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Generation of Electrical Power by Integrating Horizontal Wind Turbine into the Spoiler of Electric Car

M. Harikrishna Mukeshkumar[1]*, S. Srihari[2]
[1,2]*Department of Mechanical Engineering, Amrita Vishwa Vidyapeetham, Amrita School of Engineering, Coimbatore-641 112, Tamil Nadu, India.*
**Corresponding Author Email and Phone Number: mmuniaraj@gmail.com*
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Abstract

The transportation industry consumes most of the fossil fuel and releases enormous amount of Co_2 which leads to global warming. Hence there is always a need for generating green energy for replacing fossil fuel-based transportation. The recent booming of electrical vehicle is considered as alternative but still they are using the power for charging synthesized by burning fossil fuels. If the wind energy of a moving car is used to generate electrical power, then the charging frequency can be reduced and there by indirectly reduce the consumption of fossil fuel. Moreover, the main disadvantage of electric car is frequent charging. If a system to generate power by using wind energy in moving car, it could supplement the power requirement. Hence, we have designed a prototype spoiler integrated with inbuilt turbine and motor to supplement the power requirement by utilizing wind energy of a moving electric car.

Keywords: *Electric power, wind turbine, spoiler, electric car, fossil fuel, CO_2 emission.*

1. INTRODUCTION

The transportation industry is one of the major areas responsible for the movement of people and goods across the globe, consuming 28% of the total energy produced and 37% of CO_2 emissions [1]. From the total energy consumption, passenger automobiles alone are responsible for nearly 41% [2]. With the increasing global population, this energy requirement and consequent emission of CO_2 are ever-increasing. This is mainly because most automobiles are made up of internal combustion engines that run on petrol, diesel, and natural gas. A huge uncertainty prevails in predicting the future supply and demand of the fossil fuels [3]. The global reserve of fossil fuels was estimated to be exhausted by 2050 [3]. The burning of liquid fuel produces a variety of pollutants that continuously reduce the air quality and threaten human and animal life [2]. The increasing cost of fuel causes severe economic crisis in many countries and forces them to adopt alternative modes to reduce fuel consumption [4]. The economic crisis and environmental issues caused by liquid fuel consumption made those in the field develop alternative, clean, and sustainable energy sources.

Recently, the electric vehicles from both exclusive makers like Tesla, BYD and general players such as TATA, MG, Hyundai, KIA are becoming increasingly popular mainly as it reduces the carbon addition to the air and completely cut the fuel expenses [5]. Apart from other issues such as short recharge mileage, slower charging periods, and difficulty in finding public charging ports, the use of electricity generated by burning fossil fuels increases CO_2 emissions and speeds up the greenhouse effect. The average travel distance on an electric-powered vehicle is less than that of a gasoline vehicle. These issues can be averted or reduced, when the electric vehicle charges its batter when the vehicle is on the run. This can be achieved by harnessing the air currents and utilizing their force to run the turbine to generate electricity [6, 7] with minimal drag force. There are two types of wind resistance act on a moving object, namely frictional drag and form drag. Frictional drag arises due to the viscosity of air and form drag arises due to variations in air pressure on the front and rear sides of the vehicle. If the force of the air current and its physical energy in a running car is successfully harnessed to convert into electrical energy, then the harnessed electricity can be used to supplement the electricity needs of the car. Although several studies have reported generating energy in a moving motor vehicle by various mechanisms, such as installing wind turbine over the car surface or in front portion, vibration energy from suspension, recovering the waste heat-energy, brake-energy, and renewable-energy recovery, to support the energy needs of a motor vehicle, [8-13] none of them is widely in use due to several reasons that the drag force created by the wind turbine, etc, when using other methods. Therefore, we have made a prototype design of spoiler with in-built turbine & motors and evaluated its efficiency in generating electricity. We have also calculated the lift and drag force ratio of the spoiler by simulation studies.

2. MATERIALS AND METHODS

2.1 Designing Car Spoiler with Integrated Turbine

First, we have made the spoiler with integrated turbine design using, *SolidWorks* design software and created 2D, 3D working models (Figure 1). The possible location in the car and the cross section of the spoiler with integrated turbine is shown in Figure 2.

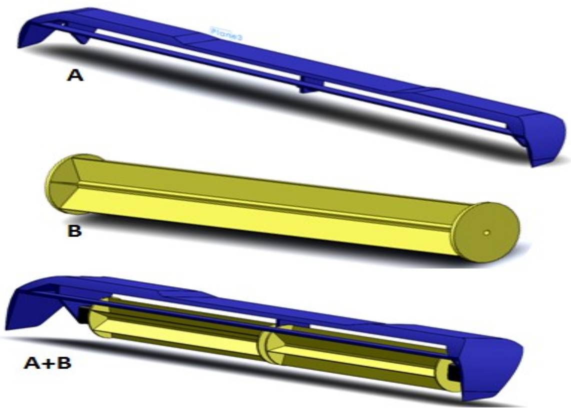

Figure 1 A. Car spoiler; **B.** Wind turbine; **A+B** Wind turbine fixed inside the spoiler.

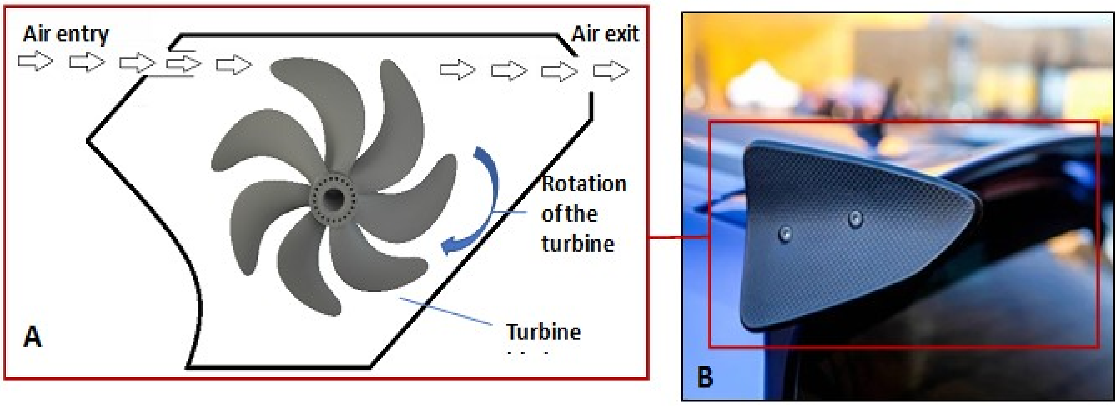

Figure 2 A. Design of the passive spoiler with inbuild turbine for electrical power generation (Cross sectional view). **B.** Location of the designed spoiler in a car.

2.2 Air Flow Analysis and Calculating Lift and Drag Ratio

Then ANSYS software was used to determine the simulated air flow analysis of the spoiler to calculate the lift and drag (L/D) ratio. An object if it is kept in a running fluid, the fluid exerts certain amount of force on the object. Lift is the component of this force that is perpendicular to the oncoming flow direction. Similarly, the drag (resistance) is a force acting opposite to the relative motion of any object moving with respect to a surrounding fluid as shown in Figure 3.

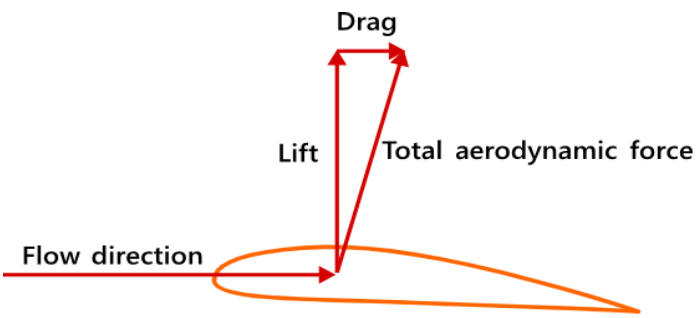

Figure 3. Fluid or Air flow direction and lift vs drag (L/D) forces acting on an object.

In any aerodynamic models, the lift-to-drag ratio (or L/D ratio) is the lift generated by an aerodynamic body such as an aircraft, divided by the aerodynamic drag caused by moving through air. It describes the aerodynamic efficiency of the body. For example, the L/D ratio of passive spoiler is around 2-3, the L/D ratio of active spoiler is around 3-5 and the L/D ratio of aeroplane is around 15-20 are above depending on the size of the aeroplane. The L/D ratio varies with speed of the vehicle. In this the lift force should always be higher than the drag force for proper aerodynamic functions. The L/D ratio of the turbine integrated spoiler at different speed was calculated using *ANSYS* software. The model of the spoiler which was developed using *SolidWorks* was imported and placed in a rectangular chamber, which was constructed using the *ANSYS* software. The spoiler was fixed in the bottom of the chamber at an appropriate position. Using Boolean option, subtract target and tool body i.e, the chamber and the spoiler. Then through the meshing option, mesh was selected, from there, insert was selected and then method, followed by the geometry and method as tetrahedrons. Then the sizing option was used for the bodies, after updating the work done on mesh. The setup option was opened, then in default domain the air temp was set as 25^0 C. Since this is turbulence case the shear stress transport option was used. Now the boundary conditions were set such as the inlet where the speed of air was given (eg.20 km/h). The sides, the top, and the bottom were set as walls (Free slip wall). The spoiler was set as no slip wall and then the outlet was set with relative pressure of 0 pa with some blending factor of 0.05.

After finishing the setup, the solution option was opened. In define run bar, the double precision was selected and then run mode was selected as intel MPI local parallel then start run was selected. Then by using plot monitor option, normal forces and tangential forces acting on the spoiler in X, Z direction were selected. After the iteration was done from the plot obtained, the lift and drag values were identified which was then used to derive the lift by drag ratio. For the visualization of the work done, the result option was used. In the location option, the plane was selected where conditions (eg. pressure) can be changed based on the requirement to get visual model. For better visualization, the streamline option was used so that the stream line flow of the air through the spoiler in the chamber can be visualized. The pressure acting on the spoiler was drawn in a separate visual model. Then the L/D ratio of the spoiler is derived using the lift and drag values obtained from graph generated in the Ansys software. Using the L/D ratio the quality of the spoiler design is verified by comparing to the standard L/D ratio for a passive spoiler (i.e, 2-3). For example, at 20 km/h speed the lift value is 0.26 and the drag value is 0.13, then the L/D ratio obtained is 2 which is within the standards for passive spoiler (Fig 4).

2.3 Theoretical Calculation of power generated

The power generated by the wind turbine was measured using the given formula:

$$P = 0.5C_p \rho A v^3 \qquad (1)$$

Where P = Power generated (watts); ρ = Density of air (the standard density of air is 1.225 kg/m^3); v = Velocity of the wind (m/s); A = sweep area

The sweep area varies for horizontal axis wind turbine (HAWT) and vertical axis wind turbine (VAWT). The formula for calculating sweep area for HAWT is A =1/2 x r^2, r is the radius of the circle formed by the turbine motion and for VAWT is A=D x H; D= Diameter of the wind turbine, H= Height of the wind turbine. As the wind turbine described in the present study is HAWT, the calculations were done accordingly. c.p = the coefficient of performance (0.2); the value 0.2 is obtained based on the Betz limit of wind turbine (Betz limit: It is the theoretical maximum efficiency for a wind turbine).

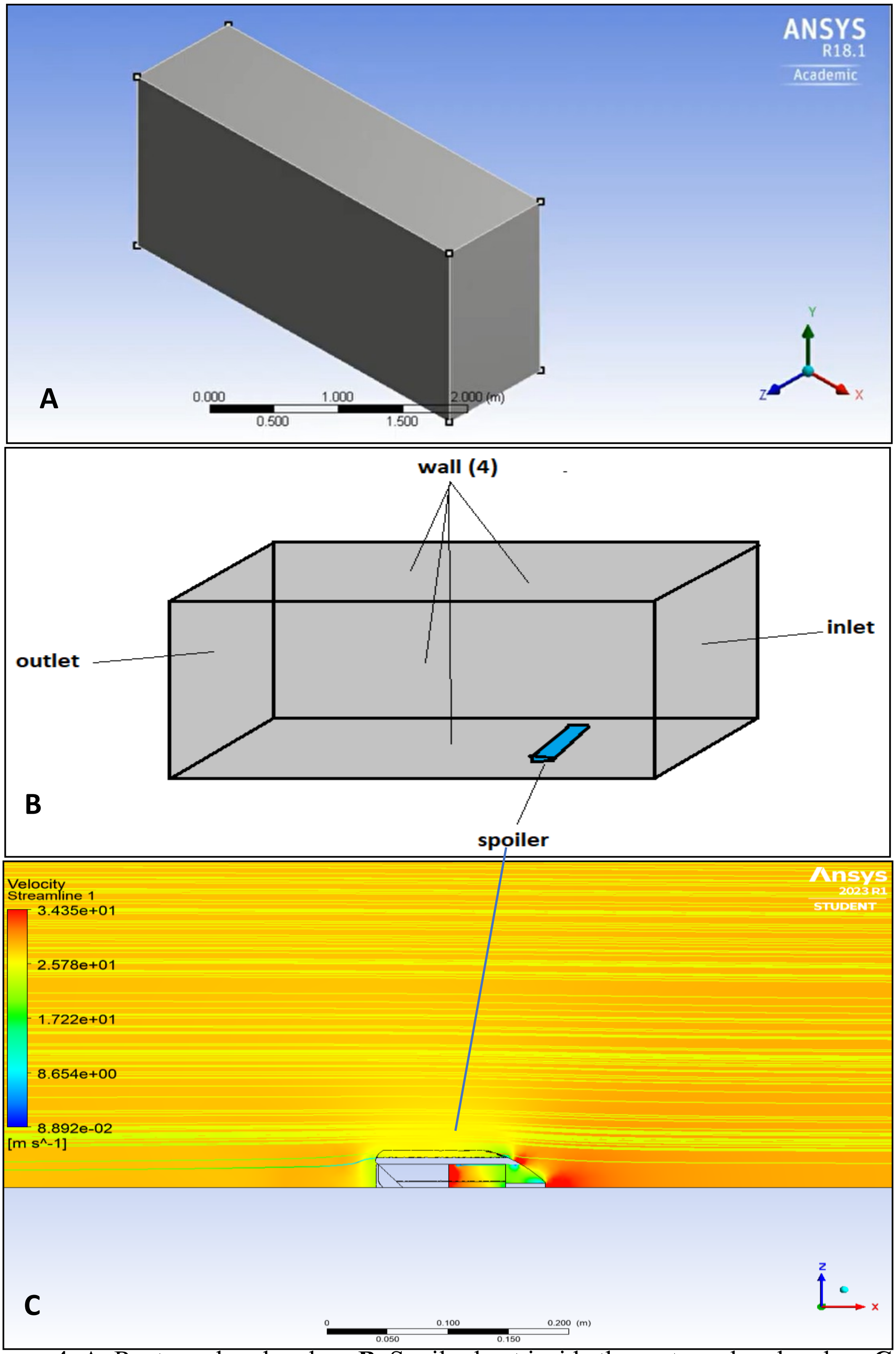

Figure 4. A. Rectangular chamber; **B.** Spoiler kept inside the rectangular chamber; **C.** L/D ratio determination at a speed of 20 km/hr.

According to Betz limit the maximum efficiency for a perfectly designed wind turbine is 0.593. The general value used for HAWT is 0.3-0.4. At 20 km/h the power generated by the turbine is calculated using the formula mentioned above;

$P = 0.5Cp\,\rho A\,v^3$

A = D x H, D= 80 mm=0.08 m , H=265 mm= 0.265 m.

$= 0.5 \times 0.2 \times 1.225 \times 0.08 \times 0.265 \times 5.5556^3$ i.e, 20 km/h=5.5556 m/s

= 0.44 W.

Similarly, power generated at various speeds (40, 60, 80, 100) were calculated using the same formula and the values obtained are given below in table along with a plot for better visualization (Figure 5)

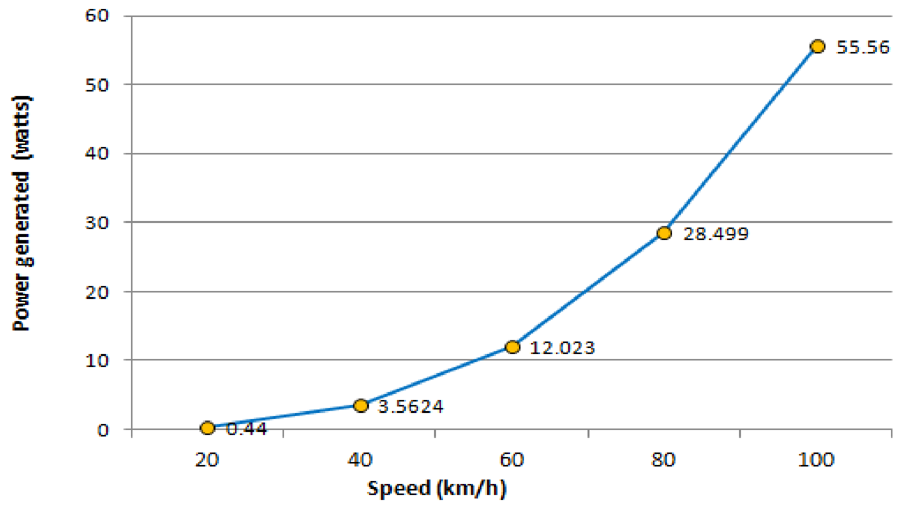

Figure 5. The potential power generation at different wind speed.

2.4 Proto-type design

After the simulation work, we have developed the prototype design of spoiler with build in turbine. There are several processes involved in the prototype making such as 3D printing of required parts, cutting, drilling of a spoiler, etc. The horizontal turbines used in this project work were fabricated using 3D printing method. The spoiler was cut at two places with proper dimensions for the incorporation of the turbines. The drilling was done on the spoiler to make several holes for the fixing of the motor, the soldering process was used in connecting the wires to the terminals of the motor. Now let's look into the various steps that were involved in developing the prototype.

The prototype making processes of the spoiler design was initiated with selection of suitable material, here we have selected a spoiler of suitable dimension as the base for the prototype. The dimension of the spoiler is as follows 1240 mm (L) x170mm (B) x 90mm (H). The spoiler material is ABS (Acrylonitrile Butadiene Styrene) plastic which is preferred for several useful properties such as lightweight, sturdiness, ductility, etc. After the selection of spoiler, the turbines were made based on the design using the process of 3D printing, two sets of turbines were made (Fig. 6). The spoiler was cut at two places as per the design to make two cavities were the turbines were installed. The dimensions of the cut were 310mm (L) x 70mm (B) (Fig. 7). Then 12V DC motors were selected and fixed as one for each turbine. In the assembly process, holes or ports were made to hold the turbine using metal pins. Then to fix the motors at suitable position, L shaped holders were used to hold the motor with spoiler. For this purpose, holes were made in the spoiler to screw the holder in place, zip tags were also used as additional support to hold the holders in position. A rubber belt was used to connect the turbine with the dc motor (Figure 8). When wind blows the turbine, it spins and the rubber belt connected with it makes the motor to run to produce electricity. A two sets of 5 LEDs in each were fixed on the spoiler and was connected to the terminals of the dc motor, to demonstrate the power generation when the turbine is rotated. A vacuum pump blower was used to blow the air over the turbine to generate wind and the speed of the air was calculated using anemometer. The prototype (Figure 9) was first tested indoors and was successful in generating electricity following the successful indoor testing, the prototype was then tested outdoors by fixing the spoiler at the top of the vehicle. After that the vehicle was driven at various speeds and the power generated at each speed was obtained by measuring the voltage and current values using the Multi-meter. The values of voltage and current were multiplied to obtain the power values. For measuring the wind speed Taylor anemometer was used.

Figure 6. 3D printed horizontal turbine.

Figure 7. The spoiler cut at appropriate locations.

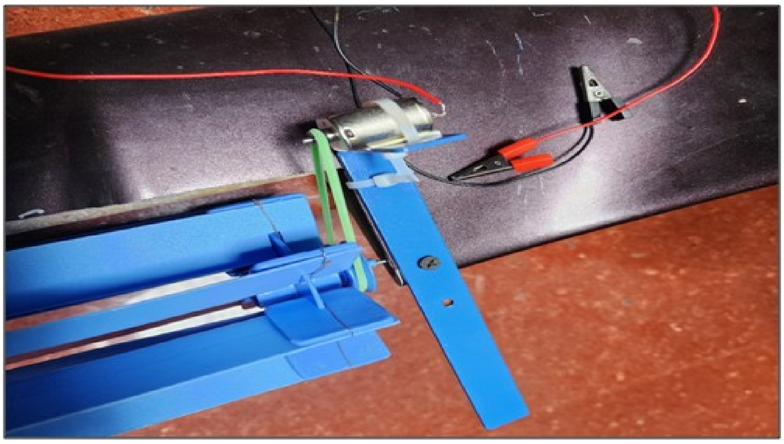

Figure 8. Belt driven setup attached to the L-shaped holders

Figure 9. Entire setup of prototype, top view

3. RESULTS AND DISCUSSION

3.1 L/D Simulation Analysis

The L/D ratio is obtained for various speed, calculated using the lift and drag values that were obtained from the plots generated in the ANSYS simulation and to check whether the values obtained were in the standard value range. If the values derived are around the standard values of the specific type of spoiler then the design is in standard form (i.e., for passive spoiler L/D ratio is around 2-3). The plots that are obtained in the ANSYS simulation show L/D analysis at a speed of 20 km/h. The values of the lift and drag values are acquired from the graph that is obtained in ANSYS air flow analysis. In the graph, the green line represents the lift force and the red line represents the drag force, the other two-line i.e, blue and yellow lines are the frictional forces. The above given graph was obtained for the speed of 20 km/h, and the L/D ratio values is given below (Figure 10),

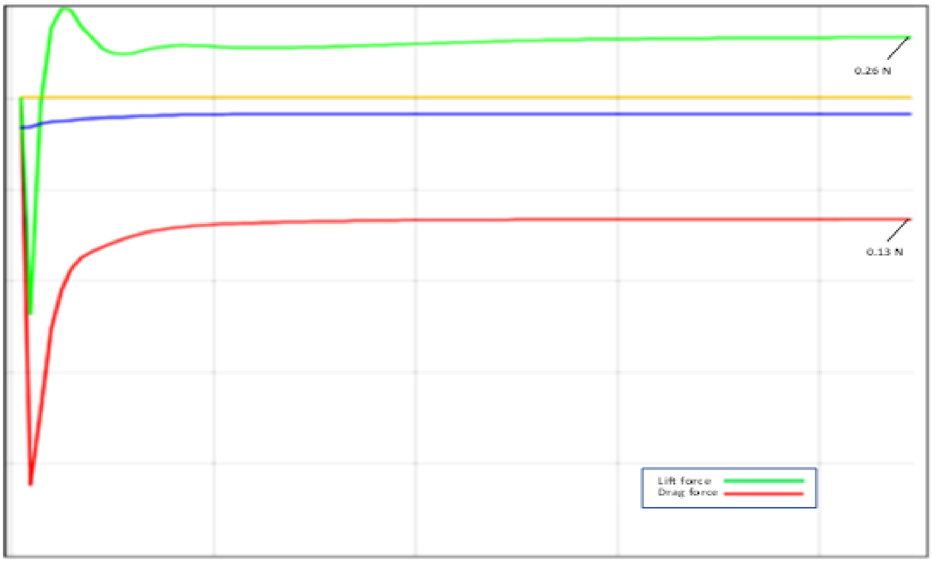

Figure10. Lift and Drag value plot obtained from Ansys (at 20km/h)

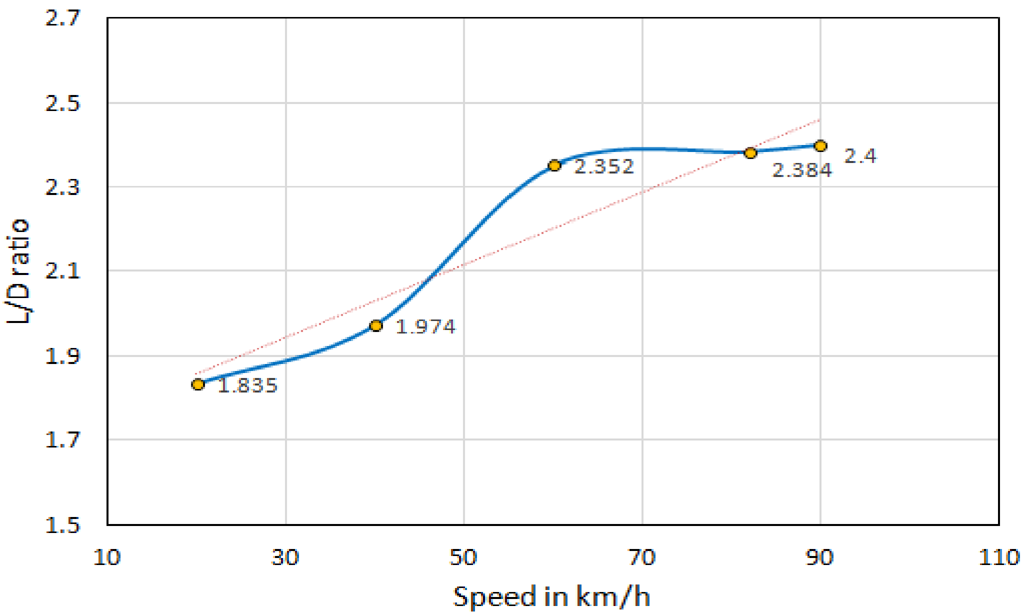

Figure 11. The L/D ratio generated at various speed.

Lift, L=0.26 N

Drag, D=0.13 N

L/D= 0.26/0.13 = 2

Since the L/D ratio of general passive spoiler is 2-3, the value obtained is acceptable, so the design is safe. Similarly, the L/D ratio at various speeds are calculated using the same method, they are,

- At speed of 40 Km/h =1.93 (L=1.08 N, D=0.56 N)
- At speed of 60 Km/h = 2.352 (L=2.4769 N, D=1.0531 N)
- At speed of 82 Km/h = 2.398 (L=4.7 N, D=1.96 N)
- At speed of 90 Km/h = 2.397 (L=5.54 N, D=2.32 N)

All the values that are obtained are within the limits of given L/D ratio of the general passive spoiler, Hence the spoiler design developed is good. The values that are obtained are plotted in the graph given below in Figure 11.

4.2 Field Testing of Prototype

After the completion of the theoretical and simulation work, the prototype was tested outdoors by attaching it to a car and driven at various speeds. Since the theoretical calculation was done for DC motor with more voltage, the values of power generation vary for the actual work since low power motor of 12v is used. Steps involved in this process were, fixing the spoiler at the back of the car, while driving the voltage and current values are noted using a multi-meter at various speeds. These values are then multiplied to obtain the power values. During the field testing, the LEDs were indicators were removed, as they would consume some electricity load that may reduce the overall power generated significantly. At the speed of 20 km/h the voltage and current values are noted using the multi-meter, by connecting the two probes of the multi-meter to the terminals of the dc motor. Voltage = 6.1 V; Current =65.2 mA. By multiplying the above values, the power produced at that specific speed was calculated to be 0.406 W. Since there are two motors present in the prototype, the total power produced was 0.406 x 2 = 0.81 W. Similarly, the power generated at the speed of 40 km/h was 2.414 W. Total power generated for other speed were; At 60 km/h= 4.257 W; At 80 km/h= 8.761 W; At 90 km/h= 12.431 W. The power levels obtained are plotted against the speed in a graph (Figure 12 and Table 1) to give a proper visualization of the data obtained.

Table 1. The electric power generated by the motor integrated with turbine in a moving car at various speed.

Speed (km/h)	Power generated-2 motors (watts)
20	0.81
40	2.414
60	4.257
80	8.761
90	12.431

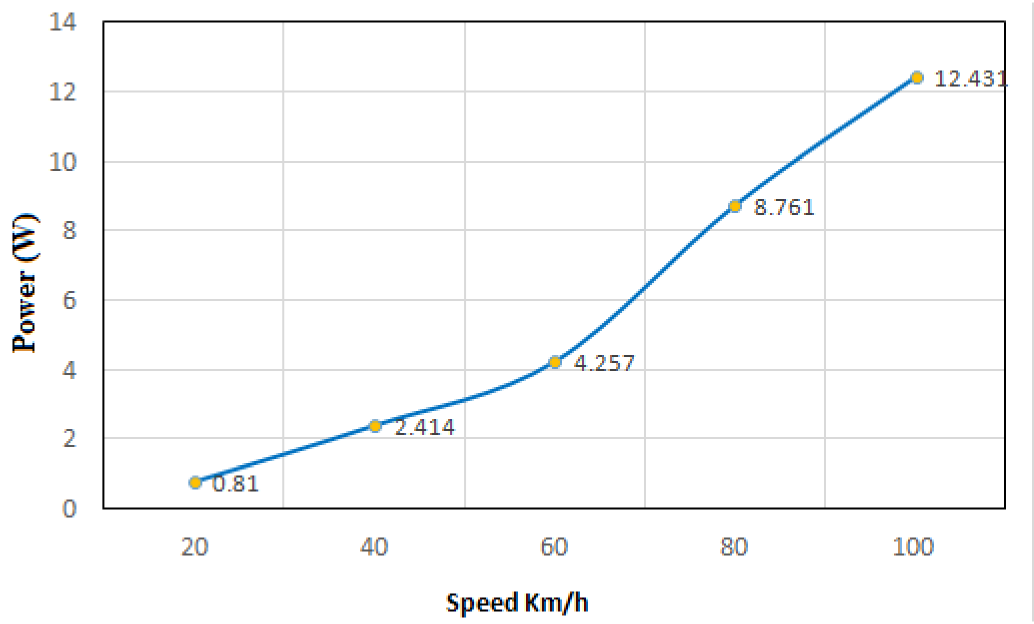

Figure 12. Graphical representation -power generated vs speed

5. CONCLUSION

The designed spoiler with integrated turbine can synthesis maximum of 12.4 watts of electricity at the speed of 90 km/hr when using 12 v motor. The power generated can be increased by using the motor with higher capacity. The power generated could be used to recharge the electric car when it in motion. Thereby one can reduce the duration of recharge which will increase the running time of the vehicle and reduce the power consumption and subsequent cost.

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Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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