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Based on AVL-CRUISE Hybrid and Electric Vehicle Simulation and FTP-72 Circle Power Consumption Factor Analysis

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Abstract: With the rapid advancement of technology and the growing scarcity of energy resources, finding effective ways to reduce power consumption has become increasingly crucial. Hybrid and electric vehicles play a vital role in this endeavor, warranting deeper exploration and focus. In this study, I utilized AVL-Cruise software, a powerful tool for simulation and data modeling, to conduct comprehensive simulations of hybrid and electric vehicle performance, with a specific focus on analyzing the FTP72 cycle.The simulation results are highly encouraging. The vehicle achieved a maximum speed of 164 km/h, an acceleration rate of 3 m/s^2, a 0 to 100 km/h acceleration time of 9 seconds, and a maximum climbing slope of approximately 74%. These figures not only demonstrate that hybrid and electric vehicles can meet performance expectations but also highlight their capability to deliver on key metrics. Furthermore, the total energy consumption was recorded at 4200 kJ, underscoring the efficiency of these vehicles.In addition to the simulation outcomes, I delved into various factors that influence vehicle performance, including vehicle mass, drag coefficient, and motor power.Using MATLAB, I conducted a detailed analysis of the relationships between these factors and energy consumption, incorporating residual analysis and deriving a mathematical equation to describe these interactions.Through this extensive data analysis and model fitting, we gain a deeper understanding of hybrid and electric vehicle dynamics. This research not only contributes to the field but also has the potential to drive further development, broadening the focus and scope of hybrid and electric vehicle technology.

Keywords: AVL-Cruise, simulation, hybrid and electric vehicle, cycle.

1. Introduction

The ongoing shortage of oil resources, coupled with the environmental pollution associated with the automotive industry, poses significant challenges for sustainable development. As global awareness of these issues grows, hybrid and electric vehicles emerge as a viable solution, offering unmatched advantages in energy efficiency and environmental protection[1].Therefore, research in this field is vital, as it provides insights into optimizing vehicle performance and energy consumption. The utilization of advanced tools such as AVL-CRUISE offers effective modeling of dynamic performance, allowing for accurate simulation of urban driving cycles and other operating

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conditions[2].In this paper, I focus on key performance indicators related to vehicle dynamics, including maximum speed, acceleration time, and maximum climbing ability. The simulation results demonstrate satisfactory performance, with a maximum speed of approximately 164 km/h, a 0 to 100 km acceleration time of 9 seconds, and a maximum climbing capacity of 74%.By utilizing both AVL-CRUISE and MATLAB, I illustrate and develop a mathematical equation to describe the relationships between these parameters and the overall performance of hybrid and electric vehicles. The study incorporates comprehensive data analysis and model-fitting techniques, offering a deeper understanding of the factors that influence electric vehicle performance.Through this research, I aim to provide valuable insights that can help optimize the design and development of more efficient and environmentally friendly hybrid and electric vehicles.

2. Dynamic simulation

2.1. Vehicle Motion Equation

The performance of an electric vehicle mainly depends on the external forces acting in the direction of its movement, specifically the driving force and the driving resistance[3].

The driving force of an electric vehicle is obtained by transmitting the torque output from the motor to the drive wheels through the transmission system. The relationship between the driving force of the electric vehicle and the motor output torque is as follows.

$$F_t = \frac{T_e i_t \eta_t}{r}$$

where F_t is the driving force of the electric vehicle,T_e is the motor output torque,$i_t$is the overall transmission ratio of the transmission system,$\eta_t$is the efficiency of the transmission system, and r is the rolling radius of the tires.

The relationship between motor output torque and speed is the primary basis for calculating vehicle performance. Electric motors have the characteristic of constant torque at low speeds and constant power at high speeds, so the motor torque can be calculated based on motor speed. The calculation formula is:

$$T_e = \begin{cases} T_c & n \le n_b \\ \dfrac{9550 P_e}{n} & n > n_b \end{cases}$$

where T_c represents the motor's constant torque at low speed; P_e represents the motor's constant power at high speed; n is the motor speed, and n_b is the base speed of the motor.

The relationship between the vehicle speed and the motor speed for an electric vehicle is given by:

$$u = \frac{0.377rn}{i_t}$$

where u is the speed of the electric vehicle.

During the operation of an electric vehicle, the main resistive forces include rolling resistance, air resistance, gradient resistance, and acceleration resistance.

The rolling resistance of an electric vehicle refers to the energy loss per unit distance traveled by the tires, primarily caused by the deformation between the tires and the road surface. Its expression is given by:

$$F_f = mgf\cos\alpha$$

F_f represents the rolling resistance of the electric vehicle, m is the mass of the electric vehicle, f is the rolling resistance coefficient, and α is the slope angle.

The air resistance of an electric vehicle refers to the component of the force exerted by the air in the direction of travel when the vehicle is moving in a straight line. This force depends not only on

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the driving speed but also on the front area of the vehicle and the air resistance coefficient. Its formula is given by:

$$F_w = \frac{C_D A u^2}{22.15}$$

where F_w represents the air resistance of the electric vehicle, C_D is the air resistance coefficient, and A is the front area.

When an electric vehicle is climbing, the component of gravitational force along the slope is known as the gradient resistance of the electric vehicle. Its expression is given by:

$$F_i = mgsin\alpha$$

where F_i represents the grade resistance of the electric vehicle.

The acceleration resistance of an electric vehicle refers to the inertial force that must be overcome due to the vehicle's mass when it accelerates. The expression is as follows:

$$F_j = \delta m \frac{du}{dt}$$

where $F_j$represents the acceleration resistance of the electric vehicle, δ represents the rotational mass conversion factor, $\frac{du}{dt}$ represents the acceleration of the electric vehicle.

Therefore, the overall driving equation for an electric vehicle is:

$$\frac{T_e i_t \eta_t}{r} = mgfcos\alpha + \frac{C_D A u^2}{22.15} + mgsin\alpha + \delta m \frac{du}{dt}$$

2.2. Select Hybrid and Electric Vehicle Parameters

The parameters of the Hybrid and Electric Vehicle which is selected in this article and the model of it that is built by AVL-Cruise are given below[4][5]:

Table 1: Driving Parameters and Motor Battery

Driving Parameters	
Projects	Value
Curb Weight kg	1060
Gross Weight kg	1400
Friction Coefficient of Tire η	0.012
Air Resistance Coefficient μ	0.292
Front Area (m^2)	1.8
Wheel Base (mm)	2500.0
Reference Wheel Load (N)	3260.0
Static Rolling Radius (mm)	285.0
Static Rolling Radius (mm)	296.0
Motor Battery	
Maximum Charge	10.0 Ah
Initial Charge	95.0%
Nominal Voltage(V)	300.0
Maximum Voltage(V)	400.0
Minimum Voltage(V)	200.0
Running Temperature	25.0℃

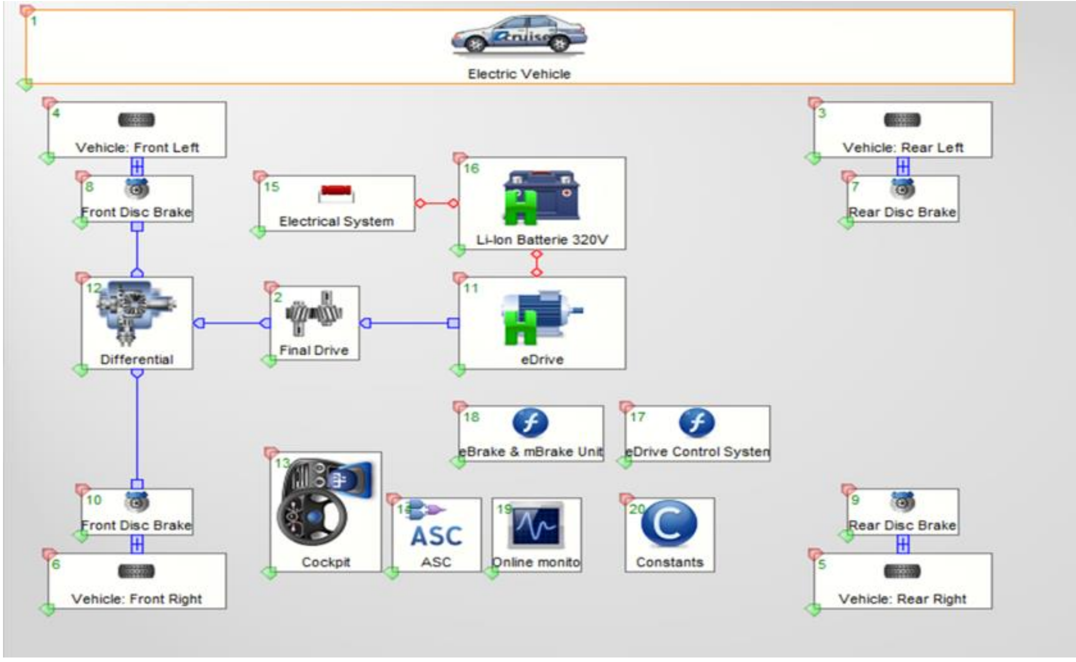

Figure 1: Urban Cycle Simulation of Distance, Velocity and Acceleration of Vehicle.

2.3. Simulation results and analysis

To enhance the understanding of vehicle performance, I conduct simulations of acceleration performance, maximum speed acceleration and incline under appropriate environment and vehicle conditions[6].

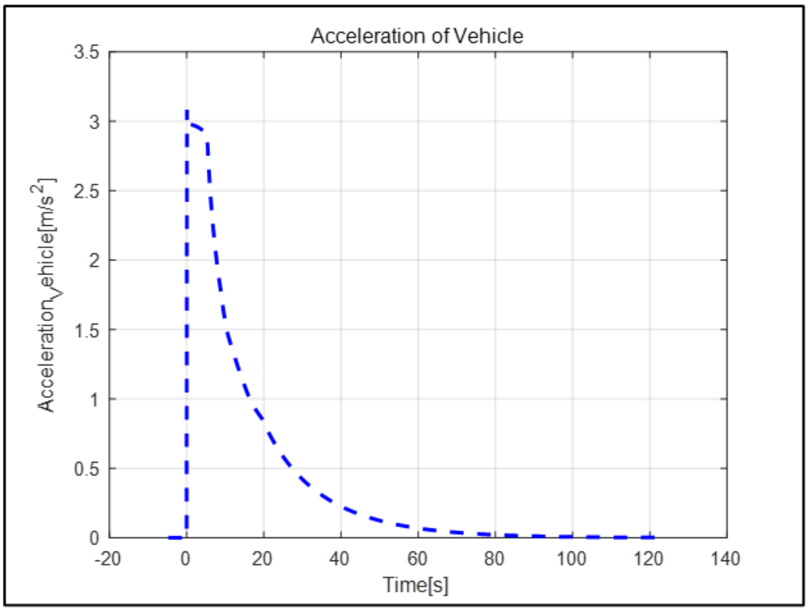

Figure 2: Simulation of Acceleration Performance.

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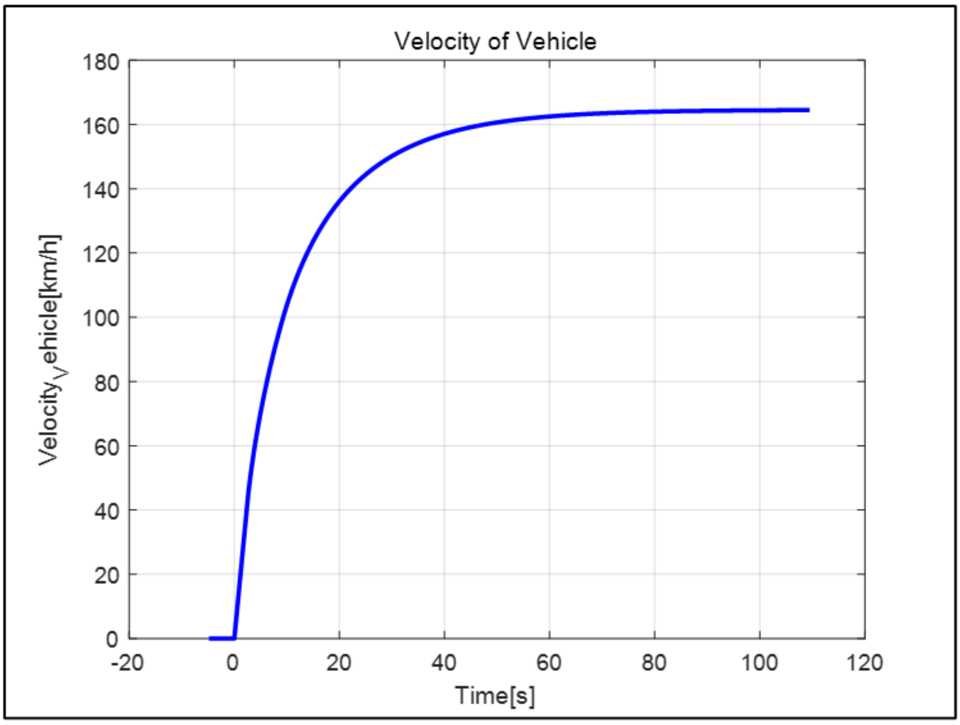

Figure 3: Maximum Speed Acceleration.

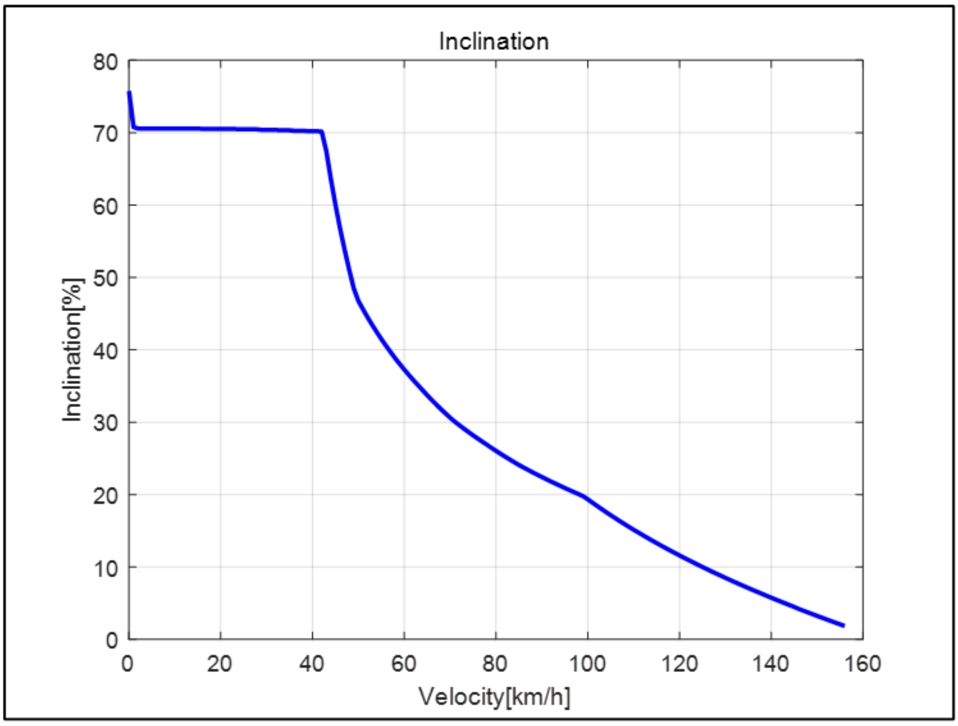

Figure 4: Simulation of Inclination Performance.

According to the Figure 2and 3,the maximum acceleration of the simulated hybrid and electric vehicle is about 3 m^2/s, and the 100 km acceleration time is about 9s.The acceleration of the vehicle from standstill to 50 km/h is about 3s,and the static acceleration response time at 50 to 80km is about 3.2s.According to the Figure 3,the maximum speed of the vehicle is approximately 164km/h. In terms of Figure 4,the max climb slop is around 74%.The slop remains at approximately 70% in the range of 1km/h and 43 km/h, followed by a continuous decrease to 6% which the velocity raises to 140km/h. Therefore, the acceleration performance and maximum speed as well as climb performance of the model meet the design requirements.

3. FTP72 cycle performance simulation and optimization

3.1. FTP72 cycle simulation

In order to learn the consumption and process of the FTP72 cycle, I remain the above selected parameters and working conditions to conduct a simulation of the cycle. And the FTP72 cycle performance simulation is shown below:

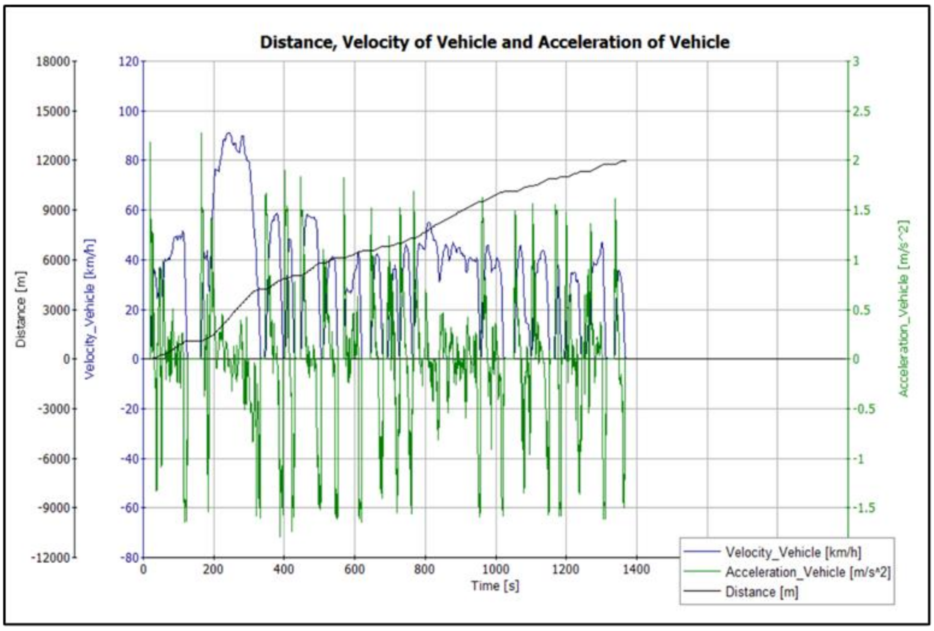

Figure 5: FTP-72 Cycle Simulation of Distance, Velocity and Acceleration.

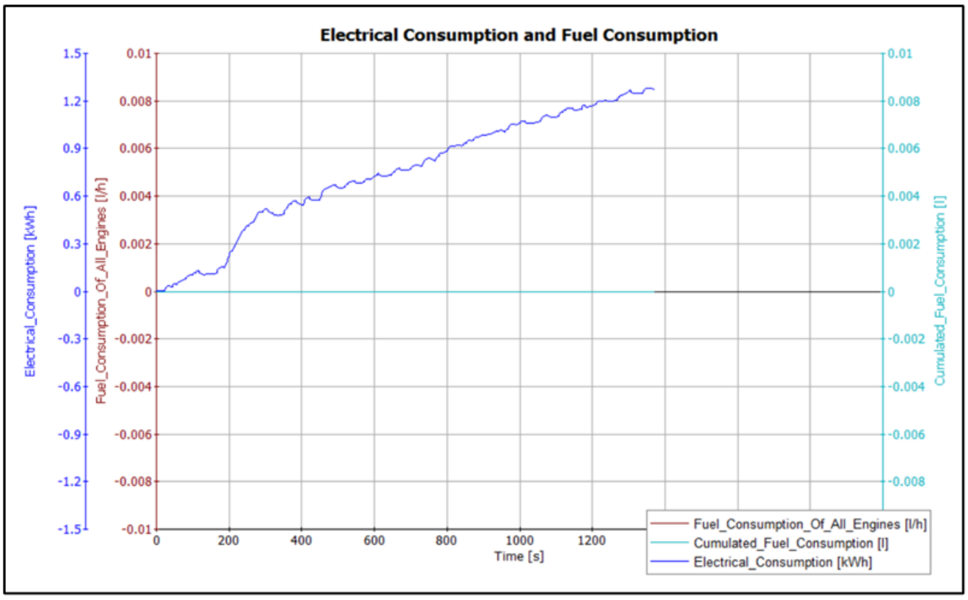

Figure 6: FTP72 Cycle Simulation of Electrical Consumption and Fuel Consumption.

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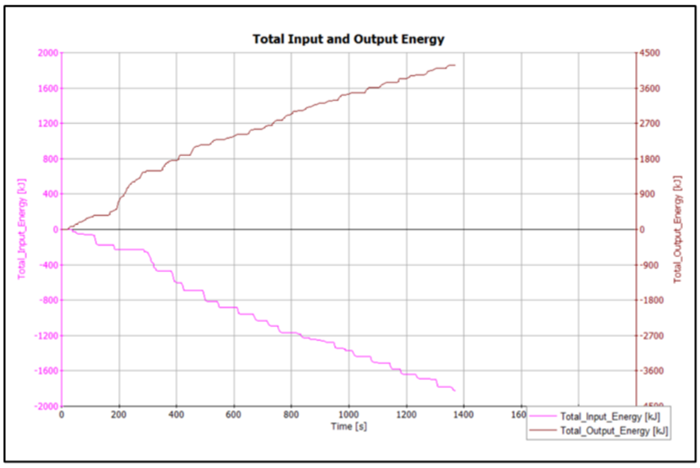

Figure 7: FTP72 Cycle Simulation of Electric Total Input and Output Energy.

The following presents the hybrid and electric vehicle cycle simulation data based on AVL-Cruise with Figures 5, 6 and 7 illustrating the Distance, Velocity and Acceleration of Vehicles, Electrical Consumption and Fuel Consumption and Electric Total Input and Output respectively. According to Figure 6,the Electrical Consumption at the end of the urban cycle is approximately 0.0082 kwh.

As shown in Figure 7, the final energy consumption of the hybrid and electric vehicle is almost 4200 KJ. To address the energy consumption issues in most vehicles which are prevalent on the market, it’s a must to learn the factors affecting the vehicle energy consumption.

3.2. Analysis on the influencing factors of energy consumption of hybrid and electric vehicle cycle condition

3.2.1. Mass and Energy Consumption

From the Figure 8,the energy relationship is obtained by changing the mass of the vehicle when simulation in the appropriate condition. We can draw mass and energy consumption has an approximate linear relevance. Matlab is used to conduct correlation analysis. And the equation of mass and energy consumption is:

$$P = 0.0042M + 4.3915$$

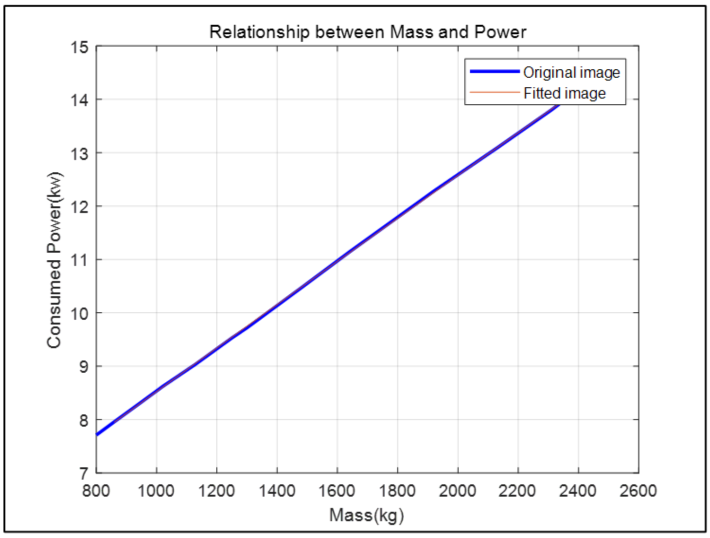

Figure 8: Relationship between Mass and Power.

In addition, in terms of Figure 9,the residual analysis is showed. All the data are in the confidence interval. As a result, the energy consumption could be decreased about 400 KJ when the mass if reduced by 100 kg. Therefore, we should try to deplete the mass of vehicle to cut down the consumption. For example, optimizing the design, structure and material or optimizing the battery's mass or construction can reduce the electric consumption.

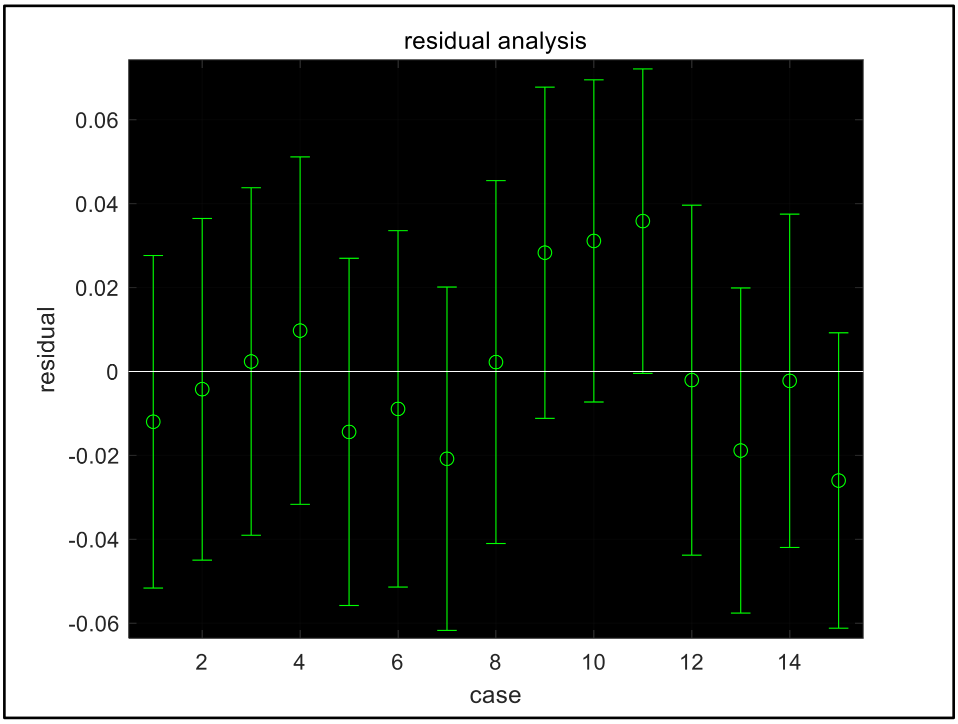

Figure 9: Residual analysis.

3.2.2. Drag Coefficient and Energy Consumption

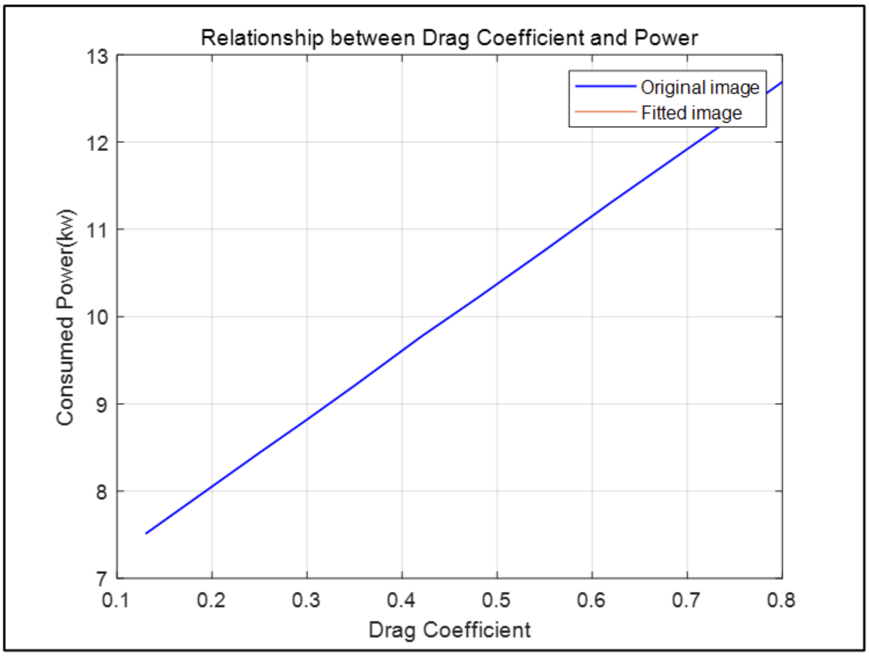

Figure 10: Relationship between Drag Coefficient and Power.

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As the same, by changing the drag coefficient we can get the energy consumption when in appropriate environment. According to fitting results, the relationship between drag coefficient and consumed power is:

$$P = -0.0741x^2 + 7.8039x + 6.4934$$

We can draw that the relationship is approximately quadratic function. And the residual analysis meets expectations in the cycle condition.

3.2.3. Motor Power and Energy Consumption

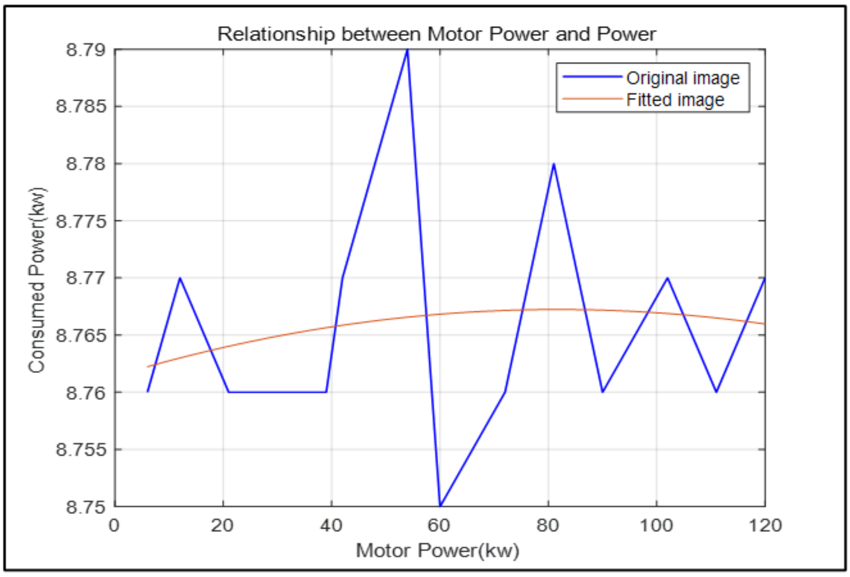

Figure 11: Relationship between Motor Power and Power.

Similarly, we can obtain the relationship between motor power and consumption by using the matlab. And the equation is showed below:

$$P = 0.0001x + 8.7614$$

According to the relationship, we can learn the motor power has a little impact on the consumed power. And by changing the number of Cells per Cell-Row, the changing tendency remains the same as well. However, the number of the Cell-Rows and its arrangement will influence the structure of battery. Thus, optimizing the number and array of Cell-Rows may enhance the performance of vehicle[7][8].

4. Conclusion

In conclusion, this paper presents the development of a simulation model for hybrid and electric vehicles using AVL-Cruise software, providing a comprehensive assessment of their performance. Initially, I derived the equations of motion relevant to the dynamic behavior of these vehicles. Following this, I conducted simulations under appropriate conditions and environments to evaluate key performance metrics. The simulation results demonstrate that hybrid and electric vehicles meet essential performance requirements, including acceleration, maximum speed, and climbing capability. The vehicles achieved a top speed of 164 km/h, an acceleration rate of 3 m/s^2, and a maximum climbing ability of 70%. These outcomes highlight the vehicles' potential to perform effectively in real-world conditions. I further analyzed the factors influencing vehicle performance during the FTP72 cycle. The results indicated a power consumption of approximately 0.0082 kWh, with total energy consumption reaching nearly 4200 kJ. A notable linear relationship between vehicle mass and

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power consumption was observed; as mass increases, energy consumption rises correspondingly. Residual analysis confirmed that all data points fall within the confidence interval, validating the reliability of the simulation results. Additionally, I explored the relationship between the drag coefficient and power consumption, identifying an approximate quadratic correlation. As the drag coefficient decreases, energy consumption also decreases, underscoring the significance of aerodynamic efficiency. Furthermore, the relationship between motor power and energy consumption was investigated. The findings, as presented in Figure 10, suggest that motor power has a minimal impact on energy consumption, unlike factors such as the number of cells per cell-row and the number of cell-rows. However, modifying the battery connection method or its structural design could potentially reduce total energy consumption, thereby optimizing vehicle design. The model developed in this study offers valuable data and insights that can facilitate the optimization of hybrid and electric vehicles, broadening their development scope and enhancing their viability as sustainable transportation solutions.

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