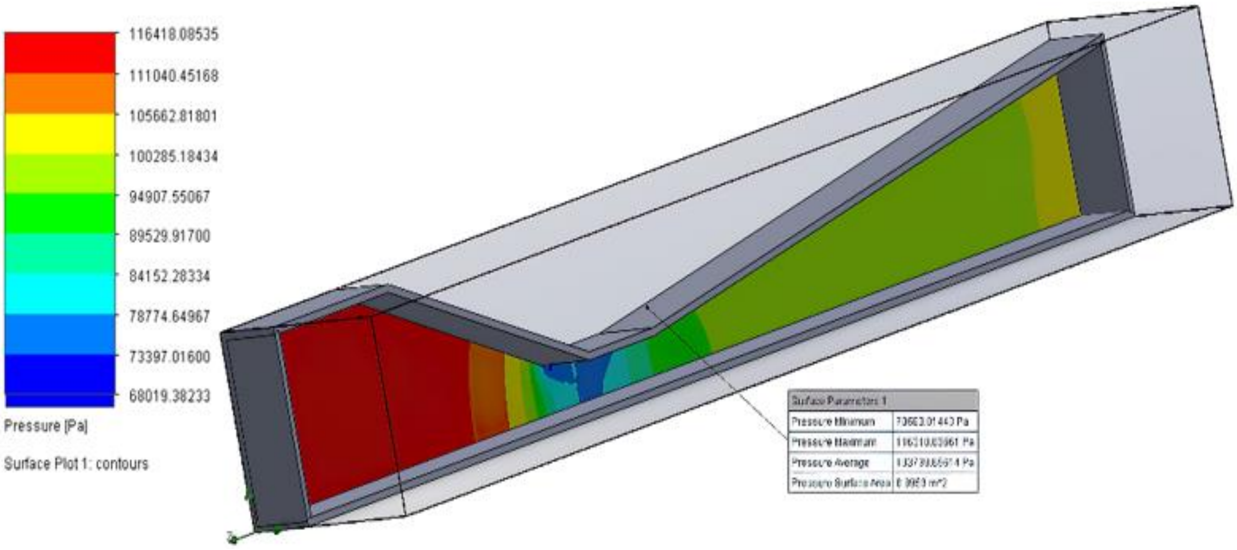

Fig 5. Pressure surface plot at 180 km/h.

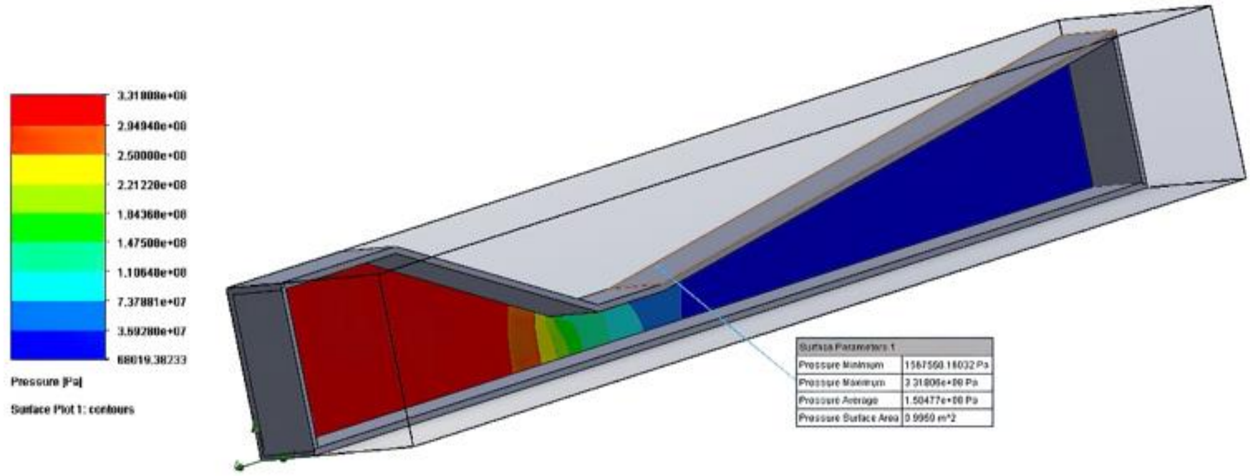

Fig 6. Pressure Surface Plot at 288 km/h.

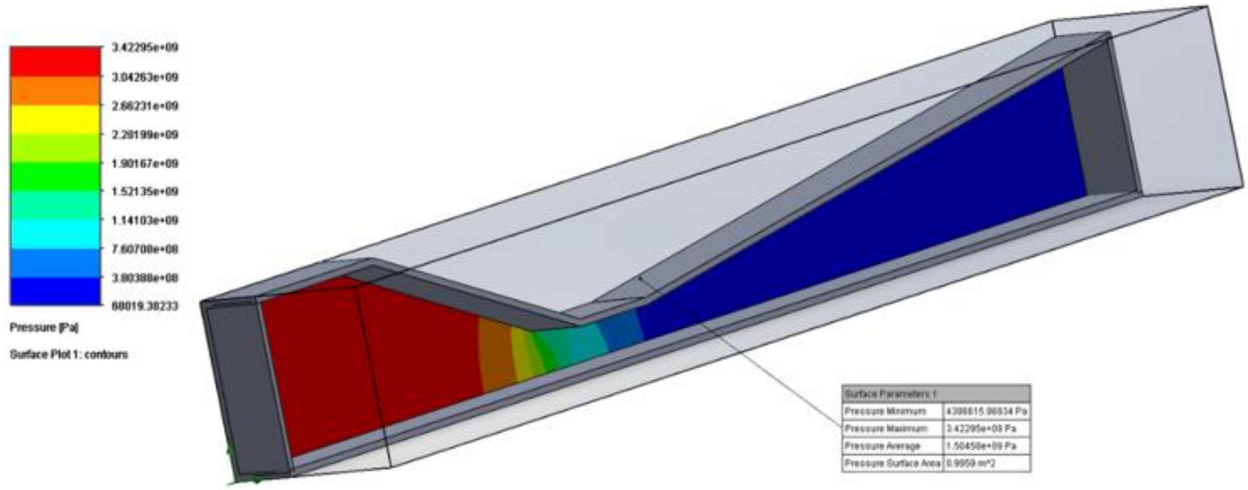

Fig 7. Pressure surface plot at 320 km/h.

3.3.3. Data analysis.

The data collected from the SolidWorks CFD will be recorded here. Under the Surface Plot, there is also a function can show the data in table on the SolidWorks' CFD. The following tables are the data achieved from the CFD analysis to support the Venturi Effect.

Table 1. Data at 180 km/h.

Local parameter	Minimum	Maximum	Average	Surface area (m^2)
Pressure (Pa)	70597.43	116334.30	103747.58	0.9959

Table 2. Data at 280 km/h.

Local parameter	Minimum	Maximum	Average	Surface area (m^2)
Pressure (Pa)	1565533.93	3.32079e8	1.50602e8	0.9959

Table 3. Data at 320 km/h.

Local parameter	Minimum	Maximum	Average	Surface area (m^2)
Pressure (Pa)	4384994.95	3.42343e9	1.50478e9	0.9959

3.4. Results

After the analysis by the CFD model, the theory of 'porpoising', or we can say aerodynamic oscillation scientifically, is now apparent. The reason for the 2022 Formula 1 aerodynamic oscillation phenomenon is the new design with ground effect. This advanced design can produce good downforce but cause this problem. This phenomenon is dangerous for the car and driver. Also, it is a disadvantage for the team to win the Grand Prix. So, the FIA and teams are still focused on figuring out this problem to build a faster but stable race car. Then it will be the next part of this article about some strategies to weaken the ‘porpoising’.

4. Regulation and Upgrade

4.1. FIA Regulation

For this severe problem in the grid, the FIA mentioned in their interview to improve the supervision of the aerodynamic oscillation amount. The FIA utilizes remote sensing technology to measure the amount of oscillation by a car sensor and record the data. Technicians will apply a complicated equation to calculate the level of oscillation (Figure 8). This formula is now called Aerodynamic Oscillation Metric (AOM). It is a representation of the energy associated with vertical acceleration [4].

The FIA will calculate each car's oscillation level during the race week with the help of AOM theory. Then they will force the team with high oscillation levels to increase the chassis height to avoid oscillation. This regulation technique will push the team to increase their speed for vehicle development or search for solutions for adjustment with low oscillation.

They are now still analyzing this aerodynamic oscillation regulation rule and calculation system. This regulation will be approved and written into the rule book next year if everything is good. Nevertheless, it will effectively avoid the excess oscillation to hurt drivers.

4.2. Team Development

Every team will not accept their cars increasing the chassis height to reduce aerodynamic oscillation. So, in this case, they will try to do more development. Some teams like Red Bull already have some ideas to solve this problem.

In Adrian Newey’s RB18, the Venturi Tunnel has a different design than other teams. Adrian made the tunnel’s narrowest part larger. In other words, the top of the tunnel will be higher. It can make the car still get some fluid flow under the car when the largest downforce lowers the car. Also, Adrian fully applied all the fluid into the tunnel in different directions. He made the bottom of the chassis has a similar shape to the deflector at the side of the car. This design can help the flow be uniform under the car to make it smooth when driving at high speed with enormous downforce. Also, FIA allows Adrian to put the small deflector near the rear tire under the car. It can also help compose the flow before the tunnel's exit. This design was the application of Red Bull’s approach. Adrian and Red Bull keep gathering back-to-back data on vehicle upgrading before applying the new technique to both cars [5]. This design is present in Figure 8.

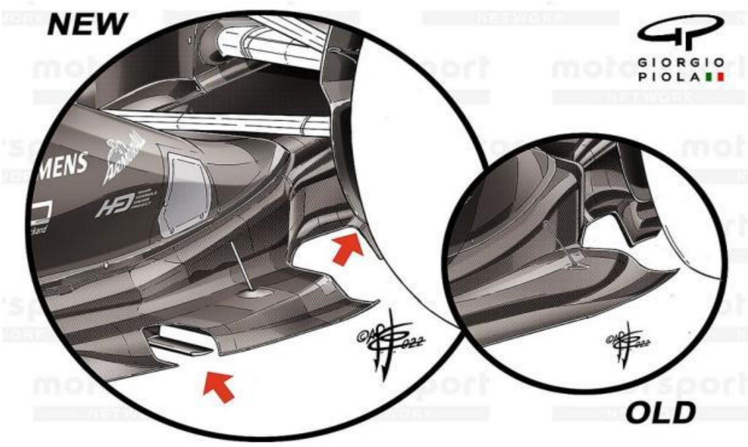

Fig 8. Red Bull RB18’s aerodynamic upgrade [14].

Right now, only Red Bull has good results in resolving the 'porpoising'. However, the other teams, such as Ferrari, are still trying to have more development. They are designing new chassis.

4.3. New Technology Applications

Around the 1990s, active suspension systems were widely used in Formula 1 teams, which is in Figure 10. As the example in the figure, this is the Front to Rear Interlinked Suspension (FRIC) of team Minardi. The basic theory behind FRIC suspension is keeping all the wheels of the car at a constant ride height under braking, acceleration and turning [6]. This technology was beneficial in controlling the car's height during the race. However, the active suspension system was forbidden by FIA due to the budget and fairness.

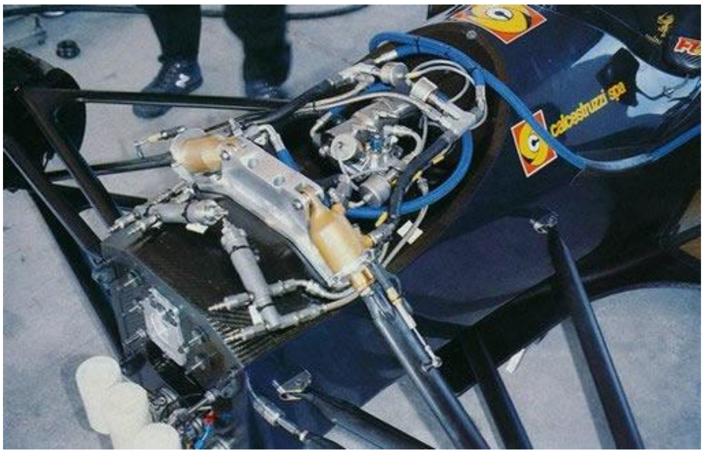

Fig 9. The Minardi FRIC system (Active Suspension) introduced on Minardi M193 in 1993 [15].

5. Conclusion

This article presented the analysis of 2022 Formula 1 'porpoising' (Aerodynamic Oscillation) and future development. The information in this article will help the aerodynamic design of motorsport. Now it is the half-season of the Grand Prix. The FIA is analyzing the AOM system to regulate the 'porpoising'. All the teams are still struggling to develop a brand-new chassis and aerodynamic system to prevent aerodynamic oscillations in their cars. The analysis of 'porpoising' will not only help the teams and FIA to improve the vehicles next year but also affect the whole automotive industry worldwide. Motorsports are the experiment of the advantage technology for the human's primary industry, automobile. Plenty of the development in Formula 1, like fluid mechanics, will be applied to the automotive industry in the future to ameliorate human life.

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