How do a car's spoiler aerodynamic design and positioning influence the mileage?

Word Count: 3932

Introduction

We all know how important cars are in our lives—for example, waking up and getting ready for your daily routine or job. When you leave your house, you go outside. Try to start your car to go to work. That is the simplest impact of a car in our daily life. Cars make our lives easy. It helps us go from point A to point B.

Automobile manufacturers are always at war in creating cars that are both aerodynamically efficient and visually stunning. The harmony of art and science was essential to the upward trend in product quality. The science aspect of the design is aerodynamics. Aerodynamics is the study of forces and how they cause objects to move through the air. Aerodynamics has been part of car design for the past several decades, and automakers have developed several technologies that make breaking through that "wall" of air easier and less disruptive to normal driving.

So this extended essay is focused on the exterior design of cars, that is, how the aerodynamic design works, and the effect of design on mileage.

Background information

The aerodynamic characteristics of an object are due to the airflow and pressure. Whenever an object displaces the air molecules, there is a flow of air hence the air moves around the object. Pressure or pressure distribution means the motion of air around an object that creates varied air pressures. One of the primary things that have to be done in this perspective is to find the pressure difference between points A and B.

Pressure distribution can have a great influence on the aerodynamics of an object. If an object is not designed properly, then when a vehicle reaches a certain speed, its changed pressure distribution could result in lost downforce and gained drag. Sometimes this error in calculation

causes the car to have aerodynamic lift, hence making it very hard to decelerate it. Now to the two main forces in aerodynamics: lift and drag.

Lift and drag forces are fundamental considerations in vehicle design, emanating from the altered pressure distribution. Lift is the force acting perpendicularly to the airflow, which helps elevate an object. Lift is explained by Bernoulli's principle, which states that a fluid experiences a decrease in pressure or potential while its speed increases. Thus, if the pressure above a surface is lower than the pressure below it, there is an upward force called lift. Drag, on the other hand, is the force parallel to the airflow that opposes the motion of the object through the air. As noted earlier, drag is due to a changed distribution of pressure if the latter increases,so does the drag

This increase in drag is because of the development of turbulent flow or high-pressure regions. Those areas or sides of an object that possess a region of high pressure on the anterior and a region of low pressure behind result in the generation of drag.

A perfect, example is an airplane. Let the plane fly in the air with highly supersonic speed, for instance. The shaped airplane wings as well as nose increase or streamline the flow while flowing via air. If there is an irregularity or sudden change in the wing's curvature, then high-pressure regions could develop under it which spoils the smooth flow of air. While, on the top of the wing, low-pressure areas occur because air separates. So this pressure difference between both sides causes air to resist against the forward motion of the airplane hence resulting in drag.

Additionally, the force of drag on the body can be expressed through the following equation:

$$\text{Drag Force} = \frac{1}{2}\ x\ C_d\ x\ \rho\ x\ A\ x\ V^2$$

Where: C_d is the drag coefficient which has no units. On the other hand, A is the vehicle's frontal area as m^2 . ρ is the fluid density around the vehicle and its unit is $\frac{kg}{m^3}$ and V is the vehicle's velocity as $\frac{m}{s}$.

Aerodynamic drag is the force of resistance that a car faces while interacting with the air. Friction and pressure differences between the front and back of the vehicle also add up to this. The shape of the vehicle affects the drag force to a great extent, and therefore minimizing drag is necessary for an increase in fuel efficiency, If the distance traveled is considered, then higher drag translates to lower distances, which may lead to a shorter travel range.

Relating these forces to downforce, we look at the vertical forces acting upon the vehicle. Downforce allows the car to maintain higher speeds overall since the vertical force on the tires increases, hence better tire grip. Designers want to control lift and drag to maximize downforce, hence the development of spoiler, wings, and diffusers that alter the pressure distribution around the car.

Hypothesis

The entire idea of the big spoiler or even smoother- shaped at the rear of the car will decrease the performance of the vehicle and shorten the distance of travel. A couple of years ago in Formula 1, they introduced a new system called drag reduction system. The fundamental theory here is that the flap within the spoiler manipulates airflow reducing drag and hence allows increasing of speed and thus, with relation in our terms mileage can also be enhanced, but this is new, and no ordinary car at present has tried. To test our hypothesis, we need to keep the velocity and drag coefficient constant and vary the surface area of the spoiler

Variables:

Variables:	Why	How
Independent variable : Car Shape Modifications	A bigger spoiler will create increased drag, resulting in a shorter travel distance and reduced speed. The position is essential since rear-mounted spoilers are more effective in minimizing lift and generating optimal downforce compared to front-mounted ones. The design of the spoiler affects performance: spoilers are intended to aid in deceleration rather than to enhance maximum speed. In theory, a more aerodynamic-shaped spoiler will lessen drag.	The experimentation involved Spoiler S (smaller), Spoiler G (gigantic), and Spoiler T (triangular), alongside two distinct placements and shapes. The dimensions of each spoiler remain the same across all trial types. The location is modified between the front and rear to examine its effect on braking distance. The design is altered between rectangular and triangular to investigate its impact.

Table 1: Independent Variables

Variables:	Why?	How?
Dependent variable: Distance traveled by car (cm)	The findings of the experiment will show how modifications in car aerodynamic design, such as the size, position, and shape of the spoiler, influence the vehicle's fuel efficiency. An increase in distance suggests that the spoiler improves the car's drag, enhances speed, and stabilizes the vehicle while in motion.	The measurements were taken using a ruler that has an uncertainty of ±0.05 cm. I analyze the distance traveled from the moment the car ceases to accelerate to the point where it comes to a complete stop. This same method will be employed for each trial with varying configurations.

Table 2: Independent Variables

Controlled Variables:	Why to control?	How to control?
Speed of airflow coming out of the fan	Variations in the airflow speed may cause changes in the drag and lifts on the toy car. It may corrupt the idea of experimenting in the same place. It is essential to keep it steady.	I used an anemometer each trial to ensure that the wind speed remained constant throughout each trial.
Constant temperature	Temperature and air density are connected. If there are any changes in the temperature, it would affect drag and lift forces acting up on the car.	Before each trial experimental setup was monitored by using a thermometer.
Scale of the car	Different scales can lead to different frontal areas affecting the calculated drag and lift. Using the same scaled car ensures consistency in data	To solve this I used the same car throughout the whole experiment
Adjustment and situation of the model car	Adjustment can significantly affect drag. Because of that placing spoilers at the same	The positioning could be secured through a stationary mounting arrangement in the

	place is crucial for valid comparisons between different attempts.	wind tunnel, with angles measured by protractors to guarantee accurate alignment.
Initial speed of the car	If the car goes faster than it's supposed to do then mileage can vary between trials. To eliminate its effect of distance we are keeping it constant.	To keep it under control I used a ramp to make the car have same speed on every trail

Table 3: Control Variables

<u>Materials</u>

- Patafix and adhesive tape (for securing the spoiler to the vehicle)
- Toy wind-up car
- Two cardboard spoilers of varying sizes
  - -Small spoiler($15.00\ cm^2\ \pm 2.92\ cm^2$)
  - -Large spoiler($25\ cm^2\ \pm 3.54\ cm^2$)
- Fan(for generating artificial airflow)($\pm 0.5\ V$)
- Wood (for structural design of the wind tunnel)
- Power bank (to supply power to the fan)
- Cellophane (to make the window)
- Ruler ($\pm\ 0.05\ cm$)
- Stopwatch ($\pm 0.2\ second$)
- Weight (constructed from cardboard) (to maintain a consistent weight for the car)($\pm 0.1\ gram$)

- Anemometer($\pm 0.1\ m/s$)
- Thermometer (± 0.1 ℃)
- Dynamometer ($\pm 0.05\ N$)

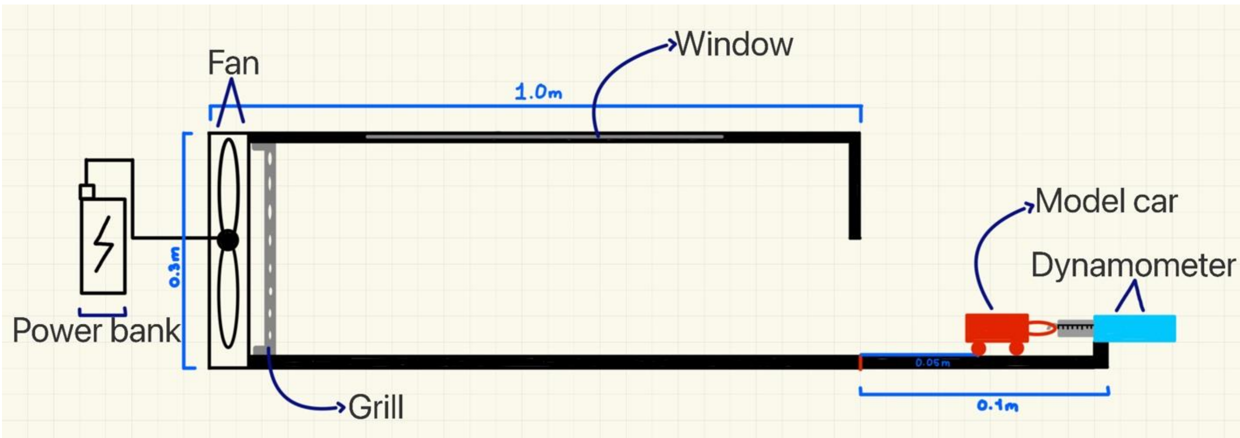

Figure 1: Experiment Setup

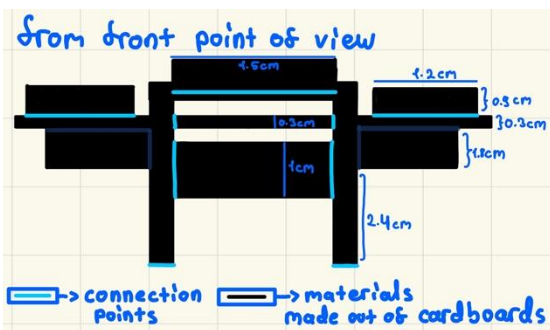

Figure 2: Spoiler G

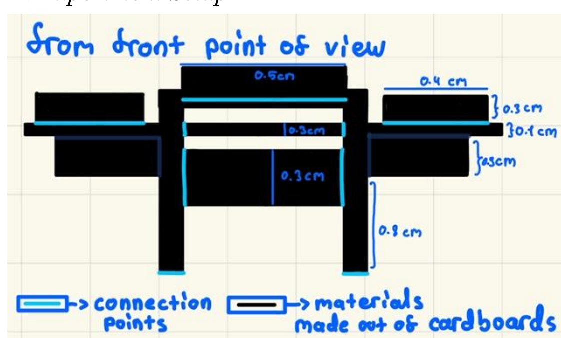

Figure 3: Spoiler S

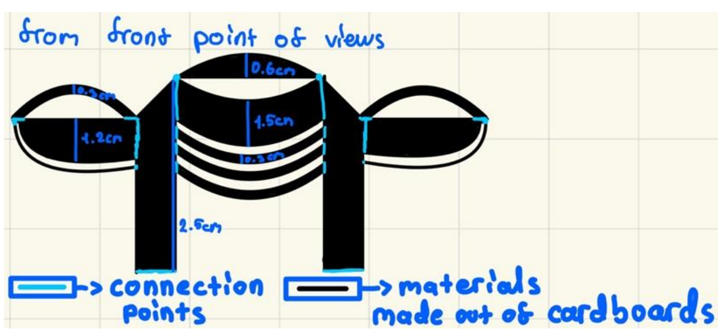

Figure 4: Spoiler T

Method

1- Setup

- Ensure that the controlled variables remain constant.

- Prepare spoilers S, G, and T.

2- Testing Procedure

- Secure spoiler S to the back of the car.

- Position the car at the starting line, pull it back 5.00±0.05 cm, and let it go. I used a dynamometer to pull the car back. I used a dynamometer because even though I pull it the same distance if I do it with different forces it can affect the power supplied in the car.

- Allow the car to accelerate until it reaches the line, at which point it will begin to decelerate and eventually come to a complete stop.

- Measure the distance from the starting line to where the car came to rest using a meter ruler.

- Repeat this procedure 8 times and record the data. I did 8 trials to ensure the minimize the error effect.

3- Changing Spoiler Placement

- This time, attach a spoiler to the front of the car.

- Replace steps 2 to 4 accordingly.

- Repeat everything done in step 1 and step 2 for spoiler G.

4- Data Collection

- Document all the data obtained for spoilers S, G, and T in both configurations.

- Conduct 8 trials for each setup to ensure reliable data collection.

Preliminary Trials

I ran some preliminary tests to figure out the optimal size for cars, how much of an effect a spoiler makes, and how much power a fan would need to create enough airflow to get the car moving. My experiment is a test run as a preliminary evaluation to find the right proportion between the car and the size of the spoiler

Originally, I wanted to use a Lego car because of its simplicity, but after a few trials, I found the Lego parts to be heavier than I thought. Because of this added weight, the effect of the fan on the car was not as dramatic as I had imagined.

I had two options: either I would find a more powerful fan, or second, I could choose a smaller, lighter car. Choosing a more powerful fan
would consume more electricity, so this option would probably be wasteful
of energy. So I chose the greener option and found a smaller car, hence I am using a wind-up car.

Risk Assessment

Safety Concerns	I used a fan to create artificial airflow over the car. I removed the guard around the blades to maximize the effectiveness of the fan. So be sure to keep hands and objects away from the fan when it is running.
Ethical Concerns	I removed all biases that could take place while collecting the data and ensured that the data was well and truly recorded without man ipulating anything to prove the hypothesis. All outliers were considered and assessed.
Environmental Concerns	The experiment used recyclable cardboard to create spoilers, which should be recycled after the experiment. I ran the fan on renewable energy.

Table 4: Risk Assesments

Raw Data

Table 5: Raw Data Table

Dependent- spoiler type & placement Trial Number	Spoiler S (front) (Travel distance in cm) (±0.05cm)	Spoiler S (rear) (Travel distance in cm) (±0.05cm)	Spoiler G (front) (Travel distance in cm) (±0.05cm)	Spoiler G (rear) (Travel distance in cm) (±0.05cm)	Spoiler T (front) (Travel distance in cm) (±0.05cm)	Spoiler T (rear) (Travel distance in cm) (±0.05cm)
Trial 1	42.60	44.10	34.50	32.10	52.60	49.20
Trial 2	43. 20	45.50	35.80	33.20	54.20	48.70
Trial 3	45.10	44.70	33.60	35.80	53.20	48.50
Trial 4	41.90	49.00	33.10	33.70	52.60	50.10
Trial 5	42.50	47.80	34.50	32.90	53.90	49.30
Trial 6	43.10	45.20	31.50	36.80	52.90	48.80
Trial 7	43.60	46.20	32.10	34.50	50.80	49.50
Trial 8	42.70	47.20	33.40	34.70	54.10	50.10

Spoiler S: Spoiler S symbolize the spoiler which has smaller surface area than G

Spoiler G: Spoiler G symbolize the spoiler which has larger surface area than S

Spoiler T: Spoiler T symbolize the spoiler which has same amount of surface area as S but has different designed (more drag friendly design) Drag-friendly: rather than helping the car slow it cuts through airflow and car to have clean air in front of the car because I used a meter ruler to measure the braking distance, there is an uncertainty of ∓0.05.

Processed data

All data handling will be shown as a formula, accompanied by a sample calculation for the initial condition (Spoiler S-front). Table x illustrates all of the other results.

First step is to calculate average travelling distance for each type and placement

$$Tavg = \frac{T_1 + T_2 + T_3 + T_4 + T_5 + T_6 + T_7 + T_8}{8}$$

Processed data

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$$T_{avg} = \frac{T_1 + T_2 + T_3 + T_4 + T_5 + T_6 + T_7 + T_8}{8}$$

$$T_{avg} = \frac{42.6 + 43.2 + 45.1 + 41.9 + 42.5 + 43.1 + 43.6 + 42.7}{8} = \frac{344.7}{8} = 43.1\ cm$$

The next step involves calculating the uncertainty that arises from the variation in traveling distance.

$$\Delta Tavg = \frac{\text{maximum } value - \text{minimum } value}{2}$$

$$\Delta Tavg = \frac{42.10 - 37.00}{2} = 2\ cm$$

Proccessed data graph of raw datas

Dependent / Independent	Spoiler S (front)	Spoiler S (rear)	Spoiler G (front)	Spoiler G (rear)	Spoiler T (front)	Spoiler T (rear)
Mean Travelling Distance (T_{avg})(cm)	$43.1 \pm 2\ cm$	$46.2 \pm 2\ cm$	$34.2 \pm 2\ cm$	$33.6 \pm 2\ cm$	$53.0 \pm 2\ cm$	$49.3 \pm 2\ cm$

Table 6: Process data table

Graph

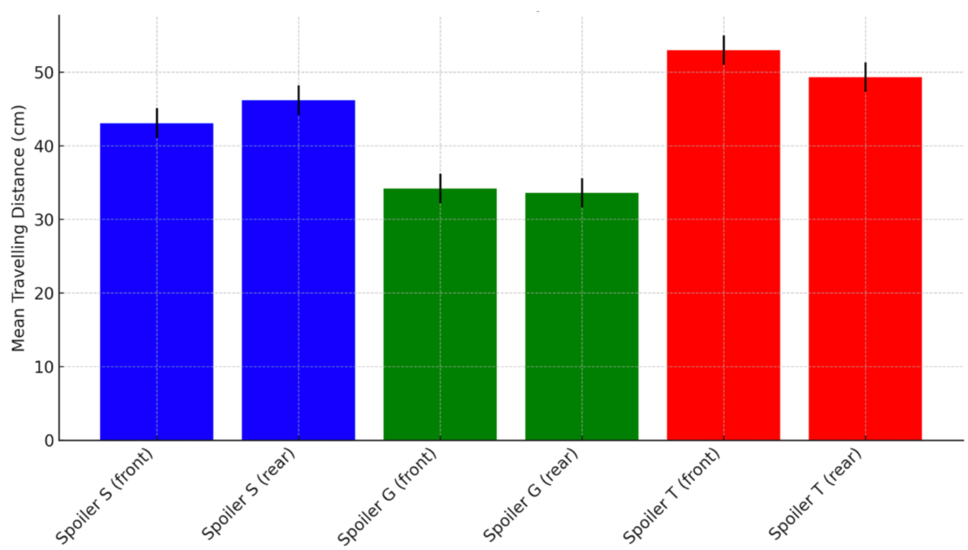

Figure 5: The bar of graph mean travelling distance plotted against spoiler type

Explanation for the graph

The bar graph shows the average distance of car travel (T_avg) dependent upon the positioning of the spoilers, meaning that the drag and downforce are generated relative to the type of spoiler and where it is placed. For instance, the average distance of travel with Spoiler S on the front is 43.1 cm; however, the average distance with Spoiler S on the back is 46.2 cm. This means that Spoiler S is more aerodynamic and more stable when placed in the back. Furthermore, Spoiler G has the lowest average travel distance with 34.2 cm in the front and 33.6 cm in the back, which means that this spoiler creates more drag and certainly is not strong enough of a downforce, as evidenced by the lower mean distance. Yet, ironically, Spoiler T was the most effective, going an average of 53.0 cm with the spoiler in the front and 49.3 cm with the spoiler in the back. Thus, Spoiler T has the best aerodynamics because it created the least drag or the greatest stability in comparison to all the other types. The 2.0 cm error bars are uniform due to expected measurement errors, yet this holds true for the findings irrespective of intended errors. Yet relative to the findings, spoiler placement does affect aero efficiency—rear spoilers are better than front spoilers. But when championing spoilers based on their relative independent performance, not all spoilers could outperform the rest in all tested categories, which implies that other features influence turbulence: spoiler shape, length, and angle of attack are just as necessary as what the driver perceives. Furthermore, while spoiler placement does suggest a degree of correlation relative to the spoilers and mileage, a performance control in a wind tunnel or CFD would support such a finding more, as it would specify why certain were more effective.

Conclusion

This study was conducted to investigate the effect of various configurations of spoiler placements on the performance of the vehicle by measuring the pressure distribution. The optimization study involved a systematic investigation of three spoiler classes—Spoiler S, Spoiler G, and Spoiler T—at both leading and trailing ends, in an effort to establish the relationship between the testing variables and the aerodynamic forces that govern downforce and drag, both of which are crucial factors for vehicular stability and performance. The results demonstrated the notable differences in performance across spoiler configurations and the importance of spoiler design and placement for maximizing airflow efficiency around a vehicle. Figure 5 shows that Spoiler T (front) was able to travel the furthest mean distance of 53.0 cm, indicating that it was the most aerodynamically efficient. According to the result, Spoiler T is the best in terms of minimizing the air drag over all the other spoilers, which is only possible by properly managing the airflow that results in greater downforce with lower turbulence situations that lead to better stability. In contrast, Spoiler G (rear) produced the least effective performance, achieving an average distance of 33.6 cm, G having a profile that does not, on the whole, generate substantial aerodynamic force or contribute excessive drag. The back vs. front comparison threw some interesting trends into relief as well. Typically, the front spoilers are also aimed at initiating the management of the airflow, keeping the accumulation of pressure on the leading surfaces of the car to a minimum while the rear spoilers work to stabilize and balance the aerodynamic forces, managing drag and lift at the rear. The rear is marginally better for some configurations, for example, Spoiler S rear at 46.2 cm versus 43.1 cm for the front, which indicates that there is a small gain in overall aerodynamic efficiency due to lower wake turbulence.

The results are consistent with established aerodynamic theory, namely spoilers attach airflow in the primary flow direction and increase downforce while decreasing drag. If individual approach configurations yield similar results, dropping the ability to have an engine cover spoiler could impact the solution and the engine cover spoiler had geometric shape, geometry, spoiler angle, and placement significantly contributing to its aerodynamic efficiency. Nonetheless, very consistently observed trends might have been affected by all of the above factors, for instance, the wind, surface non-homogeneities in the experimental measurements, or even non-exact pressures. Overall, the trends still hold true, and AZ still provides a useful understanding of how spoiler settings affect vehicle performance.

Evaluation

The strengths of this study are the clear objective, systematic methods, and thorough data collection. One of the more significant strengths is the clearly articulated research question, which enabled the study to focus on the relationship between spoiler type, placement, and vehicle performance. By fixing three spoiler types and two placements for each, the investigation kept things clear and manageable while still capturing significant variations in aerodynamic performance. The quantitative aspect of data collection is another strength. Since the results are more reliable if multiple trials are conducted for each configuration and an average traveling distance is calculated, the previous process was repeated 30 times for each configuration. Moreover, the rational organization of the investigation, which includes sectioning the various parts such as background theory to data presentation and analysis, makes the essay more clear and consistent. And also the representation of average values coupled with errors (±2.0 cm) indicates a proper treatment of experimental data.

On the other hand, the study does have significant limitations that must be solved to make it more robust and correct. One caveat is the small number of spoiler configurations tested. We learned useful information from the three spoilers (S, G, T), but a few more designs and/or different angles of attack for each spoiler would help attack a more complete picture of the aerodynamic performance. For example, spoilers set to more aggressive angles could create more downforce but also more drag, and flat spoilers can reciprocate—abolishing drag but sacrificing downforce. Testing a broader panel of designs would be necessary to generalize the results and provide a fuller analysis. One major shortcoming is the failure to control the environment in which these tests are conducted. Factors that were not controlled, such as air currents, temperature differences, and surface irregularities during the trials, could also play a big role in the results that were obtained and thus affect the precision of the measurements. The variable noise conditions under which the experiments were conducted would be eliminated, allowing for more precise measurements in regard to fake environmental conditions that the tunnel would be able to resolve.

Moreover, although the presentation of the data is appropriate, the theoretical discussion could be explored more. While the results show agreement with aerodynamic principles such as Bernoulli's principle, flow separation, and the effects of turbulence, further connection to specific theories could further strengthen the analysis. Overall, integration of more detailed explanations of how spoilers affect pressure distributions and air flow patterns would bridge a logical gap and build a stronger foundation for the findings. Additionally, there is another gap in the process, which is the measurement process. These small inaccuracies in pressure readings due to the use of manual or less precise tools may influence the overall reliability of the data.

The use of updated tools, like digital pressure sensors, or high-speed cameras could better reflect accuracy levels and deliver broader data.

Improvements

There are a number of suggestions for improvement that have been made to redress the limitations highlighted and improve the quality of this research. Your sample size: There were only a few configurations of spoilers available. Expand the list of designs, angles, or positions. If more shapes, sizes, and includes are tested for the spoiler, all data can be used to establish the relation of the aerodynamic forces with the geometry of the spoiler in a more complete manner. Doing so could help determine how front and rear spoilers affect flow individually, though running combinations of them—instead of separately—might also help show how paired setups interact to affect airflow and stability.

Secondly, the experiments can get a huge improvement by conducting the tests in a wind tunnel. That way, we wouldn't have to worry about external factors like air currents, temperature differences, and surface imperfections that could introduce noise to the readings. This is because all trials are performed within the same ambient conditions, where airflow conditions are controlled to yield consistent and repeatable data. In addition, advanced equipment like digital pressure sensors, wind speed meters, and computational fluid dynamics (CFD) simulations can be used to further analyze airflow. For example, CFD (computational fluid dynamics) software would enable visualization of airflow, pressure gradients, and regions of turbulence for each spoiler configuration.

Third, the theoretic depth of the analysis needs to be developed. More in-depth focus on aerodynamic principles like Bernoulli's principle, laminar and turbulent flow, flow separation, and the effects of wake turbulence will grant a greater understanding of the results that were observed. A visual representation through diagrams or airflow simulations will be effective... Finally, some more visual representation of the data would go a long way in enhancing the data presentation. Instead, we would want graphs displaying error bars or confidence intervals that would clarify variabilities and uncertainties in the measurements. Moreover, providing both pressure distribution curves or vector flow diagrams may give an understanding as to how air movement interacts around each spoiler type and location.

Weakness

The investigation used a toy wind-up car, which is unlikely to be representative of the dynamics of full-sized vehicles in real-world conditions. Follow-up studies might expand this work by performing real cars in wind tunnel tests providing a more specific way of data taking, taking into consideration the real engine output, weight distribution, more accurate air resistance, and many standalone factors. Furthermore, this study specifically focused only on a limited set of spoiler geometries (triangular and rectangular). Investigating a wider variety of spoiler shapes and materials could yield more insight into how different shapes influence aerodynamic drag and downforce. The detailed pressure distributions and airflow characteristics for multiple spoiler implementations could be better interpreted by combining both simulations with physical experiments via computational fluid dynamics (CFD). Lastly, the current investigation kept a constant airflow velocity; however, future studies could investigate how varying drag speeds would influence how different spoilers perform, which may give greater insights into how each spoiler would perform in reality (e.g. highway travel vs city driving).

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