The Analysis of Traditional Aerodynamic Optimization for Race Car and Future Model

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***Abstract*—Traditional aerodynamic optimization changes the aerodynamic forces on the race car by adding aerodynamic kits and modifying the body shape. It can improve the propulsion, reduce drag force, and enhance handling and control, which have a significant impact on the performance of race cars. With the increasingly fierce competition, the demand for the performance of race cars has increased yearly. However, traditional aerodynamic optimization can't meet the higher requirements. After analyzing the shortcomings of conventional aerodynamic optimization, the author developed a new model "flying race car" combining the landing race car and aircraft. It has the extendable wings mounted at the side and the ducted fan installed on the bottom providing vertical lifting force and horizontal driving force. Therefore, the flying race car can rise into the air like a helicopter and fly forward rapidly like a jet fighter. Meanwhile, the fan enhances the handling and control by changing the direction. In addition, the adjustable air duct is designed to weaken the drag mainly caused by flow separation. The twin jet engines result in higher speed. In conclusion, the aerodynamic efficiency of the flying race car will be improved dramatically based on the new aerodynamic devices.**

***Keywords*—aerodynamic optimization, aerodynamic kits, race car, racing performance**

I. Introduction

The aerodynamics of race cars mainly studies the interaction between the race car and the surrounding air during high-speed movement. It affects the performance of the race car by changing the aerodynamic force on the race car. Therefore, the optimization of aerodynamics for race cars becomes an essential aspect of modern motorsport. Because it can increase a vehicle's speed, reduce air resistance, and enhance handling and control, which determines the success of racing competition. Gradually the research of race car aerodynamics and the exploration of aerodynamic optimization strategies have become the focus of race car engineers and researchers.

Traditional aerodynamic optimization mainly focuses on changing the aerodynamic forces on the race car by adding the aerodynamic kits within the existing model. Propulsion is produced by the engine which is affected by the inlet airflow. The air filter and intake restrictor installed in the air inlet promote the quality of inlet airflow to increase propulsion. The drag mainly results from the flow separation when the race car is at high speed. The spoiler, fins, and diffuser can weaken the flow separation to scale down the drag. Handling and control can be reinforced by increasing the downforce with the help of the rear wing. Traditional aerodynamic optimization benefits the race car to some extent.

However, there are also shortcomings of traditional aerodynamic optimization. The extra aerodynamic kits add weight, which increases the consumption of fuel to maintain the high speed. What's more, increasing energy consumption leads to high environment-damaging emissions. The most important is that these kits can't make the performance of the race car a leap forward. The speed of race cars doesn't make a breakthrough by the traditional methods.

Aiming at the bottleneck problem of race car performance, the author proposes to integrate race cars and flying aircraft, which creates a new model "flying race car" that transcends the technology boundary. The wing-body fusion layout of the flying race car integrates the traditional fuselage and wing structures. With integrated design and manufacturing, it increases the lift and reduces the structural weight and drag, which improves the fuel efficiency and significantly the flight performance of the flying race car. Compared with the traditional wing, the truss-supported wing layout is conducive to weight reduction because the truss bears part of the load and reduces the bending moment of the wing root. The wing area can be increased under the same weight, which is conducive to the reduction of drag and the improvement of the lift-to-drag ratio. Distributed electric propulsion layout dispenses and installs multiple culvert fans on the wing or fuselage, which can improve aerodynamic efficiency and reduce drag. Among them, the boundary layer suction technology installs an embedded fan at the tail of the flying race car to reduce drag and improve aerodynamic performance by accelerating the suction of the fuselage boundary layer. Flying a race car combining the advantages of a race car and flying aircraft has many technical advantages that cannot be reached by the current race car. It has a wider market and application prospects in the future racing competition.

This dissertation contains five parts in the body paragraph. In the second chapter, the current research and related analysis are shown. The illustrations and the benefits of traditional aerodynamic optimization of race cars are shown in detail. After that, the disadvantages of these traditional methods are discussed. A new model "flying race car" combining the race car and aircraft is proposed accordingly in the discussion section. Following the conclusions and, Lastly, the evaluation writes about self-comment on the performance during the writing session, the regrets, and expectations of further studies.

II. Overall Features of Race Car Aerodynamics

A. Aerodynamics of Race Car This Section Basically

The aerodynamics affect the performance of race cars by primarily influencing drag and negative lift (known as downforce), as shown in Fig. 1. Drag is opposite to the direction of the airflow, blocking the race car from moving through the air and dragging the car in the opposite direction.

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Reducing drag can result in more efficient energy consumption and more competitive speed. When air flows around the race car, it produces vertical lifting force on the race car due to the pressure gap between the top and bottom. With the extra kits, the lifting force faces down. The lift force is perpendicular to the incoming flow direction. The lift is vital to the race car's handling and control. The performance of GT race cars can be improved by aerodynamic optimization which influences the forces.

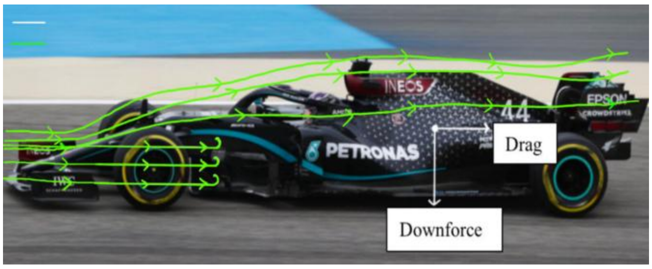


Fig. 1. Forces and airflow on a race car.

Based on the previous research, the most useful methods for studying the aerodynamic optimization of race cars are tunnel experiments and CFD simulation. These two methods have played a vital role in the design and optimization of new race cars. However, I don't have access to these methods since they are unaffordable and difficult to apply for the author at the moment. Therefore, the aerodynamic optimization of race cars and the corresponding opinions are raised by reading abundant literature papers and analyzing the traditional methods of improving the aerodynamic performance of race cars.

B. *The Aerodynamic Optimization of Propulsion by Optimizing Air Filter and Intake restrictor*

The air filter promotes the thrust of powertrain performance by improving the quality of intake airflow [1]. A racing powertrain is a key component of race car performance, and its performance plays a crucial role in the competition. At present, one of the key technical difficulties affecting the engine powertrain is the poor air quality in the intake system. A useful way to solve this problem is to install an air filter. The air filter is installed at the critical inlet of the air intake system. This filter improves engine performance by optimizing the aerodynamics of the intake system. The air filter effectively gets rid of pollutants and impurities from the air, which helps improve engine life and performance by filtering contaminants from the air and maintaining a clean environment inside the engine. Another important role of the air filter is to improve combustion efficiency [2]. Good air quality can provide more oxygen, allowing fuel to burn more fully, thereby improving combustion efficiency. Efficient combustion can improve the engine's power output, reduce fuel consumption, and reduce exhaust emissions. The aerodynamic optimization in the inlet system by the air filter contributes to the higher speed of the race car.

Another common method of improving powertrain performance is to optimize the intake restrictor in the intake system to increase the mass flow of intake air. The common model of the intake restrictor in the engine of the race is as shown in Fig. 2. The diameter of the intake restrictor inlet d1 is 35mm, throat diameter d0 is 20mm outlet, and outlet diameter is 42mm. It can be known through engineering thermodynamics that there is no loss at the nozzle only when the backpressure of a reducing pipe equals the outlet pressure, while in the case of a convergent-divergent tube, the flow shall keep unchanged when critical flow is reached inside the tube; moreover, since the inlet diameter d2 (42 mm) of the compressor is larger than the throat diameter d0 (20 mm) of the restrictor, therefore, a convergent-divergent tube is generally used for a restrictor. Meanwhile, according to the relationship between the converging half angle and the outlet flow discussed in Ref. [2], particularly according to Ref. [3], when the converging half angle α is less than 45°, the nozzle flow increases as the converging half angle decreases; when the converging half angle α is larger than 45°, the nozzle flow almost keeps unchanged. According to Refs. [1] and [4], if the divergent section of the nozzle is too long, the irreversible loss of friction will be too large; while if the divergent section of the nozzle is too short, the section expansion will be too large, which will separate the airflow and the tube wall, thus generating eddy loss, which is adverse to energy conversion. From the simulation by Chen (2014) [5], the internal flow field characteristics of the tapering and expanding ends of the intake throttle of an internal combustion engine intake system by CFD without violating the competition rules. It is found that when the tapering angle of the throttle is less than 45°, the outlet flow rate decreases with the increase of the angle. It shows that the pressure difference between the inlet and outlet ends of the throttle gradually increases with the difference in the tapering angle, which affects the intake efficiency of the engine.

Fig. 2. Car air filter.

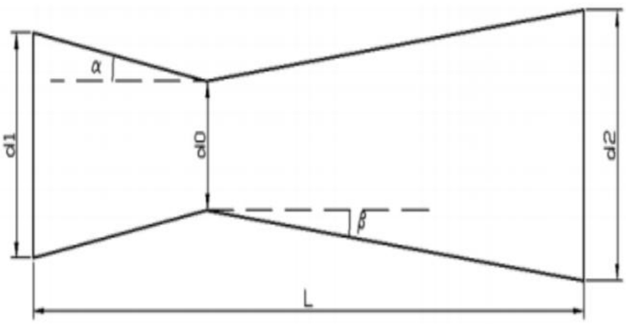


Fig. 3. Intake restrictor angle configuration.

C. *The Aerodynamic Optimization of Drag Force by Spoiler, Fins, and Diffuser*

The aerodynamic drag is induced by the air flowing over and around the vehicle. The optimization for low drag becomes an essential part of the design process which contributes to the fuel economy and enhances the efficiency of the vehicle [6]. Drag force predominantly depends upon the velocity, frontal area, and coefficient of drag of the body. It can be expressed as:

$$F_D = 0.5 C_D \rho A V^2$$

From the drag equation, it can be seen that the drag force is in proportion to the square of the speed. This implies that the resistance due to air increases exponentially as the speed of the body increases. Flow separation control is also a major interest in fundamental fluid dynamics and various engineering applications. Flow Separation location determines the size of the wake area and the amount of aerodynamic drag is determined accordingly. When the air moving over the vehicle is separated at the rear end, it leaves a large low-pressure turbulent region behind the vehicle known as the wake. This wake contributes to the formation of pressure drag [7], as shown in Fig. 4. Numerous techniques have been explored to control flow separation either by preventing it or by reducing its effects [2].

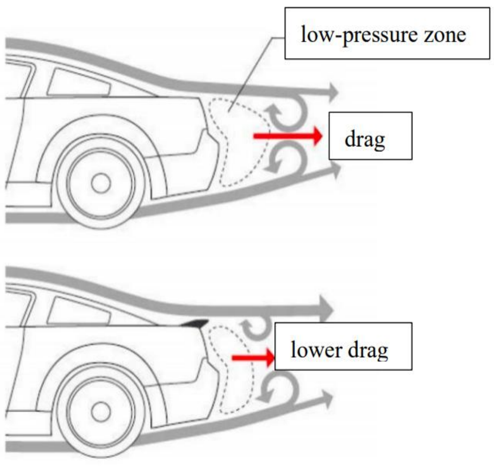
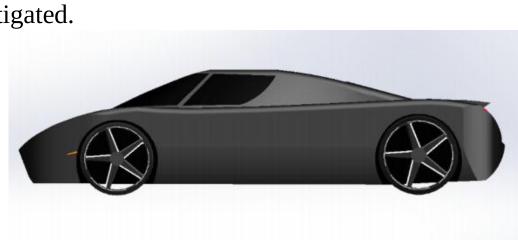
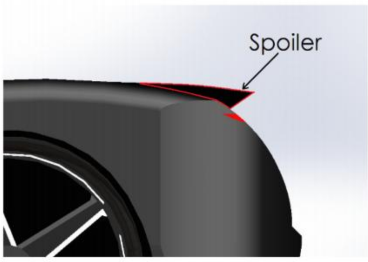


Fig. 4. Low-pressure zone and drag.

To achieve the optimized drag for the vehicle, research is being carried out on these certain add-on aerodynamic devices to reduce the resistance offered by wind and improve the efficiency of the vehicle [8]. In this research, the effects of various aerodynamic devices like spoiler, fins, and diffuser are examined and the change in the coefficient of drag is investigated.



(a) Side view

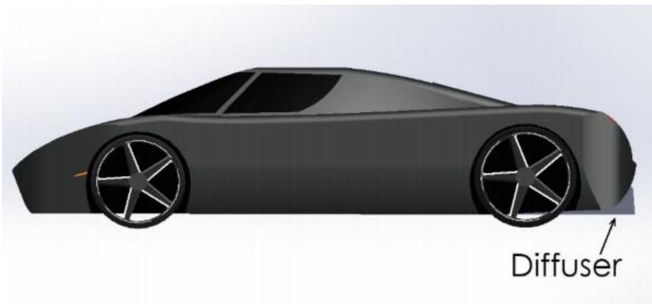


(b) Spoiler

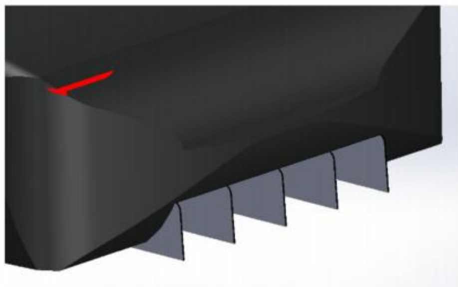
Fig. 5. Spoiler of a race car.

Spoiler is one of the most widely used and important aerodynamic devices in the automotive domain, as shown in Fig. 5. Its main purpose is to “spoil” the unwanted airflow and channel the airflow in order, which helps in reducing the drag. Thus, most high-performance vehicles adapt it to achieve higher speeds. The low-pressure zone behind the vehicle is reduced, thus less turbulence is created, which subsequently leads to drag reduction.

The diffuser is one of the prominent aerodynamic devices found in Eq. (1) cars, as shown in Fig. 6. The wide versatility offered by diffusers has found its way down to high-speed production vehicles. Diffusers are capable of reducing drag and increasing downforce for driving cars [9]. The role of the diffuser is to expand the flow from underneath the car to the rear, and this in turn produces a pressure potential, which will accelerate the flow underneath the car, resulting in reduced pressure [10]. The principle behind the working of diffusers is based upon Bernoulli’s principle which states that “a slow-moving fluid will exert greater pressure than the fast-moving fluid”. Thus, the role of the diffusers is to accelerate the flow of air beneath the car so that less pressure is exerted in comparison to the outer body flow. This serves to eject the air from below the car. The diffuser then lightens this high-speed air down to normal speed and helps fill the area behind the car, making the entire bottom a more robust downforce and importantly reducing the drag on the vehicle.



(a) Side view



(b) Diffuser

Fig. 6. diffuser of a race car.

For the first time in the automotive industry, the application of fins at the rear part of the vehicle’s body is witnessed by Swedish hyper-car manufacturer Koenigsegg Automotive AB. Their flagship model “Jesko Absolut” which has the least coefficient of drag in their lineup has fins instead of the wing as shown in Fig. 7. Fins are inspired by fighter jets to provide high-speed stability and to reduce aerodynamic drag.

Fig. 7. Fin of a race car.

D. The Aerodynamic Optimization of Handling and Control by the Rear Wing

While racing speed is important, its handling and control can be effective in avoiding accidents and favoring turns. By adding a lifting surface to the car body and the ground effect of the car body, the downforce can contribute to the handling and control of the race car. A rear wing [11], Zhang & Zerihan (2000) designed to improve motoring performance and enhance stability during cornering needs to generate a large downforce at a relatively low speed, as shown in Fig. 8. The wing is an essential aerodynamic device often used by race car. A rear wing may look like a spoiler but is different in its functioning. It is shaped like a wing of an airplane turned upside down [12]. Its main objective is to provide sufficient downforce or negative lift so that the vehicle has increased traction and the vehicle doesn't lift off at higher speeds. The paper [13], Ni *et al.* (2012) implies that the effect of crosswind is gradually reduced with the increase of the attack angle. So it is necessary to install a rear wing with a large attack angle to improve the crosswind stability of a race car, which also allows it to corner faster and improves stability at high speeds [14]. However, using a wing may add up the drag on the vehicle's body. Thus, for any amount of lift gained, drag also increases. It is generally regarded as a tradeoff between drag and lift.

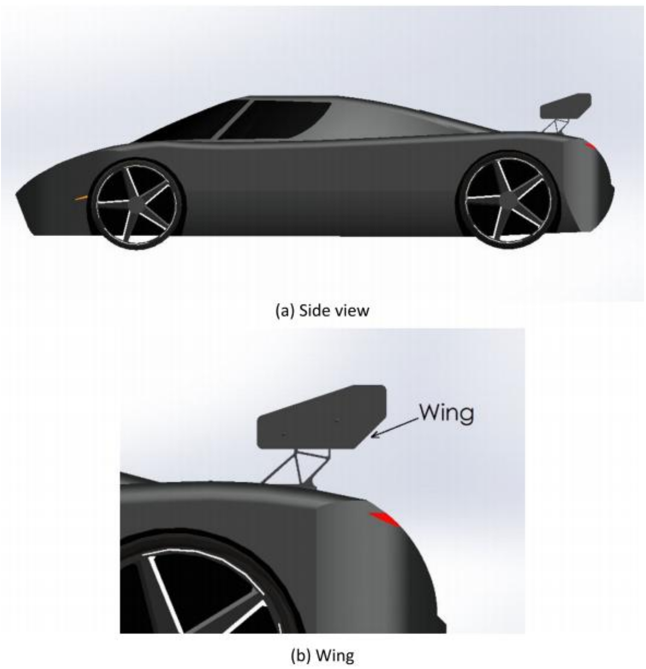


Fig. 8. Wing of a race car.

III. Common Issues Shared by Aedoynamics of Race Cars and Possible Innovations

A. The Disadvantages of Traditional Methods of Aerodynamic Optimization

Despite all the positive effects mentioned in the previous section, there remain multiple flaws in the optimization of the race car's aerodynamic design. This section discusses the disadvantages of the above aerodynamic optimization for race cars.

1) The shortcomings of air filters and intake restrictors

Although air filters and intake restrictors increase the engine's operating efficiency and result in increased vehicle power [1], the modifications are not perfect. The air filter reduces intake inertia, leading to low-speed weakness. As a consequence, the fuel consumption increases to keep the high speed. At the same time, the modified air filter will accumulate dust and eventually lead to insufficient air intake. The engine with the improved air filter [2] may not be able to hold the high intake, which will affect the poor power or low torque. Intake restrictors contribute to problems such as unstable idling, rattling, trembling, and vibration. These problems will accelerate the wear and tear of the engine, which will in turn affect the performance of the race car.

2) The flaws of the spoiler, fins, and diffuser

Although the spoiler, fins, and diffuser fitted on the race car will cause a reduction of air resistance [6], these components add extra weight to the race car which increases the friction between the race car and the ground. The work of the powertrain shall be increased to keep the high speed, which requires higher energy consumption. It is really difficult to find the balance between these features. Meanwhile, these components consist of high-performance materials that require high craftsmanship and an increased budget.

3) The downsizes of the rear wing.

The traditional method is installing a rear wing to improve handling and control by increasing negative lift [13]. However, it also increases friction between the race car and the ground, which contributes to the drag. In addition to that, the increasing friction accelerates the wear of the tires. What's more, it adds energy consumption to maintain high speed.

B. My Future Model Design of a Race Car

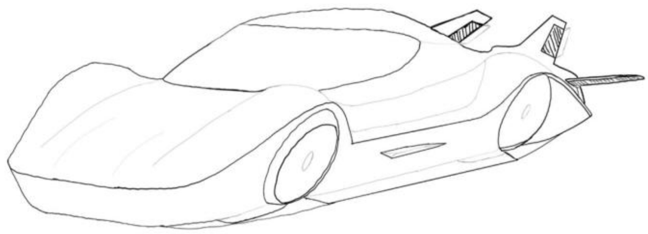


Fig. 9. Model of flying race car.

Regarding the disadvantages of traditional aerodynamic optimization summarized above, the author has come up with a newly designed model of a race car that might bring a revolution to the race car industry, as shown in Fig. 9. The new model combines the advantages of modern race car and aircraft, then creates a flying race car which features better performance. First, the flying race car can reach a higher speed compared with the modern race car due to a new propulsion system and less aerodynamic drag in the air. Then it consumes less fuel and releases less air pollution, which makes a great contribution to the environment. Second, thanks to the advanced aerodynamic configuration, the flying race car performs better in handling and control systems, which results in fewer accidents in the race. Last but not least, it has no demands for the quality of the race track. On account of the absence of a demand for the track, the race can be hosted anywhere.

Due to the revolutionary impact of cutting-edge innovations on the modern transportation system, the flying race car is practical. At the moment, the simple model of a flying car is already available. For instance, the "Transition", a fordable wing flying car made by the Americans, and the "PAL-V" from the Netherlands, even China made a flying car in 2012. Another flying car made in Slovakia, equipped with a collapsible wing and a Rotax 912 engine, giving it access to normal parking spaces in the city while being able to reach a top speed of 200 kilometers per hour in the air and 160 kilometers per hour on the ground. The flying car models mentioned above were considered to be human's first attempts in the field. Therefore, there is no doubt that flying a race car in the sky will no longer be a dream.

However, the overall design of the above flying car does not integrate the two main elements of the aircraft and the car very well. Regarding this, the author proposed a new model that owns both the advantages of modern race cars and aircraft. The details are shown below.

1) Ducted fan

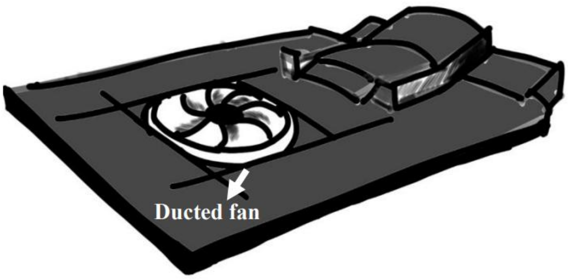


Fig. 10. The configuration of the ducted fan on the chassis.

The new propulsion system consists of a ducted fan protruding at the rear of the aircraft, as shown in Fig. 10. Compared with the closed rotor with a closed ducted fan, the ducted fan can provide forward force during the flight in normal cases. It achieves the function of vertical lifting by providing upward lift at the front and back of the vehicle body. The enclosed ducted fan allows the flying race car to move efficiently through all kinds of environments, potentially giving it talent when it comes to different corners on the race track.

The fins of the ducted fan installed at the bottom of the vehicle feature a 360-degree rotational angle, as shown in Fig. 11. The fins help provide forces in all directions, which improves handling and control to a great extent. With the fins located above and below the ducted fan for lateral control, the flying race car runs smoothly during flight. In addition, the rotational fins can assist the air braking system and fan thrust system. The fins serve as s thrust reverser by rotating to the contrary direction of the moving vehicle. The fan's speed will be adjusted with the sensor set at the original braking system to obtain the force of the wanted braking. The force of the two braking systems will be non-linear correlated, with priority given to the air braking system. When the driver steps on the braking pedal, air braking will be activated first. This can save energy through the heat of the brake disc and also prolong the life of the braking system while featuring a more intelligent braking force achieved by the computer. What's more, if the fins on the ducted fan face forward, they work as a part of the powertrain and make the whole powering system more sufficient.

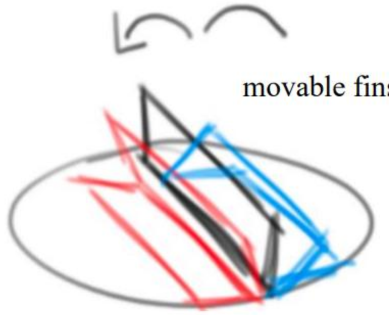


Fig. 11. Direction controlling fins on the ducted fan.

Nowadays race car faces the balance between high downforce with high drag and low downforce with low air resistance, which affects the handling and control. The overall body design will meet the streamlined distribution. The detailed design will depend on environmental situations to reduce unnecessary drag that has no contribution to the vehicle's downforce. For instance, when downforce is needed, the fins on the ducted fan will be directed to face upward, suck the air from the bottom away and assist the formation of the low-pressure zone under the car.

2) Adjustable air duct

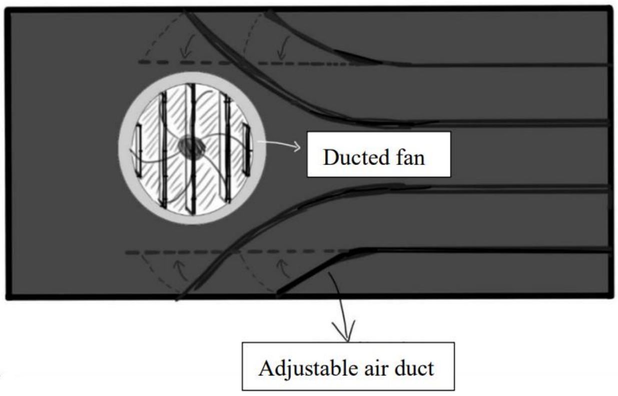


Fig. 12. Adjustable air duct.

To reduce drag caused by flow separation, an adjustable air duct is set at the bottom for the usage of a tunnel for high-speed air, as shown in Fig. 12. The air duct opens during the corners when negative lift and vehicle stability are required. It can accelerate the air flowing through the tunnel and reduce the pressure when the airflow exits inside the tunnel, which results in a low-pressure gap. A set of panels will be equipped inside the air duct, enabling the control of the air duct's angle, and making the air duct adjustable in function. Then the drag will be reduced to the maximum extent.

3) Extendable wing

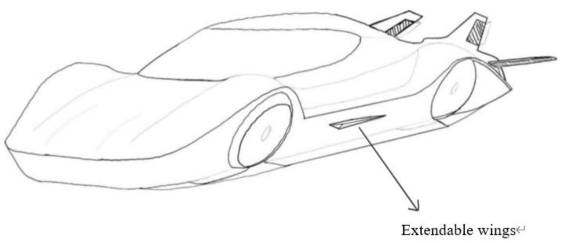


Fig. 13. Configuration of extendable wings.

An extendable wing is installed at the sides of a flying race car, as shown in Fig. 13. It would assist the ducted fan to keep the flying race car stable in the air and provide sufficient lift through a take-off session. An extendable wing can not only reduce the overall space of the vehicle but also enhance the mobility and flexibility of the car on the ground and through relatively tight dimensions. More importantly, it occupies a small space due to its flexibility.

4) Binary vector jet engine

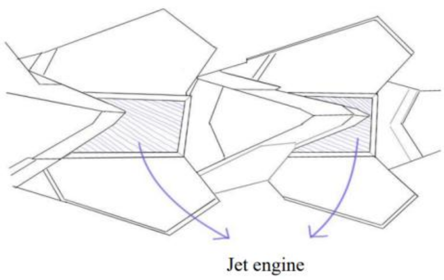


Fig. 14. Binary vector jet engine.

A set of binary vector jet engines is designed to provide power to the massive amount of active systems mentioned in 3.2.1–3.2.3, as shown in Fig. 14. More importantly, the binary vector jet engine can collect the thermal and kinetic energy to generate a large amount of electricity which in return offer power to other aerodynamic kits. This contributes to saving energy and the environment.

IV. Conclusion

The constant evolution in the history of vehicle aerodynamics has resulted in the development of certain devices which led to the enhancement of the overall aerodynamic characteristic of the vehicles. Not only does it improve the efficiency of the vehicle but also reduces fuel consumption. The analysis of the baseline with different aerodynamic devices was studied by reading a lot of papers. It has been found that aerodynamic force can be influenced by using different aerodynamic devices. In consideration of increased propulsion, it is favorable that the air filter and intake restrictor are added to the vehicle's body. In the case of spoiler, fins, and diffuser, the drag is reduced to a great extent. The rear wing increases the drag but its prime function is to provide downforce at the cost of increased friction, and it is much like a trade-off. In conclusion, traditional aerodynamic optimization can lead to better aerodynamics of the vehicle in different scenarios.

However, it's difficult to get a breakthrough in the performance of race cars regarding the shortcomings of traditional aerodynamic optimization. Regarding the limits, a new model of a race car is proposed by the author. This new model "flying race car" combines the advantages of landing race cars and aircraft. With the help of a ducted fan and extendable wing, it can take off vertically and fly forward at a higher speed by changing the angle. What's more, the speed is higher since the air drag is reduced to an extent. In addition, ducted fans can contribute the handling and control by producing backward force. The adjustable air duct with a massive diffuser results in less flow separation, which reduces the drag dramatically. To sum up, the flying race car has a much better capability of high speed, handling, and control. The performance has improved hugely. The flying race car makes a breakthrough in the technical boundary, saves more resources, and unfreezes race track restrictions. The race car industry might be revolutionized by this flying race car.

Conflict of Interest

The author has claimed that no conflict of interest exists.

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