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Effect of Aerodynamic Drag Force Parameters on Electric Vehicle Motion Performance

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Abstract
This paper is aiming to study the effect of the aerodynamic drag force parameters which represents the air resistance on a vehicle motion performance, these parameters includes air density, aerodynamic drag coefficient, the equivalent frontal area of the vehicle, and Head-wind velocity. The complete vehicle was studied under different values of each parameter. Four mathematical equations of forces acting on a vehicle will be used to implement the Matlab Simulink model; these forces are Tractive, Aerodynamic, Gravitational, and rolling force. Various computer simulation results show significant differences of the vehicle motion and behaviour at some of aerodynamic drag force parameters.

Keywords: Vehicle model; Aerodynamic force; drag coefficient; Simulink model

Introduction

Electric vehicles are by many seen as the cars of the future as they are high efficient, produces no local pollution, are silent, and can be used for power regulation by the grid operator. However, electric vehicles still have critical issues which need to be solved. The three main challenges are limited driving range, long charging time, and high cost. The three main challenges are all related to the battery package of the car. The battery package should both contain enough energy in order to have a certain driving range and it should also have a sufficient power capability for the accelerations and decelerations. In order to be able to estimate the energy consumption of an electric vehicles it is very important to have a proper model of the vehicle (Gao et al., 2007; Mapelli et al., 2010; Schaltz, 2010). The model of an electric vehicle is very complex as it contains many different components, e.g., transmission, electric machine, power electronics, and battery. Each component needs to be modeled properly in order prevent wrong conclusions. The design or rating of each component is a difficult task as the parameters of one component affect the power level of another one. There is therefore a risk that one component is rated inappropriate which might make the vehicle unnecessary expensive or inefficient. In this paper a method for modelling the electric vehicle is presented and the effect of the aerodynamic drag force parameters which represents the air resistance on a vehicle motion performance will be obtained.

The focus in this paper will be on the modeling and design of the body motion of an electric vehicle and show how to implement the Matlab Simulink model of the car using the mathematical equations of the vehicle motion.

The work is organized as follows: After the introduction Section 2 describes the modeling of the vehicle, Section 3 presents the proposed Matlab Simulink model of the car, Section 4 provides a study the effect of the aerodynamic drag force parameters which represents the air resistance on a vehicle motion performance, these parameters includes air density, aerodynamic drag coefficient, the equivalent frontal area of the vehicle, and Head-wind velocity.

Vehicle Dynamic Model

The forces acting on a moving car are Tractive force, Aerodynamic force, Gravitational force, and Rolling force. Figure 1 shows the forces acting on the vehicle and the vehicle geometry.

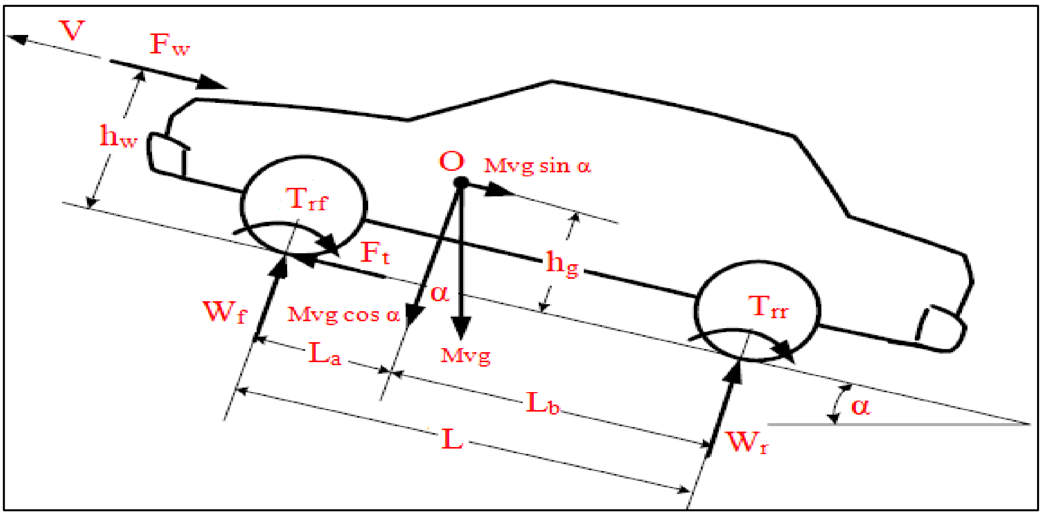

Fig.1: Forces acting on a vehicle.

Tractive force F_t: is the force pushing the car forwards and comes from the engine turning the wheels.

Aerodynamic force F_a: Aerodynamics is the science of how air flows around and inside objects. More generally, it can be labeled "Fluid Dynamics" because air is really just a very thin type of fluid. Above slow speeds, the air flow around and through a vehicle begins to have a more pronounced effect on the acceleration, top speed, fuel efficiency and handling.

$F_{AD}= sin[V]\ \{0.5\rho C_D A_F\ (V+V_w)^2\}$

Where

- ρ : Air density
- C_D: Aerodynamic drag coefficient
- A : Equivalent frontal area of the vehicle
- V : is vehicle speed
- V_w : Head-wind velocity

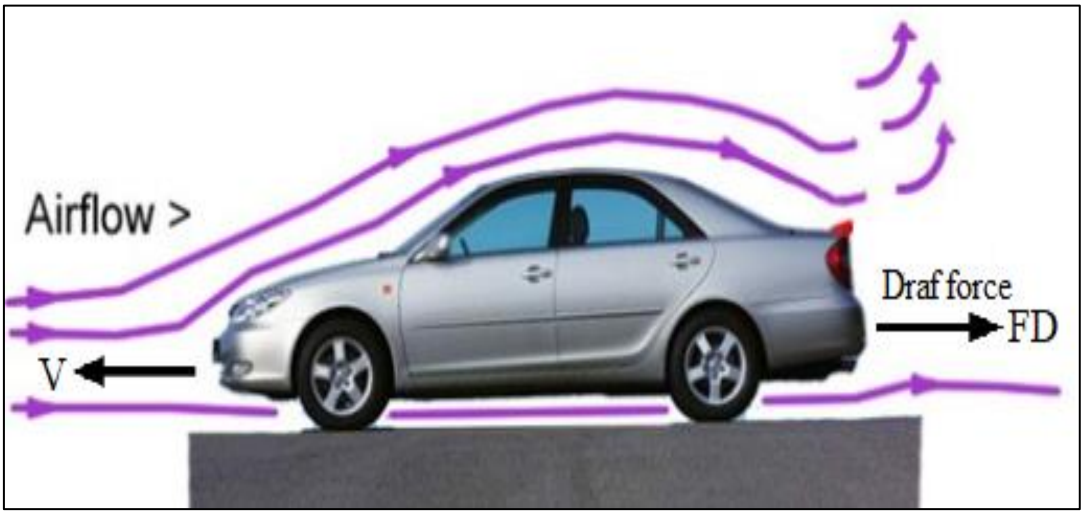

Fig.2: The drag force due to air flow acting on a car.

Rolling force F_{roll} : sometimes called rolling friction or rolling drag, is the force resisting the motion when a body (such as a ball, tire, or wheel) rolls on a surface. It is mainly caused by non-elastic effects; that is, not all the energy needed for deformation (or movement) of the wheel, roadbed, etc. is recovered when the pressure is removed.

$F_{roll}= sin[V]mg(\ C_0+\ C_1V^2)$

Where

- V : vehicle speed
- C_0: C_1 are rolling coefficients
- m : the total mass of the vehicle
- g : the gravitational acceleration constant

Gravitational force F_g: The gravitational force, Fg depends on the slope of the roadway; it is positive when climbing a grade and is negative when descending a downgrade roadway.

$F_g= mg\ sin\alpha$

Where

- α : the grade angle with respect to the horizon.

Vehicle Simulink Model

Figure 3 shows The Simulink model of the vehicle Simulink model which built by using the above equations in section 2.

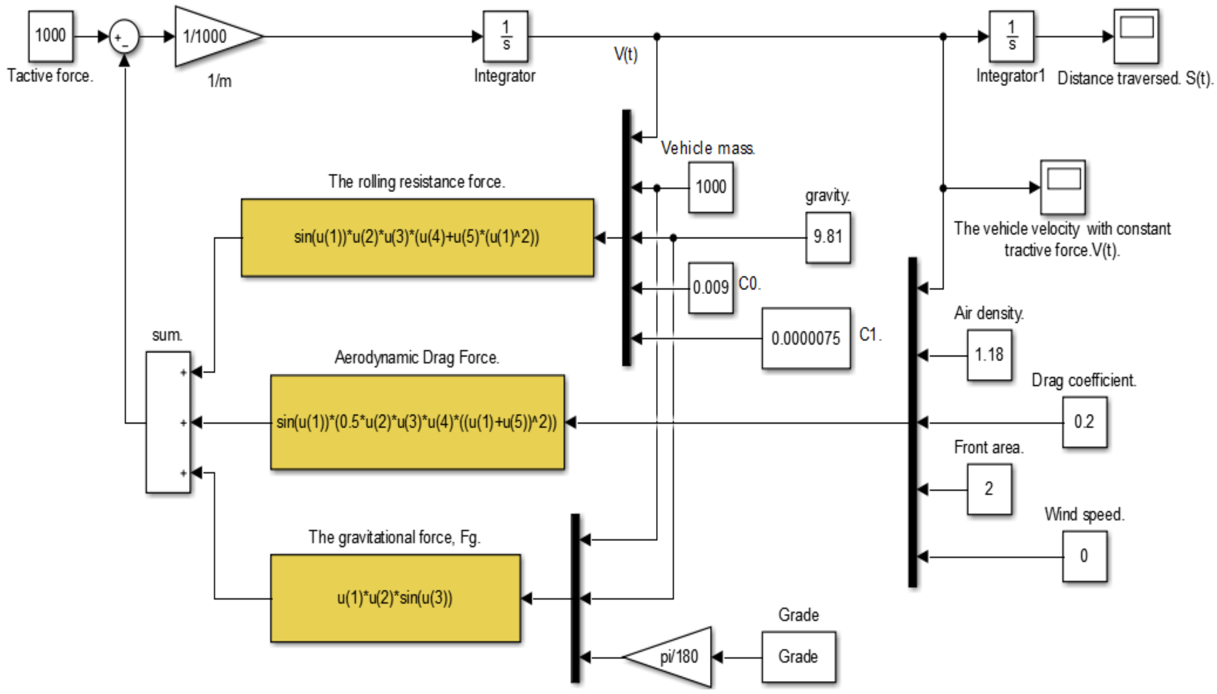

Fig.3: Vehicle Simulink Model.

Simulation Results

In this paper, the vehicle parameters used are given in the table below.

Table.1: The Main Parameters of Vehicle

Symbol	*Unit*	*Value*
A_F	m^2	2
C_0	s^2/m^2	0.009
C_1	s^2/m^2	0.0000075
m	Kg	1000
ρ	Kg/m^3	1.18
C_D	Non	0.2
α	Degree	0
g	m/s^2	9.81
V_w	m/s	0

Figure 4 shows the performance of the speed of the car at the physical parameters shown in the previous table where we note that the speed of the car increases until the maximum value and then became a constant value with constant tractive force.

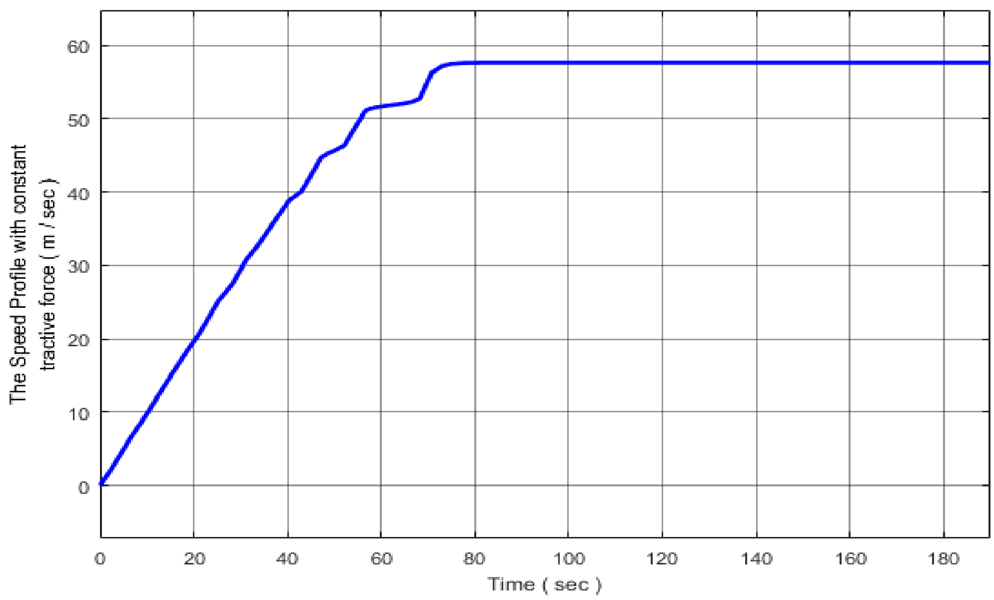

Fig.4: The Speed Profile with constant tractive force.

Effect of aerodynamic force parameters on the vehicle speed profile

Figures 5 to 7 show Analysis and results of effect of aerodynamic drag force parameters on electric vehicle motion performance when the grade angle with respect to the horizon.

Figure 5 presents the effect of the equivalent frontal area of the vehicle on the speed profile with constant tractive force (The selected value of the tractive force is 1000N), figure 6 illustrates the effect of the drag coefficients the speed profile, and figure 7 show the effect the Head-wind velocity on the vehicle speed.

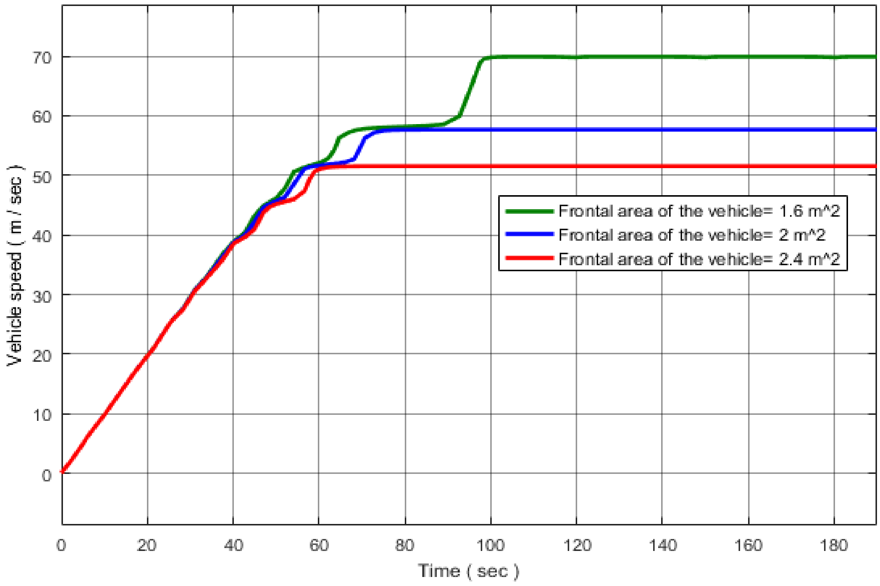

Fig.5: The Speed Profile with constant tractive force at different values of the equivalent frontal area of the vehicle.

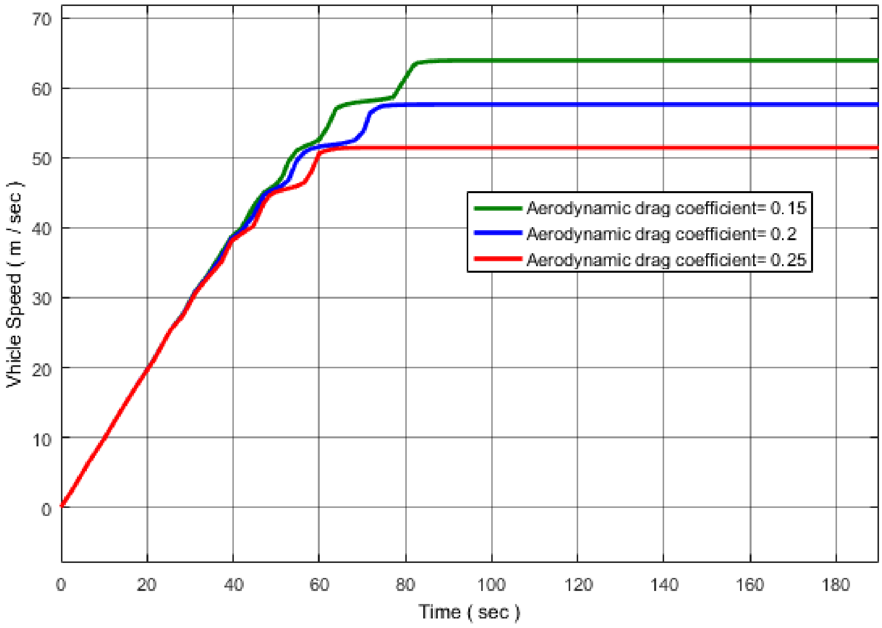

Fig.6: The Speed Profile with constant tractive force at different values of Drag Coefficients.

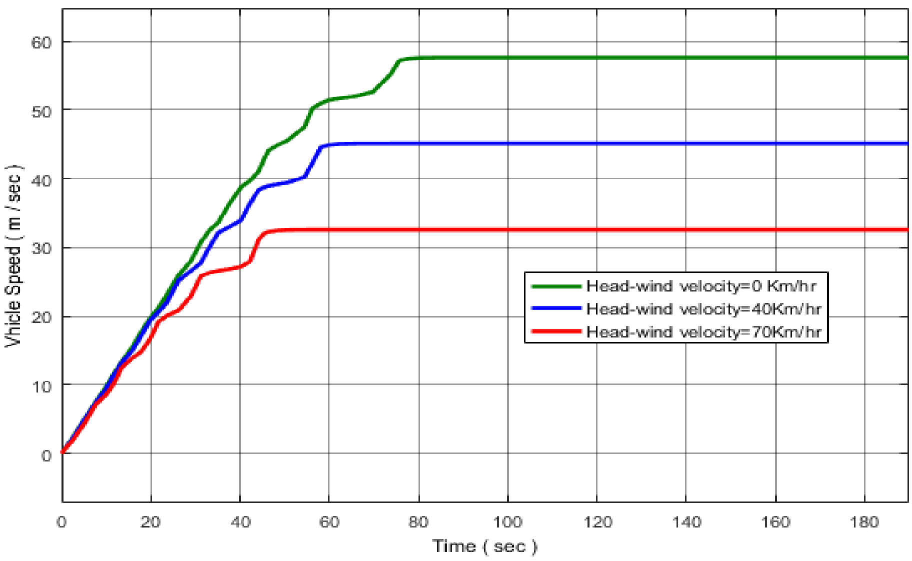

Fig.7: The Speed Profile with constant tractive force at different values of the Head-wind velocity**.**

Conclusion

This study shows significant effects of the aerodynamic drag force parameters which represents the air resistance on an electric vehicle motion performance, these parameters are the aerodynamic drag coefficient, the equivalent frontal area of the vehicle, and the head-wind velocity. The selected values of the equivalent frontal area of the vehicle were 1.6 m^2, 2 m^2, and 2.4 m^2, the selected values of the aerodynamic drag coefficient were 0.15, 0.2, and 0.25, while the selected values of the aerodynamic drag coefficient were 0 Km/hr, 40 Km/hr, and 70 Km/hr. It has been observed that the speed of the vehicle is directly proportional with the parameters mentioned above.

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