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Aerodynamic Effect and Power from an Auxiliary Wind Turbine with Selected Motorcycles

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Abstract: Aerodynamic forces on motor cycles are important for its stability and fuel economy. In this paper, two motor bikes with and without wind turbine are tested in a subsonic open circuit wind tunnel. The parameters C_D, C_L and C_S are measured for a Reynolds number (R_e) range of 5.61×10^4 to 22.44×10^4 and the angle of attack (α) between 0° to 30°. It is found that there is no or little effect in lift and side forces if a wind turbine installed. Using Microsoft Excel, the functional relationship as third degree polynomial between the drag at $\alpha = 0^\circ$ and Reynolds numbers are proposed. The power loss was found using the air density, speed and frontal area with the corresponding drag coefficient. A comparison has been drawn between the power consumption in drag for the two motor cycles. In terms of power losses, installing a wind turbine is suitable up to a speed ≤ 55 km/h for racing bike and in all ranges in speed for dirt bike.
Keywords: Aerodynamics; motorcycle; Reynolds number, angle of attack; drag; power loss.

Nomenclature

Re	Reynolds number
v	Free stream velocity
w	Model width
$A_{frontal}$	Front projected area
A_{plan}	Plan area
A_{side}	Side projected area
C_D	Drag coefficient
C_L	Lift coefficient
C_S	Side force coefficient
F_D	Drag force
F_L	Lift force
F_S	Side force
P_{atms}	Atmospheric pressure
t_{room}	Room temperature
α	Angle of attack
γ	Kinematic viscosity
ρ_{tunnel}	Air density in wind tunnel
ρ_{air}	Air density
A	Turbine swept area
P	Available power
C_{Ddt}	Drag coefficient for dirt bike with turbine
C_{Ddn}	Drag coefficient for dirt bike without turbine
C_{Drt}	Drag coefficient for racing bike with turbine

1. Introduction

Motor cycles are used as popular means of transport in urban and rural areas. The motorcycles are categorized into two types namely racing and dirt motor cycles. Body design of two motor cycles is different due to their applications. The drag, lift and side forces on these motor cycles are depended on their body shapes and Reynolds numbers. The motor cycles should have minimum drag to achieve fuel efficiency. The lift mustbe zero or negative to become more stable. The side force should be minimum, so that it is not susceptible to toppling due to cross wind.

The wind blows in the opposite direction of the motorcycle when it is moving. The blowing wind has kinetic energy. Part of it can be recovered by a suitable designed wind turbine fitted in front of the motorcycle, which in turn will create additional drag. If the energy loss due to fitting a turbine is less than the energy gain from the turbine, then it is useful to use an auxiliary turbine. An experimental study has carried out in a wind tunnel to investigate the above.

A combined experimental and numerical study of motorcycle aerodynamic performance through belly pan design and improvement process has been discussed [1]. A $1/6^{th}$ scale motorcycle model was adopted and tested in a closed-return low-speed wind tunnel. A CAD model was also re-constructed and flow simulations using computational fluid dynamics (CFD) were performed. Based on wind tunnel tests and CFD simulations of the baseline model, it was found that the use of a belly pan improved the motorcycle aerodynamic performance.

Analyses on power storage alternatives for a specific case in the Columbia River Gorge for wind power have proposed [2]. A hierarchical decision model is developed with criteria including political, social, environmental, technical and economical.

A new usable solution to reduce the energy balance funding and increase the system reliability has been proposed in [3]. According to the results of the proposed system, system reliability has obtained more than 80% and the wind penetration level has increased by 9%.

A stand-alone wind power system with battery/super capacitor hybrid energy storage has proposed [4]. In this wind power system mainly consists of a wind turbine, a permanent magnet synchronous generator, hybrid energy storage devices based on a vanadium redox flow battery and a super capacitor, an AC/DC converter, two bidirectional DC/DC converters, a DC/AC converter and a variable load. S.N. Singh et al [5] have presented a technique on how to implement wind driven generator technology to produce electricity in charging of two wheeler (12V) automobile battery.

Yong Yin et al. [6] have studied and developed a fuzzy control strategy for battery charging or discharging used in a renewable power generation system to achieve the optimal charging and discharging status of the battery.

ower losses from aerodynamic drag and rolling friction for class-8 tractor tailor is calculated [7]. At a speed less than 50 mi/h, the losses from aerodynamic drag is less than that of rolling friction. When the speed increased beyond 50 mi/h, these losses from aerodynamic drag increases abruptly. In addition, average fuel consumption savings for three vehicles at 0.8 car-length spacing is about 6-7%.

G. Angle and W. Huebsch [8] have performed wind tunnel tests at various airspeeds on a full-scale racing motorcycle in the Closed Loop Tunnel at West Virginia University and in Old Dominion University, Langley. Counter-rotating vortices were generated using small commercially available vortex generators and 10% reduction in drag was obtained. Their research shows that the use of small vortex generators can reduce the overall drag.

In this paper, lift, drag and side forces on a model of racing and dirt bikes have determined using a wind tunnel. These aerodynamic data from the models were collected with and without auxiliary wind turbine. The power loss was calculated using the drag coefficient.

2. Experimental Measurement

The racing and dirt types of motorbikes (Scale 1: 12) was taken into consideration for the present investigation. For the wind tunnel experiment, 1:12 scale models of the above two types of motorbikes were used. The blockage ratio for the models was less than equal to 5 %. The models were placed horizontally to the wind tunnel floor for measuring drag and side forces. For measuring the lift force, the model was placed vertically with an end plate. All the experiments were conducted in the open subsonic HM 170, Eiffel type wind tunnel. In this type of tunnel, the air is taken and returned to the atmosphere. The designed nozzle shape of the wind tunnel ensures the constant distribution of velocity within the closed measurement section. The maximum velocity in the working section is 30 m/s. A honeycomb at the inlet ensures a low degree of turbulence. The wind tunnel consists of the inlet hopper with honeycomb, nozzle, working section, diffuser and fan as shown in Fig. 1.

Fig. 1. Wind tunnel.

The nozzle, inlet hopper and the working section are mounted on a guide rail to insert the testing model. An axial fan with a guide wheel is used to reduce the noise level and to improve efficiency. This fan is mounted on rubber elements to minimize vibration during operation. It is driven by a speed controller motor with the frequency converter and is connected permanently with the diffuser. The output signal from a two-component transducer measures the force experience by the model in two directions. The drag and side forces are measured when the motorcycle is placed in the normal to the bottom wall of the wind tunnel. In addition, the lift force is measured when the motorcycle is placed to the bottom wall with an end plate. The positive direction of angle of attack, lift, side forces and drag are shown in Fig. 2. The measured values are displayed on a measuring amplifier. An electronic velocity measuring device is used to display the velocity. A slanted tube manometer is used to compare displayed velocity at the inlet to the working section.

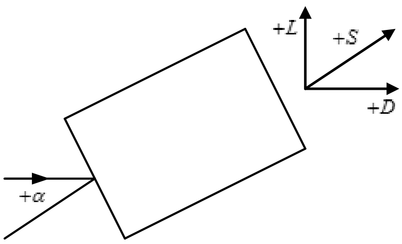

Fig. 2. Positive directions of angle of attack and aerodynamic forces.

The coefficients C_D, C_L and C_S are computed for a R_e range of 5.61×10^4 to 22.44×10^4 and α between 0° to 30°. At $\alpha = 0^\circ$, the drag coefficient versus Reynolds number curve is extended using the D-plot software to determine the drag coefficient as a function of Reynolds number. Power consumption due to drag has been calculated using the proposed equations. A comparison has been drawn between the power consumption in drag for the two motorbikes.

The Reynolds umber was computed based on the following equation:

$$\text{Re} = \frac{wv}{\gamma} \tag{1}$$

The air density in the tunnel is calculated by assuming the perfect gas equation as follows:

$$\rho_{tunnel} = \frac{P_{room}}{R(t_{room} + 273)} \tag{2}$$

The drag, lift and side force coefficients are calculated using the following formulae:

$$C_D = \frac{2F_D}{\rho_{tunnel} \times v^2 \times A_{frontal}} \tag{3}$$

$$C_L = \frac{2F_L}{\rho_{tunnel} \times v^2 \times A_{plan}} \tag{4}$$

$$C_S = \frac{2F_S}{\rho_{tunnel} \times v^2 \times A_{side}} \tag{5}$$

3. Results and Discussion

3.1. Aerodynamics

Drag-coefficients

The drag coefficient calculated from the data measured for racing bike with rider plotted against the angle of attack for different value of Reynold numbers, without wind turbine and with wind turbine respectively as shown in Figs. 3 and 4. From Fig. 3, it is seen that the C_D values increased with increasing angle of attach for all the investigated ranges of Reynolds numbers. For $\alpha = 0^o$, the drag coefficient is between 0.15 to 0.28 and at $\alpha = 30^o$, it is between 0.6 to 0.80. The same trend in variation of C_D with angle of attack can be seen in Fig. 4, except the ranges of variation are narrower. For $\alpha = 0^o$, the drag coefficient is between 0.32 to 0.35 and at $\alpha = 30^o$, it is between 0.65 to 0.75. At $\alpha = 0^o$, the drag coefficients without and with turbines is nearly the same for all Reynolds numbers. But, with increased α, the C_D values are increasing more for racing bike without the turbine compared to that with turbine, which means that it is advantageous to install a turbine when there is a cross wind and have no adverse effect when there is no cross wind. The drag coefficients of dirt bike with and without turbines are shown in Figs. 5 and 6.

From Fig. 5, it is observed that for $\mathrm{Re} = 11.2 \times 10^4$ to $\mathrm{Re} = 2.24 \times 10^4$, the variation of C_D with angle of attack follow an increasing trend with a narrow band. For the above Reynolds numbers C_D is around 0.15 and it is increasing with the angle of attack. At $\alpha = 30^o$, the drag coefficient is around 0.25. For $\mathrm{Re} = 5.7 \times 10^4$, the variation of C_D with α shows increasing trend with sinusoidal mode. However, the slope of the mean trend (0.004/deg.) line of $\mathrm{Re} = 5.7 \times 10^4$ is nearly same with curves for other Reynolds numbers (0.0042/deg.). In general, the value of C_D at $\mathrm{Re} = 5.7 \times 10^4$ is higher than other Reynolds numbers. For $\mathrm{Re} = 11.4 \times 10^4$ to $\mathrm{Re} = 22.83 \times 10^4$, the trend of variation of C_D with the angle of attach for dirt bike with and without turbines remains the same. This means that there will be no adverse effect by installing a wind turbine for the above mentioned ranges of Reynolds numbers. Whereas for $\mathrm{Re} = 5.7 \times 10^4$, there is an increase in C_D when installing a turbine. It may be mentioned that the actual motor bike will not operate at the above mentioned Reynolds number.

Lift coefficients

The Figs. 7 and 8 shows the lift coefficient calculated from measured data for racing bike and plotted against the angle of attack for different values of Reynold numbers, without and with wind turbines respectively. For dirt bike, the above are shown in Figs. 9 and 10 respectively.

In general, the value of the lift coefficient is higher for the lower Reynolds numbers and vice versa for all ranges of angle of attack. However, it will not be a major disadvantage as the lower Reynolds means a low speed, which the motor bike will not be operating for most of the time. In higher Reynolds numbers, installing a wind turbine will not create much additional lift, which means the stability will not affected by installing wind turbine.

For dirt bike, the lift coefficient versus angle of attack follows the same trend has already been discussed for racing bike. At higher Reynolds numbers, installing a wind turbine will not have an adverse effect on stability when there is no significant side wind.

Side Force coefficients

The side force coefficient for racing bike plotted against the angle of attack for different values of Reynolds numbers, without and with wind turbines as shown in Figs. 11 and 12 respectively. From Figs. 11 and 12, it is observed that the side forces increases with angle of attack. At $\mathrm{Re} = 5.6 \times 10^4$, the side force coefficient is always higher compare to other Reynolds numbers without wind turbine in all the ranges of angle of attack. From Reynolds numbers of $\mathrm{Re} = 11.2 \times 10^4$ to $\mathrm{Re} = 22.4 \times 10^4$, there is not much significant difference between the values of side force coefficients for both cases. Since, the motor bike will be operating in the above mentioned ranges of Reynolds numbers, as such installing a wind turbine will not be affected by toppling when there is a significant side wind (cross wind).

Figs. 13 and 14 shows the side force coefficient calculated from the data measured for dirt bike without and with wind turbine plotted against the angle of attack for different values of Reynolds numbers. The side force coefficient without and with the wind turbine increases with increasing of angle of attack for all the ranges of Reynolds numbers as can be seen in Figs. 13 and 14. There are no significant differences (for all ranges of α and Re) in side forces. Therefore, installing a wind turbine will not be susceptible to toppling when there is a significant cross wind.

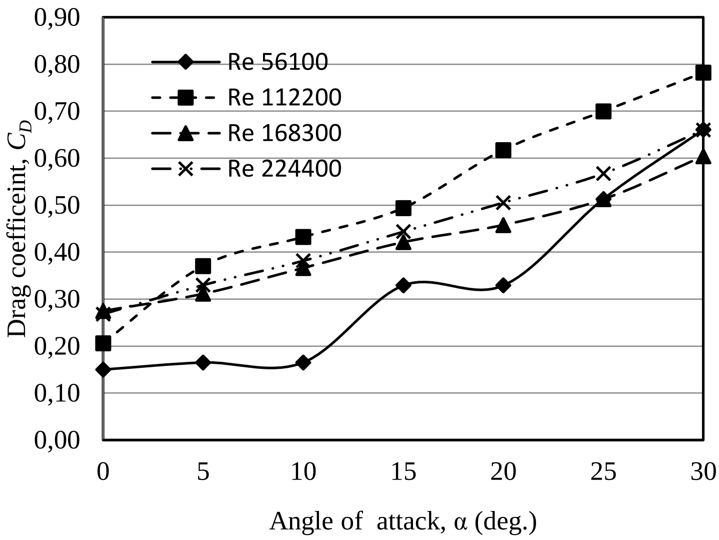

Fig. 3. Drag coefficients for racing bike without wind turbine

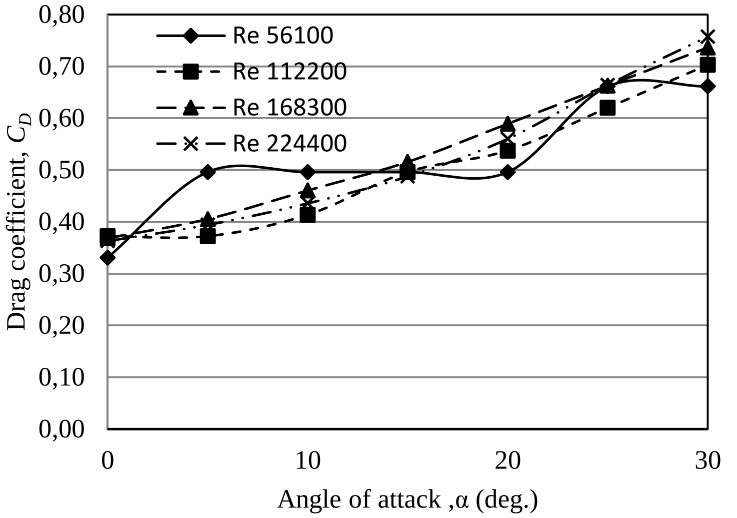

Fig. 4. Drag coefficients for racing bike with wind turbine

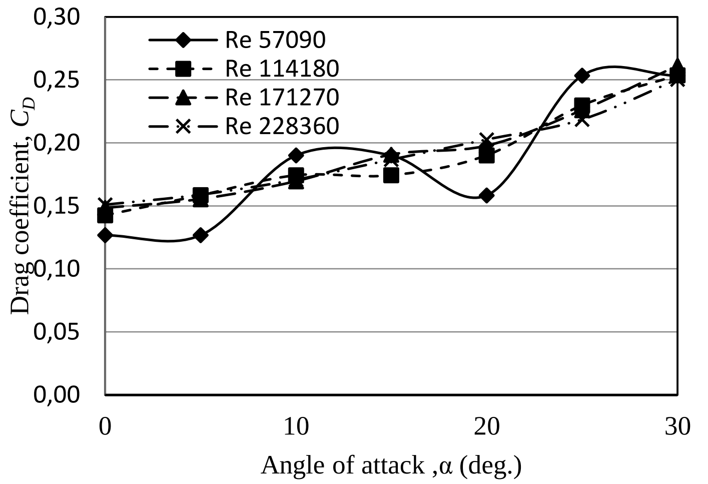

Fig. 5. Drag coefficients for dirt bike without wind turbine

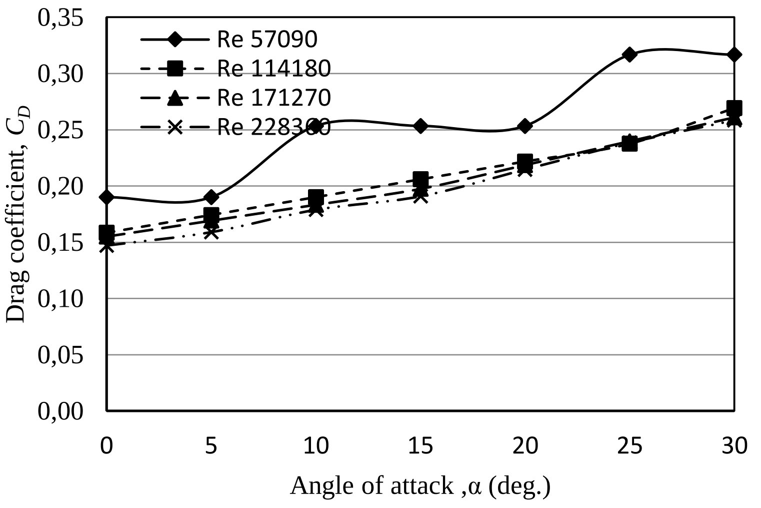

Fig. 6. Drag coefficients for dirt bike with wind turbine

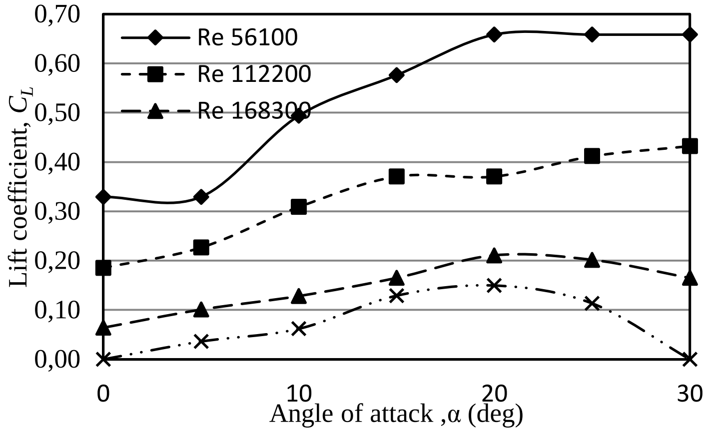

Fig. 7. Lift coefficients for racing bike without wind turbine

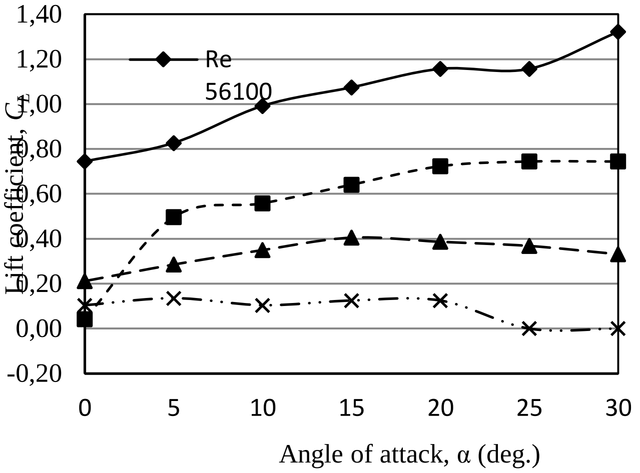

Fig. 8. Lift coefficients for racing bike with wind turbine

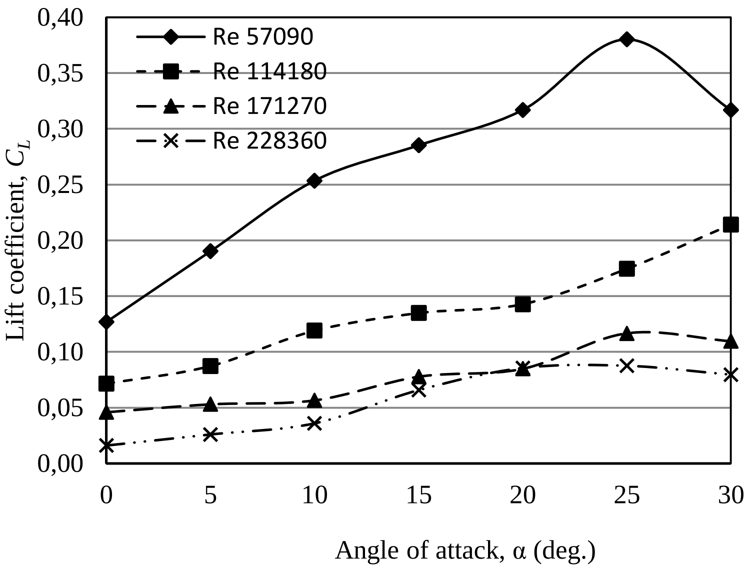

Fig. 9. Lift coefficients for dirt bike without wind turbine

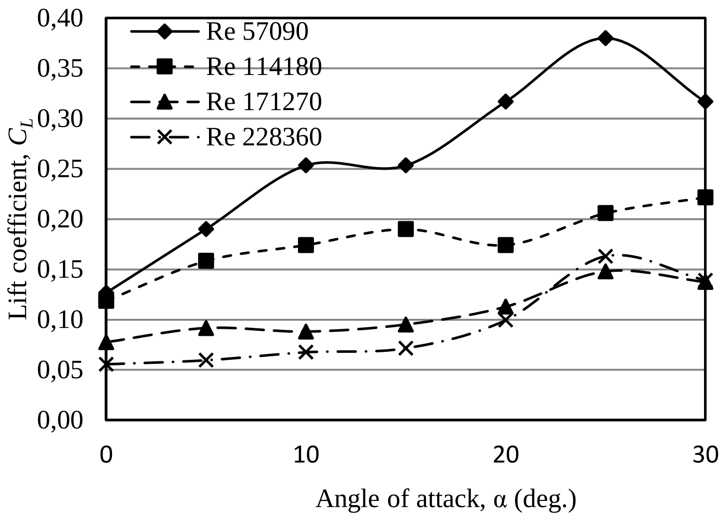

Fig. 10. Lift coefficients for dirt bike with wind turbine

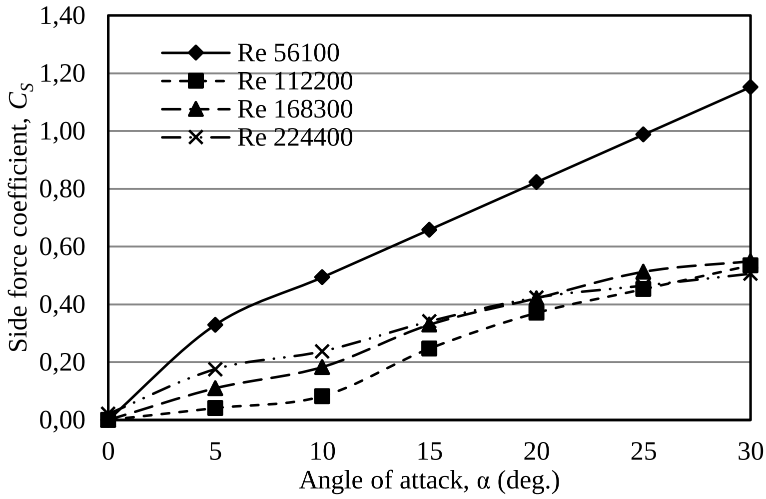

Fig. 11. Side force coefficients for racing bike without wind turbine.

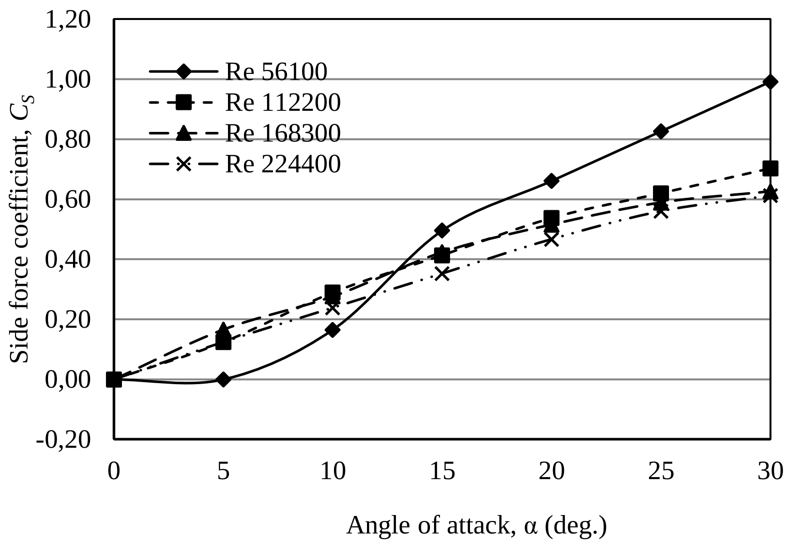

Fig. 12. Side force coefficients for racing bike with wind turbine

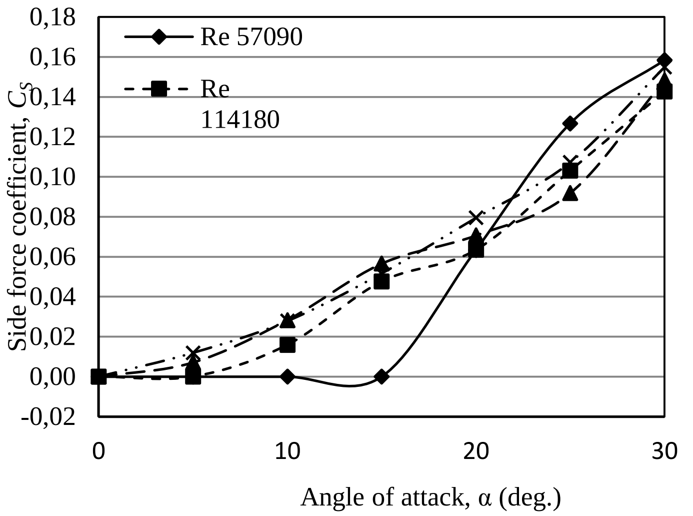

Fig. 13. Side force coefficients for dirt bike without wind turbine.

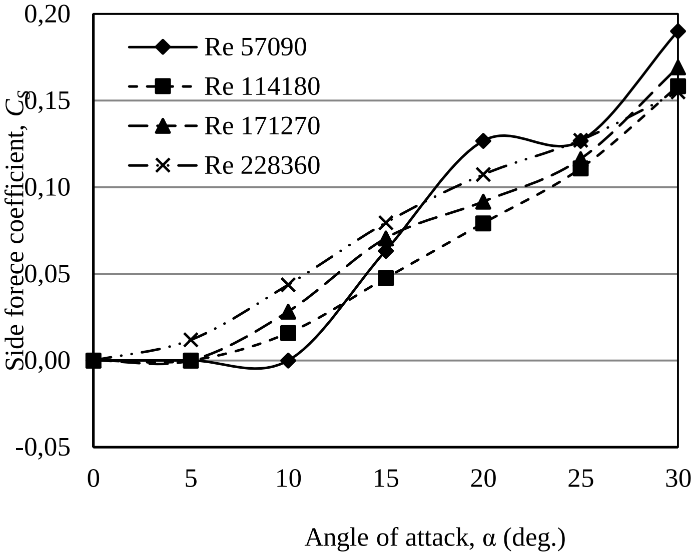

Fig. 14. Side force coefficients for racing bike with wind turbine.

3.2. Output Power from Wind Turbine

From the discussion in section A, it is evident that there is no or little adverse aerodynamic effect due to toppling or stability if the wind turbine is installed in front for both types of motor bike. As such the available power from the wind turbine will be free from those types of aerodynamic losses. The power available from a wind turbine with different propeller diameters can be determined as,

$$P = \frac{1}{2}\rho_{air} A v^3 \tag{6}$$

For the selected motorcycles, turbines with the rotor diameter from 0.1 m to 0.2 m are suitable. The density of air is found to be 1.2 kg/m^3 by using the normal atmospheric pressure of 102.325 kPa and the ambient temperature 25^{o} C. The available power is calculated for two different rotor sizes and speed using the calculated air density as shown in Table 1. The power loss can be determined as,

$$E_{loss} = \frac{1}{2} C_D \rho A_{frontal} v^3 \tag{7}$$

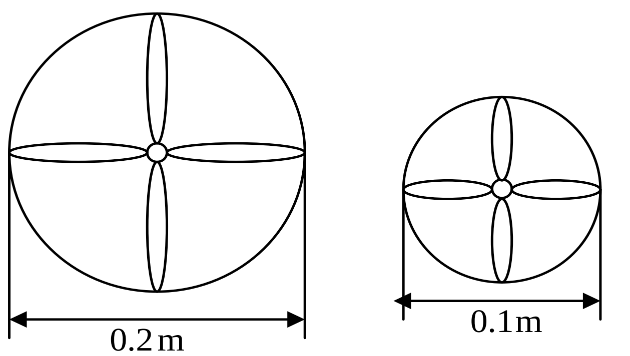

Fig. 15. The selected diameter of the wind turbine propeller.

Table 1. Available power from wind turbine for different wind speed.

Wind speed	Available power (W)

(m/s)	0.1 m diameter	0.2 m diameter
5	0.60	2.39
10	4.77	19.09
15	16.10	64.41
20	38.17	152.68
25	74.55	298.20

The third order functional relationship between the drag coefficient at zero degree angle of attack and the Reynolds is obtained by scatter plotting with Microsoft Excel software. Equations for racing and dirt bikes are as follows:

$$C_{Ddt} = 2e^{-17}\,\mathrm{Re}^3 + e^{-11}\,\mathrm{Re}^2 - 2e^{-6}\,\mathrm{Re} + 0.2745 \quad (8)$$

$$C_{Ddn} = 4e^{-18}\,\mathrm{Re}^3 - 3e^{-12}\,\mathrm{Re}^2 + 6e^{-7}\,\mathrm{Re} + 0.0988 \quad (9)$$

$$C_{Drt} = 2e^{-17}\,\mathrm{Re}^3 - e^{-11}\,\mathrm{Re}^2 + 2e^{-6}\,\mathrm{Re} + 0.2367 \quad (10)$$

$$C_{Drn} = 4e^{-19}\,\mathrm{Re}^3 - 4e^{-12}\,\mathrm{Re}^2 + 2e^{-6}\,\mathrm{Re} + 0.0532 \quad (11)$$

The power losses due to drag for racing and dirt bikes with and without turbines have been calculated using equations (7) and replacing C_D with corresponding values taken from equations (8) to (11). The calculated power loss due to drag for racing and dirt bikes are shown in Figs. 16 and 17 respectively.

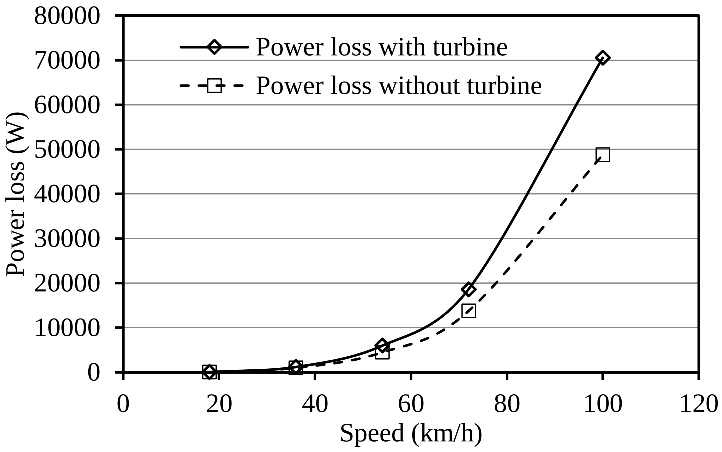

Fig. 16. Power loss for racing bike.

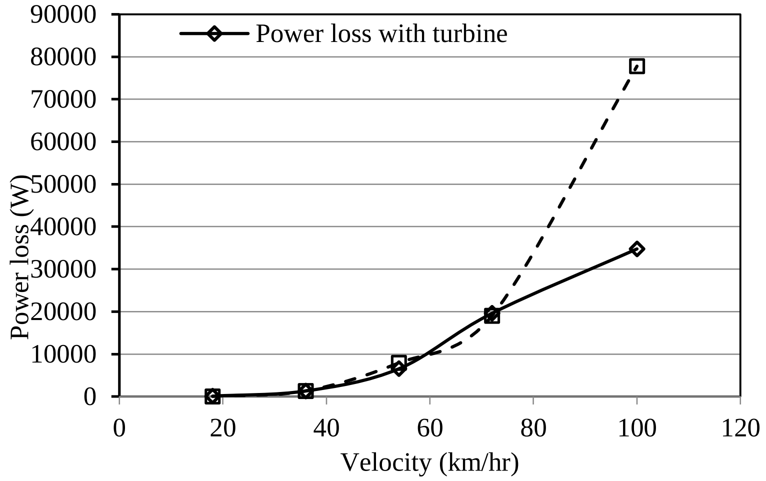

Fig. 17. Power loss for dirt bike.

From Figs. 16, it is seen that the power losses increases with increasing speed. The difference of power loss with and without turbine increases rapidly with the increase of speed. At the speed ≤ 55 km/h, the differences between two energies are minimum. Therefore, a wind turbine is suitable up to a speed of ≤ 55 km/h for a racing bike. For a speed of ≥ 60 km/h, the power gain from a wind turbine will be offset by the power loss from the drag. The same trend for power loss is also observed in Fig. 17. However, there is no or little difference in power loss between the two cases up to a speed of 72 km/h. When the speed increases more than 72 km/h, then there is a gain of power with installing wind turbine. Therefore, dirt bike is suitable for installing a wind turbine in all ranges of speed.

4. Conclusion

Drag, lift and side forces are measured for different angle of attack and Reynolds numbers with and without wind turbines for racing and dirt bikes. It is found that there is no adverse aerodynamic effect on lift and side forces if a wind turbine is installed in the frontal part of the motor bike. To find the power loss, the functional relationship between the drag coefficient and the Reynolds numbers are proposed by using Microsoft Excel with third degree polynomial. In terms of power losses, racing bike is suitable for installing a wind turbine up to a speed ≤ 55 km/h. In case of dirt bike, it is found that the installation of a wind turbine is suitable in all ranges of speed.

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