MINISTRY OF INDUSTRY AND TRADE
HANOI UNIVERSITY OF INDUSTRY

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RESEARCH ON THE INFLUENCE OF THE WEIGHT OF 5 - SEATER CARS ON FUEL CONSUMPTION

Major: Mechanical Engineering

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SUMMARY OF DOCTORAL THESIS IN ENGINEERING

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This dessertation has been completed at:

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The dessertation can be found at**:**

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INTRODUCTION

1. The urgency of the topic

In the context of Vietnam's strong economic growth, the demand for five-seat passenger cars has been increasing, leading to a significant rise in fuel consumption in the transportation sector. In response to fluctuations in fuel prices and the growing need for efficient energy use, studying the factors affecting vehicle fuel consumption is of considerable economic, technical, and environmental significance. Among these factors, vehicle mass is a fundamental parameter that directly affects the tractive force and the power required from the engine, thereby influencing fuel consumption; however, it has not yet been adequately addressed in practical research in Vietnam. Investigating the relationship between the mass of five-seat passenger cars and fuel consumption provides a scientific basis for optimizing vehicle design, applying lightweight materials, reducing vehicle mass, improving fuel efficiency, and lowering CO_2 emissions, thereby contributing to the development of energy-saving and environmentally friendly automobiles.

Based on the issues mentioned above, it is affirmed that the topic " *Research on the influence of the weight of 5-seater cars on fuel consumption* " is necessary and has practical significance, contributing an important factor to the problem of fuel saving, improving energy efficiency, and supporting the direction of design, production, assembly, and use of automobiles in Vietnam in the future.

2. Novelty of the thesis

Studies quantitatively assessing the specific impact of vehicle weight on fuel consumption, particularly for 5-seater passenger cars under Vietnamese traffic conditions, are still relatively limited.

Based on this reality, the thesis proposes a new approach that integrates dynamic modeling, simulation, and experimentation to truly clarify the relationship between the overall weight of a car and fuel consumption in real-world operation. On this basis, the thesis has the following novel points:

- To develop a longitudinal vehicle dynamics model in order to establish a quantitative relationship between vehicle mass and fuel consumption, while separately analyzing the effect of vehicle mass on resistance forces and required power;
- To develop the algorithm and the FC_{stat} simulation model in Matlab/Simulink for calculating fuel consumption under varying vehicle mass conditions, with comparison against experimental results to improve reliability;
- To design and fabricate a real-time fuel measurement system capable of collecting operational data such as vehicle speed, throttle position, pedal force, and fuel consumption;
- To combine theoretical analysis, simulation, and experimental studies in order to establish an empirical function describing the relationship between vehicle mass and fuel consumption with high accuracy;
- To propose fuel consumption reduction solutions through vehicle mass reduction, particularly by using lightweight materials in vehicle design.

The novelty of the dissertation lies not only in its research content but also in its integrated approach combining theoretical modeling, experimental data acquisition, simulation, and comparative analysis, which is well suited to the practical operating conditions of automobiles in Vietnam.

3. Research objectives, research subjects, and scope of the thesis.

a) Objectives of the dissertation topic:

General Objective:

To investigate, analyze, and quantify the influence of the mass of a five-seat passenger car on fuel consumption, thereby proposing technical solutions and recommendations to optimize fuel efficiency under actual operating conditions in Vietnam.

Specific Objectives:

- To establish the theoretical foundation for the relationship between vehicle mass and fuel consumption. This includes systematizing vehicle dynamics theoretical models related to the influence of mass on resistance forces, tractive force, and power consumption. The characteristic mass parameters of a five-seat passenger car, including curb mass, gross vehicle mass, and load distribution, are identified, and the mechanisms by which they affect energy consumption are clarified.

- To develop a mathematical model describing the relationship between vehicle mass and fuel consumption. This includes establishing equations and theoretical computational models to represent fuel consumption as a function of vehicle mass under different operating conditions, including urban, suburban, and highway driving modes. The accuracy of the model is validated through comparison with experimental data.

- To conduct experimental measurements of fuel consumption for a passenger car under real driving conditions. An experimental procedure for fuel consumption measurement suitable for Vietnamese operating conditions is designed, and experimental data are collected and processed based on at least 3–5 real-world driving cycles.

- To quantitatively analyze the influence of vehicle mass on fuel consumption. The correlation function and the influence coefficient between vehicle mass and fuel consumption (L/100 km) are determined for each operating mode. In addition, the individual contribution of vehicle mass is evaluated and analyzed in comparison with other factors, such as the aerodynamic drag coefficient and the rolling resistance coefficient.

- To propose technical solutions and application-oriented recommendations. Engineering solutions for reducing vehicle mass through the use of lightweight materials are proposed in order to improve fuel efficiency.

b) Research subjects:

It is the relationship between the overall weight of a 5-seater car and its fuel consumption, mediated by factors including drag force, engine power, and powertrain characteristics.

The specific subject of study was the 5-seater Toyota Vios, chosen because its technical characteristics are common in the passenger car segment in Vietnam, making it suitable for simulation and experimentation.

c) Scope of research: This study investigates, simulates, and experimentally examines the influence of the overall weight of a 5-seater passenger car (Toyota Vios 2009) on fuel consumption under real-world operating conditions in Vietnam. The research is conducted using a motion dynamics model and a fuel consumption simulation model, combined with experimental fuel consumption measurements to verify the model results.

4. Scientific and practical significance.

- Scientific significance: The dissertation establishes a scientific foundation for the calculation and simulation of the relationship between vehicle mass, motion resistance forces, and fuel consumption. It also proposes a simulation basis for replacing conventional body mass with lightweight materials, thereby contributing to the enhancement of the scientific database supporting research, simulation, and experimental studies on fuel consumption, energy efficiency, and emissions in transportation.

- Practical significance: The research results support manufacturers in vehicle design and structural optimization toward mass reduction and improved fuel efficiency, thereby contributing to the development of sustainable transportation systems and the reduction of environmental impacts.

- Applicability in the automotive industry: The topic is consistent with current development trends in the automotive industry, in which manufacturers focus on the application of lightweight materials and advanced technologies to reduce vehicle mass while still ensuring safety, durability, and operational efficiency.

- Significance for users: The research findings help raise users' awareness of the influence of vehicle load on fuel consumption, thereby encouraging more rational vehicle use and improved fuel-saving practices.**

5. Research content and structure of the thesis:

The thesis has four chapters:

- Chapter 1: Overview of Research
- Chapter 2: Scientific Basis of Research
- Chapter 3: Analyzing the influence of weight on fuel consumption materials in the car
- Chapter 4: Experimental Research

CHAPTER 1: OVERVIEW OF RESEARCH

Chapter 1 focuses on research related to:

The relationship between fuel consumption and vehicle weight, indicators for evaluating the fuel economy of automobiles, solutions for reducing automobile fuel consumption, etc.

Research findings both domestically and internationally on the impact of vehicle weight on fuel consumption, solutions to reduce automotive fuel consumption, and methods for measuring automotive fuel consumption.

From this, we can draw the following conclusion:

Chapter 1 has clarified the urgency as well as the scientific and practical significance of the research topic in the context of climate change, environmental pollution, and the increasingly pressing demand for energy conservation in the transportation sector. The literature review indicates that vehicle fuel consumption is influenced by multiple factors, among which vehicle mass plays a particularly important role due to its direct effect on driving resistance forces and vehicle operating modes. Both domestic and international studies have confirmed that reducing vehicle mass contributes to lower fuel consumption and emissions. However, in Vietnam, related studies remain limited and are mainly confined to statistical analyses or baseline development, without systematic quantitative investigations associated with actual operating conditions. On this basis, the chapter has clearly identified the research gap and established the direction of the dissertation, focusing on the development of theoretical models, experimental studies, and quantitative analysis of the influence of passenger car mass on fuel consumption under Vietnamese operating conditions. The theoretical foundations and research gaps established in this chapter provide the basis for the subsequent chapters, including model development, experimental design, result analysis, and the proposal of appropriate technical solutions.

CHAPTER 2: SCIENTIFIC BASIS OF RESEARCH

Some of the topics studied and presented in Chapter 2 include:

2.1. DYNAMIC MODEL OF AUTOMOBILE MOTION

The power required to move the vehicle is simply to overcome resistance.

$$P=\frac{(P_f+P_w\pm P_j\pm P_i)\times v}{\eta};\ \text{W} \quad (2.1)$$

As the vehicle moves, rolling resistance constantly changes between 10% and 70%.

Rolling resistance is affected by tire pressure. For truck tires, rolling resistance increases by approximately 5 to 8% when pressure decreases by 20%, resulting in a 2 to 3% reduction in fuel efficiency.

Energy losses occurring in the tire tread within the tire–road contact patch may account for more than 40% of the total rolling resistance force.

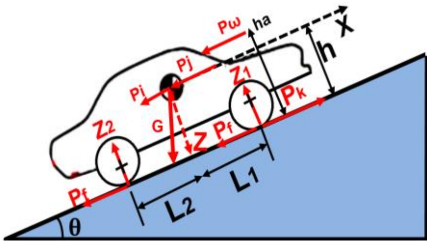
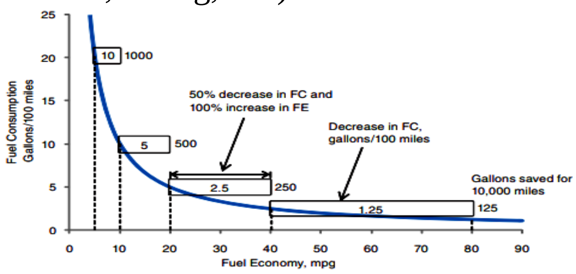


Figure 2.1. Schematic diagram of the longitudinal dynamics model of a car.

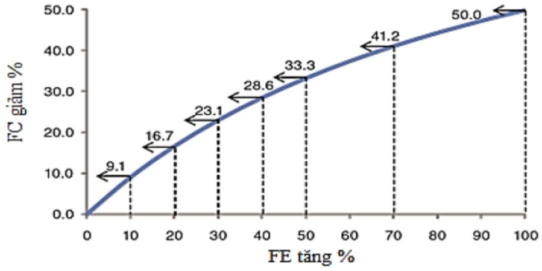
2.2. FUEL CONSUMPTION AND FUEL SAVINGS

Fuel consumption (FC) indicates the amount of fuel consumed per unit distance traveled by the vehicle (liters/km, kg/km, etc.).

Fuel economy (FE) indicates the distance the vehicle has traveled per unit of fuel (km/liter, km/kg, etc.).



a. The proportional relationship between *FC* and *FE*



b. The percentage relationship between *FC* and *FE*

Figure 2.2. Relationship between *FC* and *FE*

2.3. MODELS FOR DETERMINING FUEL CONSUMPTION IN AUTOMOBILES

2.3.1. Average vehicle operating point model

a. Modeling:

When a vehicle is operating on the road, there are many points of engine and vehicle operation (collectively referred to as vehicle operating points). The model combines all vehicle operating points into a single representative point to calculate the fuel consumption FC_{av}.

Power balance equation:

$$\overline{P}_v=\eta_g \cdot \eta_a \cdot \eta_e \cdot \overline{P}_f \text{; W} \qquad (2.6)$$

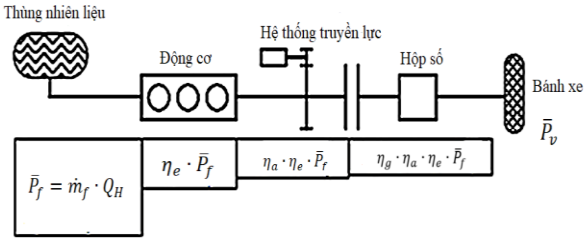


Figure 2.3. Modeling and calculation of fuel consumption in an internal combustion engine.

b. Simulation

+ Assumptions

Determine the calorific value of the fuel.

+ Determine the input parameters

+ Run the simulation program

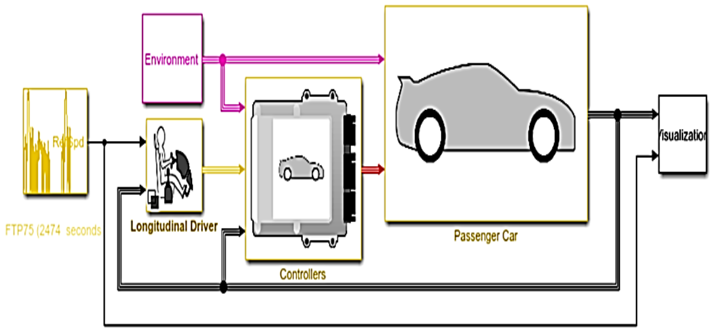


Figure 2.4. Simulink diagram for determining fuel consumption in a car using the vehicle's average operating point model

+ Determine the applicability

Published literature shows that the average operating point method can provide a reasonable estimate of fuel consumption for vehicles with simple powertrains, but it is not suitable for issues requiring structural optimization on the vehicle, and therefore does not offer options for energy management strategies.

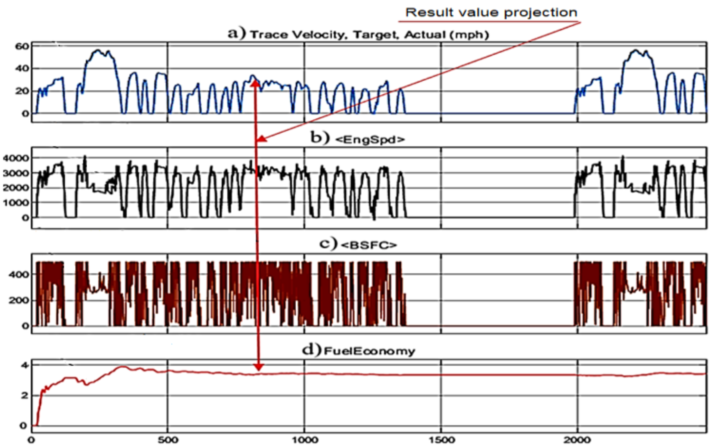


Figure 2.5. Simulation results graph determining fuel consumption on a car based on the vehicle's average operating point model.

2.3.2 Dynamic Model FC_{dyn}

Construct the FC_{dyn} equation in the form of the following equation:

$$M_1 \frac{dv}{dt} = \left(\frac{\eta i_t}{r_{bx}} T_e\right) - \left(M_1 g \cos\alpha\,(r_0 + r_1)\right) - \left(\frac{1}{2}\rho A_f C_d v^2\right) - \left(M_1 g \sin\alpha\right) - P_p \qquad (2.7)$$

Expand it into an equation.

$$M_1\left(\frac{dv}{dt} + g\cos\alpha\,(r_0 + r_1) + g\sin\alpha\right) = \left(\frac{\eta i_t}{r_{bx}} T_e\right) - \left(\frac{1}{2}\rho A_f C_d v^2\right) - P_P \qquad (2.8)$$

Equation (2.8) can be written in the form (2.9)

$$\frac{dv}{dt} = \frac{1}{C_1(\gamma)}\left(C_2(\gamma)\,T_e - C_3 v - C_4(\alpha) - P_P\right) \qquad (2.9)$$

With: $C_1(\gamma) = \frac{1}{M_1}$; $C_2(i_t) = \frac{\eta i_t}{r_{bx}}$; $C_3 = \frac{1}{2}\rho A_f C_d$; $C_4(\alpha) = M_1 g(\cos(\alpha)\, r_0 + \sin\alpha)$

At a given moment, the vehicle's fuel consumption FC_{dyn_point} related to load, engine torque, and vehicle speed, is calculated using the equation:

$$FC_{dyn\_point} = C_5 T_e(t) v(t) - C_6 v(t)^2 + C_7 v(t) + C_8; \ \frac{L}{100\ km} \qquad (2.10)$$

With: $C_5 = \frac{i_t}{\eta_e Q_H r_{bx}}$; $C_6 = \frac{P_{loss} V_{dc}}{\eta_e Q_H 4\pi}\left(\frac{i_t}{r_{bx}}\right)^2$; $C_7 = \frac{P_{loss} V_{dc}}{\eta_e Q_H 4\pi}\left(\frac{i_t}{r_{bx}}\right)$; $C_8 = C_{kt}(S)$

In real time from point p=1 to p = p-1, the total fuel consumption FC_{dyn_total} of the vehicle is the sum of the vehicle's FC_{dyn_points}, an equation relating the engine's output torque and the vehicle's average speed.

$$FC_{dyn\_total} = \sum_{i=0}^{p-1} C_5(g) T_i v_i + C_6(g) v_i^2 + C_{7f}(g) v_i + C_8; \ \frac{L}{100\ km} \qquad (2.11)$$

With $T_i = \frac{1}{C_2(g)}\left(C_1(g)\,\frac{v_{i+1} - v_i}{\tau} + C_3 f(g) v_i + C_{4f}(g, \delta)\right)$

The application of the FC_{dyn} dynamic model is used for a comprehensive survey of the vehicle convoy to address two main objectives:

Monitor the emissions levels of the vehicle fleet over extended periods and with high mileage.

Evaluate the fuel economy of vehicle fleets in use and provide feedback to manufacturers so they can modify vehicle technical features or add design elements to achieve reasonable fuel consumption figures.

2.3.3. Static Model FC_{stat}

The static model calculates fuel consumption based on the vehicle's speed, using a model that analyzes the traction forces overcoming resistance forces to move the vehicle on the road.

The fuel consumption of a car FC_{stat} is determined by the general equation:

$$FC_{\text{stat}} = \frac{\int g_e P dt}{\int v dt} = \frac{\int g_e \left(\frac{P_k v}{\eta}\right) dt}{\int v dt}; \quad \frac{\text{kg}}{\text{km}} \qquad (2.13)$$

Expanding the equation based on thermal energy and engine power, we obtain the fuel consumption equation FC_{stat}.

$$FC_{\text{stat}} = \frac{1}{Q_{\text{heat}}} \frac{Pt}{\eta_e}; \quad \frac{\text{L}}{100\text{ km}} \qquad (2.14)$$

Resistance to motion affects the vehicle's power output. Vehicle power output (VSP) is the engine power per unit mass of the vehicle:

$$VSP = (P_f + P_w + P_i + P_p)\frac{v}{M}; \frac{\text{W}}{\text{kg}} \qquad (2.16)$$

The engine's power and the car's own power are related through influencing parameters including vehicle weight, vehicle speed, powertrain efficiency, and the state of resistance forces.

Advantage:

- Simple, easy to understand, and easy to implement under experimental conditions.
- Easy to collect input data: speed, mass, drag force, etc.
- Suitable for evaluating the impact of engineering improvements (weight reduction, aerodynamic optimization, etc.)
- Highly suitable for designing and testing real-world fuel consumption measurement devices.

Disadvantages:

- Limited to simulating rapidly varying operating situations (braking, rapid acceleration)
- Not good at real-time assessment or simulating complex convoys.
- Accuracy is not high if environmental factors and operating conditions change significantly.
- It does not fully reflect the lag or nonlinear characteristics of the motor.

2.4. DEVELOPING A METHOD FOR SOLVING MODELS TO DETERMINE *FC* AND FE

2.4.1. Determining fuel consumption using the carbon balance method

Assuming that the engine produces the same amount of carbon as the fuel consumed, the amount of fuel used can be determined by the amount of carbon captured in the engine's exhaust gases.

2.4.2. Calculating FE fuel savings using the approximation method

The FE fuel efficiency level is calculated by the equation: $FE_{RL} = \frac{N}{\sum_i \frac{N_i}{T_i}}; \frac{\text{km}}{\text{L}}$ (2.17)

FE $_{RL}$ is the required fuel economy level , *N is* the total designed passenger capacity of the vehicle; *Ni* is the actual number of passengers in the vehicle; *Ti* is the target fuel economy level based on the actual number of passengers in the vehicle .

There are many software programs that use approximation methods, including CAFE software, which has been developed into a standard.

2.4.3. Online calculation method

In certain cases, it is necessary to determine fuel consumption for specific purposes, such as comparison with data measured from actual vehicle tests. For this purpose, several online calculation tools can be employed, among which the “Calculate Fuel Consumption” tool is a typical example.

2.4.4. Algebraic Calculation Methods

When direct calculation is necessary, algebraic calculations will be used; fuel consumption will be calculated in the general case: $q_d = \frac{0{,}36 g_e (P_f \pm P_i + P_w \pm P_j)}{\rho_n \eta_t}$; $\frac{l}{100km}$.

$$q_d = \frac{g_e N_e}{\rho_n};\ \frac{l}{h}.\ q_d = \frac{0{,}36 g_e}{\rho_n \eta_t}\left(fG\cos\alpha \pm G\sin\alpha + Wv^2 \pm \frac{G}{g}\delta_i\, j\right);\ \frac{\text{L}}{100\text{ km}} \quad (2.19)$$

2.4.5. Numerical Simulation Methods

There are several commonly used numerical simulation software programs for simulating car fuel consumption, such as:

- AVL Cruise software is specifically designed for simulating automotive fuel consumption and is commonly used in laboratories.

- GT-SUITE software simulates the vehicle's dynamic system.

- The programming language is Python, using two libraries: NumPy for arithmetic calculations and Matplotlib for plotting graphs.

- MATLAB/Simulink software is used in many fields, including education, research and development, and practical applications. Building algorithms on the MATLAB/Simulink platform offers many advantages.

2.5. SELECTING A SIMULATION MODEL

The static model FC_{stat} is built on fundamental mechanical equations, describing the relationship between velocity, drag, and powertrain efficiency. The model has the advantages of being simple, easy to build and implement, with input parameters such as vehicle mass, velocity, and drag coefficient easily measured directly without the need for complex simulation software. The model is highly flexible, applicable to many types of vehicles and operating conditions, supporting the evaluation of the effectiveness of technical solutions suchas weight reduction, aerodynamic optimization, and improved engine and transmission efficiency. Furthermore, the model is intuitive, highly explanatory, low-cost, and suitable for implementation in research and training institutions. Combining it with the project "Design and fabrication of a fuel consumption measurement device for automobiles" has contributed to increasing the reliability and applicability of the model in practice.

2.6 . DEVELOPING THE FC_{stat} ALGORITHM AND SIMULINK SIMULATION METHOD

2.6.1. Algorithm flowchart

The FC_{stat} algorithm flowchart, based on a static model and programmed in Matlab/Simulink, for determining fuel consumption in a car is shown in the figure 2.6.

Content and execution sequence of the algorithm:

a) Step 1: Establish the initial dataset.

b) Step 2: Prepare and configure the input data.

c) Step 3: Define the boundary conditions.

d) Step 4: Set the initial state (Start).

e) Step 5: Run the simulation and collect the results.

f) Step 6: Compare the results and evaluate the deviation.

g) Step 7: Calculate the fuel consumption for the total travel distance.

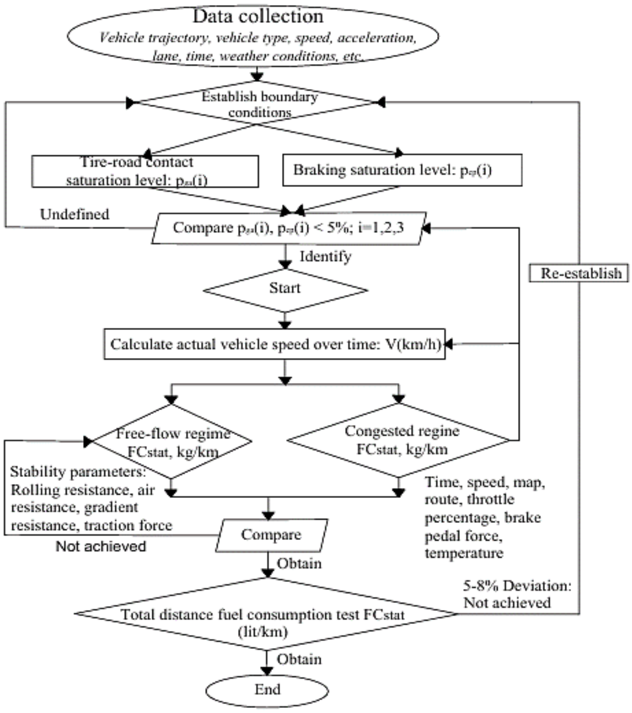


Figure 2.6. Schematic diagram of the FC_{stat} algorithm based on the static model.

2.6.2 . Simulation to determine parameters

The state and control variables of the algorithm are represented in the Matlab/Simulink environment, Figure 2.7 .

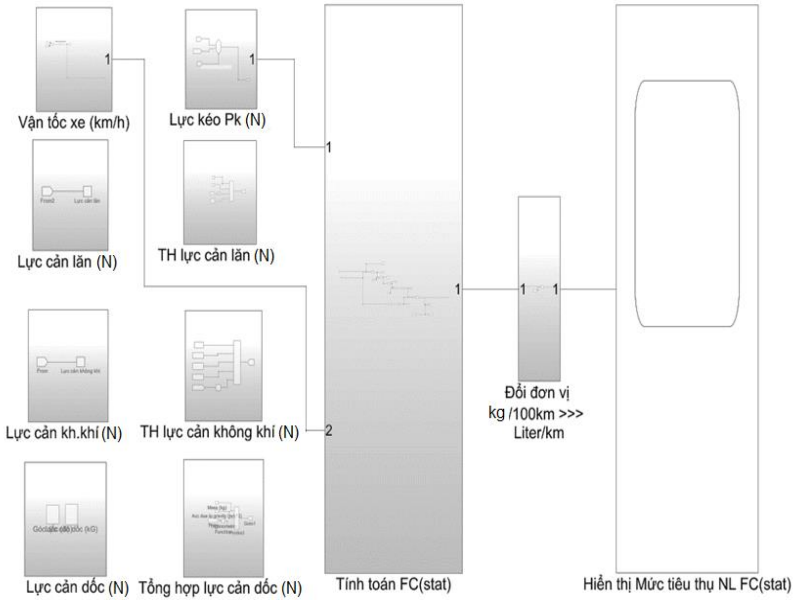


Figure 2.7. Real-space parameter variables R represented in Matlab Simulink

CONCLUSION OF CHAPTER 2

Chapter 2 has established the theoretical basis and research methodology by developing the longitudinal vehicle dynamics model, in which all resistance forces acting during vehicle motion are fully identified, including rolling resistance, aerodynamic drag, inertial resistance, and grade resistance. The analysis results indicate that vehicle mass appears in most resistance force components, thereby confirming its central role in the power balance equation and the fuel consumption calculation model. Based on the comparison of the three calculation models, namely FC_{av}, FC_{dyn}, and FC_{stat}, the static model FC_{stat} was selected as the primary research model due to its feasibility in model development, convenience for experimental implementation, and suitability for quantitatively evaluating the individual influence of vehicle mass. In addition, the calculation algorithm and the simulation program in Matlab/Simulink were comprehensively developed with 10 investigated mass levels, providing a reliable theoretical foundation and computational tool for the simulation studies, experiments, and result analysis presented in the subsequent chapters.

CHAPTER 3: ANALYZING THE INFLUENCE OF WEIGHT ON FUEL CONSUMPTION MATERIALS IN THE CAR

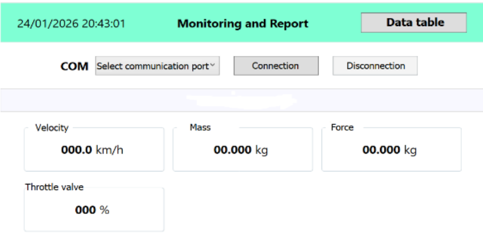
3.1 . KEY ASSUMPTIONS

- The survey vehicle is a 5-seater passenger car;
- The engine on the surveyed vehicle is a gasoline engine (forced ignition - SI);
- Fuel type: gasoline;
- Fuel energy is used to completely overcome resistance.
- The effects of mass reduction on vehicle dynamic characteristics, aerodynamic lift, mass redistribution, and vehicle structural durability are neglected.
- The vehicle mass is assumed to remain constant during operation.
- The effect of the air conditioning system on fuel consumption is neglected.

3.2. DETERMINING DATA IN N-DIMENSIONAL SPACE

3.2.1. Real-time data collection

Use real-world measurement programming to calibrate the initial data acquisition process in the algorithm and record the data in an Excel spreadsheet (xlsx).



Time	Velocity (km/h)	Force (kg)	Mass (kg)	Throttle valve (%)
2024-04-07 05:37:25.016	5.9	0	11.668	16
2024-04-07 05:37:25.887	5.9	0	11.668	16
2024-04-07 05:37:25.940	8.2	0	11.505	12
2024-04-07 05:37:26.803	8.2	0	11.505	12
2024-04-07 05:37:26.866	10	0	11.319	16
2024-04-07 05:37:27.720	10	0	11.319	16

Figure 3.1. Table format of real-time data file results

3.2.2. Vehicle speed in real time

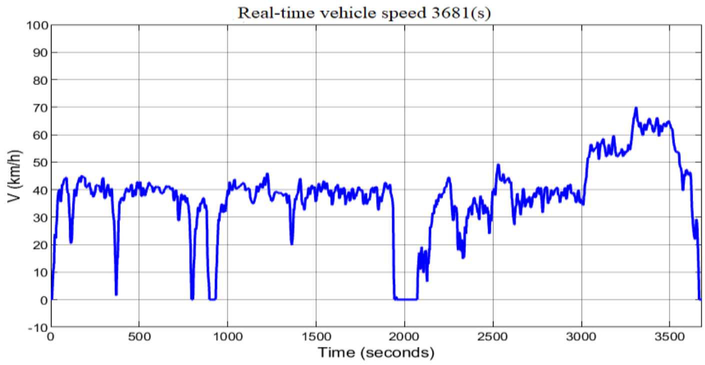


Figure 3.2. Graph of vehicle speed over time.

3.2.3. Controlling data stability conditions

- The number of times the brakes are applied and the percentage of pressure applied to the accelerator pedal will be selected as metrics for evaluating a driver's skill .

3.3. DETERMINING DATA IN *M*- DIMENSIONAL SPACE

3.3.1. Rolling resistance data on the road

Rolling resistance is determined by the equation: $P_f = C_{rr} m_i g$ (3.3)
Use the blocks in Simulink to determine the rolling resistance, Figure 3.3.

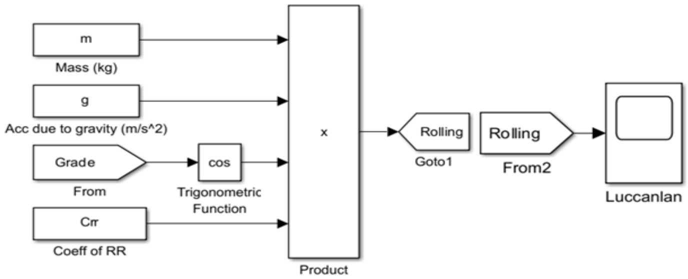


Figure 3.3. Simulink block diagram for determining rolling resistance.

3.3.2. Slope resistance data

The slope resistance is determined by the equation:
$P_i = m_i g \sin(\alpha)$ (3.4)
Use the blocks in Simulink to determine the slope resistance, Figure 3.4.

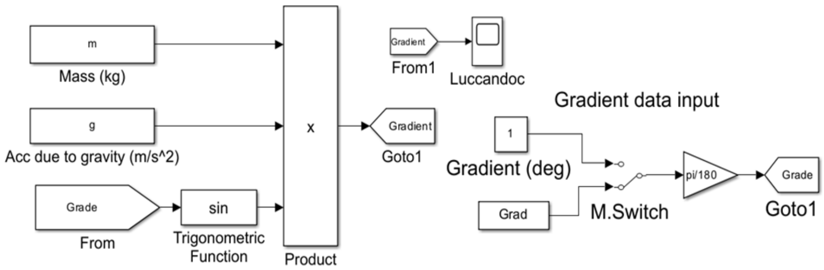


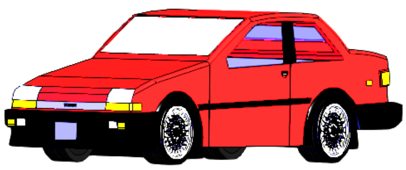
Figure 3.4. Simulink block diagram for determining slope resistance.

3.3.3. Aerodynamic drag data

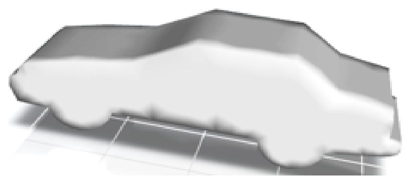
Aerodynamic drag is determined by the equation:

$$P_w = \frac{1}{2} \rho A_f C_d v^2 \qquad (3.6)$$

CFD analysis in Ansys Workbench software obtained the aerodynamic drag coefficient parameter for the 2009 Toyota Vios vehicle under investigation.



a) Toyota Vios survey vehicle



b) Vehicle modeling

Figure 3.5. CFD analysis on a 2009 Toyota Vios to determine the aerodynamic drag coefficient.

Based on CFD analyses and wind tunnel experimental studies, the aerodynamic drag coefficient of a notchback sedan is typically within the range of $C_d = 0.28–0.32$. The value $C_d = 0.29$, obtained from the CFD simulation results, was adopted for the 2009 Toyota Vios in this study.

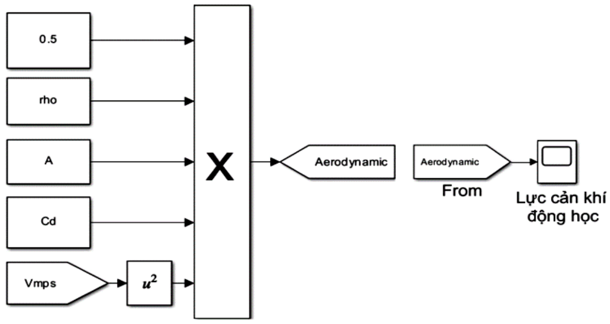


Figure 3.6. Simulink block diagram for determining aerodynamic drag.

3.3.4. Total traction data

From the traction force balance equation on a car, assuming the vehicle is running steadily without acceleration, the total traction force is equal to the sum of the resistance forces: rolling resistance, slope resistance, and air resistance. Using the blocks in Simulink to determine the traction force Pk , Figure 3.7.

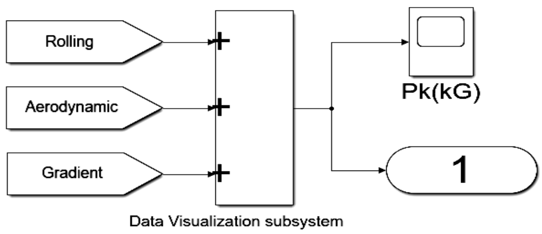


Figure 3.7. Simulink block diagram for determining total traction force

3.3.5. Useful fuel consumption rate data

The specific fuel consumption rate g_e is calculated at 85% of the engine's maximum power (N_e = 85% $N_{e\,max}$) by the equation:

$$g_e = \frac{m_f}{P_e} \left(\frac{kg}{kWh}\right) \qquad (3.7)$$

Using Matlab/Simulink on the engine parameters of a 2009 Toyota Vios to run the matlab.m program, we obtained the useful specific fuel consumption rate graph *ge* (kg/kWh) as shown in Figure 3.8.

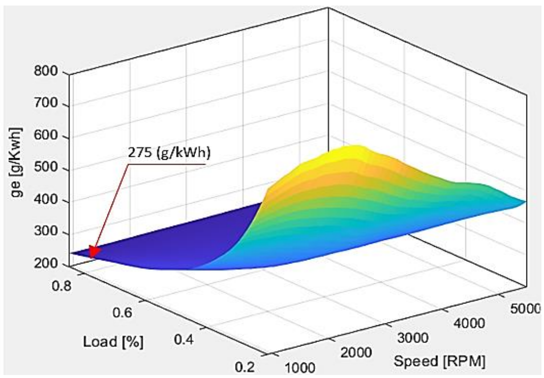


Figure 3.8. Matlab simulation results of useful specific fuel consumption rate ge

3.3.6. Powertrain System Performance Data

In vehicles with mechanical powertrains, the average efficiency is typically 0.7–0.8. In simulations, the average efficiency can be taken as 0.75.

3.4. MATLAB SIMULINK DIAGRAM SIMULATING FUEL CONSUMPTION CALCULATIONS

The fuel consumption during one driving cycle in the simulation, taken in real time, is 3681 (s). as shown in diagram 3.9.

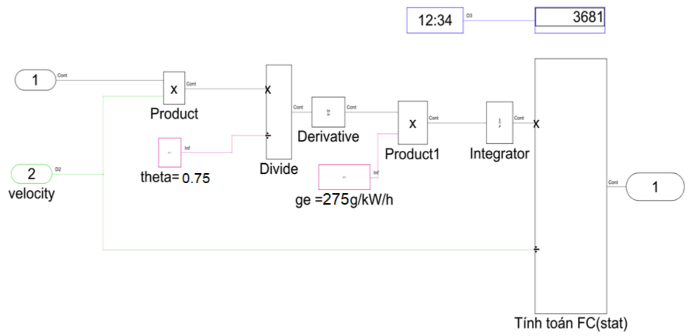


Figure 3.9. Simulink block diagram for calculating fuel consumption of a vehicle route.

3.5. ANALYSIS OF SIMULATION RESULTS

3.5.1. Driving Cycle

During the driving process:

- The simulation time is exactly equal to the actual time the car travels, which is 3681 (s).
- A skilled driver ensures that deceleration and acceleration are performed at the correct times during the cycle.
- The vehicle speed in the simulation is taken from the vehicle speed in real time, so the simulation results are shown in Figure 3.12 .

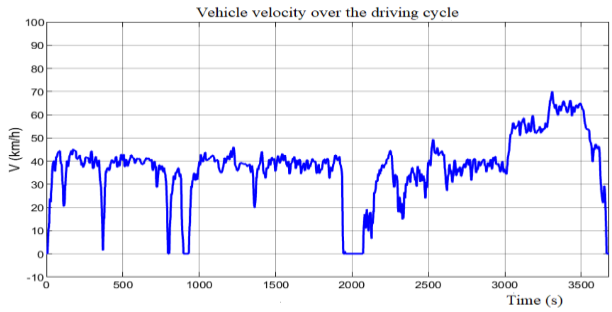


Figure 3.12. Driving cycle profile up to 3681 s

3.5.2. Engine power consumption

The vehicle's weight is determined by the following components: Unladen weight 940 kg; Fuel tank capacity 45 liters x 1/3 = 15 liters x 0.7 = 11 kg; 2 fire extinguishers = 18 kg; Driver = 75 kg; Technician = 74 kg; Vehicle accessories = 22 kg; Scale + weighing platform + fuel in the tank = 30 kg. Total weight of the fully loaded vehicle is 1170 kg.

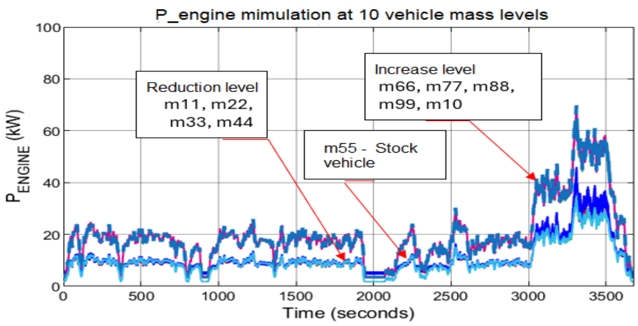
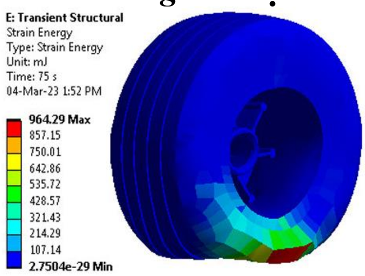


Figure 3.13: Graph of engine power consumption at different vehicle weights

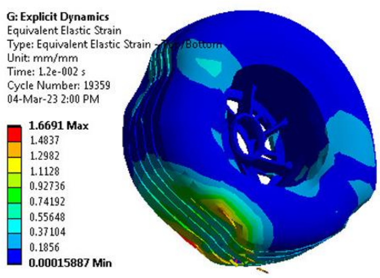
3.5.3. Rolling resistance

3.5.3.1. Phân tích đặc tính lốp xe ảnh hưởng đến hệ số cản lăn

The structural design and material properties of the tire directly influence the rolling resistance coefficient through the extent of deformation within the tire–road contact patch



a) strain energy of the tire



b) Equivalent elastic deformation of the tire

Figure 3.14. Simulated deformation

The comparison results presented in Figure 3.15 indicate that the passenger car tire exhibits lower rolling resistance and lower deformation energy loss compared with the racing tire.

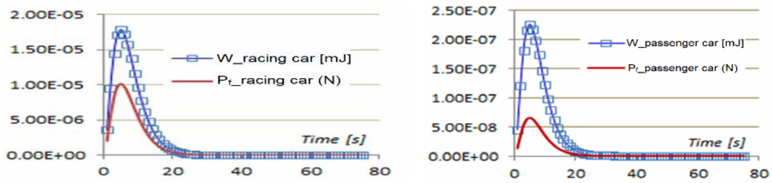


Figure 3.15. Deformation energy and rolling resistance force of tires

3.5.3.2. Rolling resistance simulation

The instantaneous rolling resistance force $P_f(t)$ as a function of time was investigated for vehicle mass conditions ranging from m11–m10, where m55=1170 kg represents the original vehicle mass, in order to clarify the variation behavior of this parameter throughout the simulation cycle, Figure 3.16.

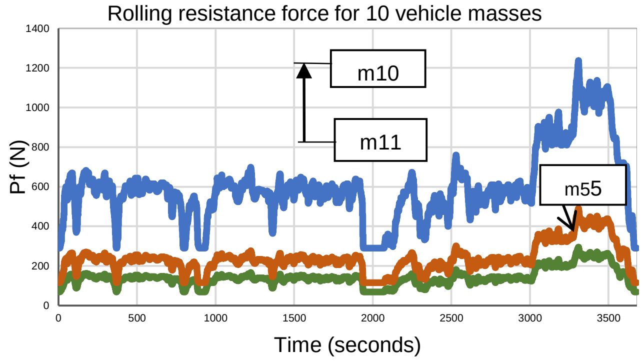


Figure 3.16. Rolling resistance force graph

3.5.4. Aerodynamic drag

Since the vehicle's shape remains unchanged under all mass changes, there is no real-time amplitude change, Figure 3.17.

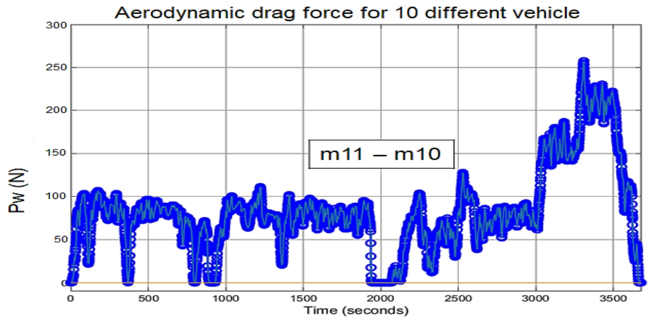


Figure 3.17. Aerodynamic drag force graph

3.5.5. Slope resistance

Since the experimental track has a small gradient and few slopes, slope resistance can be ignored and used as a hypothetical factor in the simulation.

3.5.6. Total traction force

The survey of total traction force clearly shows the dependence on various drag forces as well as different vehicle masses, Figure 3.18.

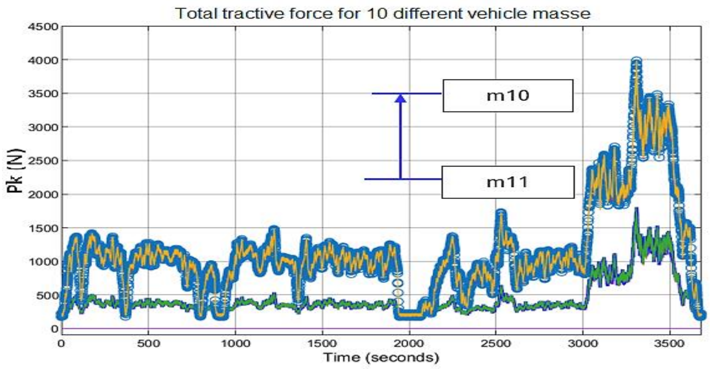


Figure 3.18. Graph of total traction force

3.5.7. Fuel consumption

Examining the changes in the total traction force values and corresponding fuel consumption will clearly show the dependence on different vehicle weights, Figure 3.19.

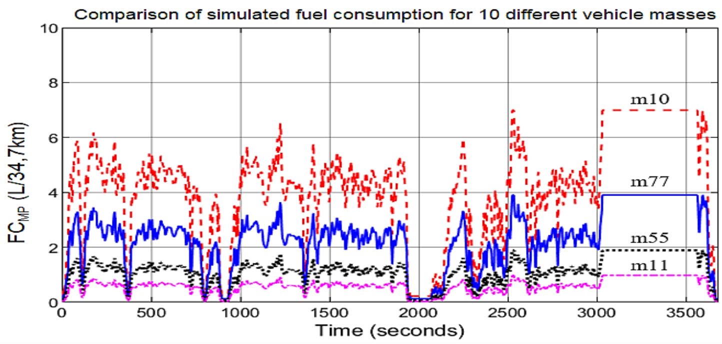


Figure 3.19. Fuel consumption graph

3.5.8. Comments

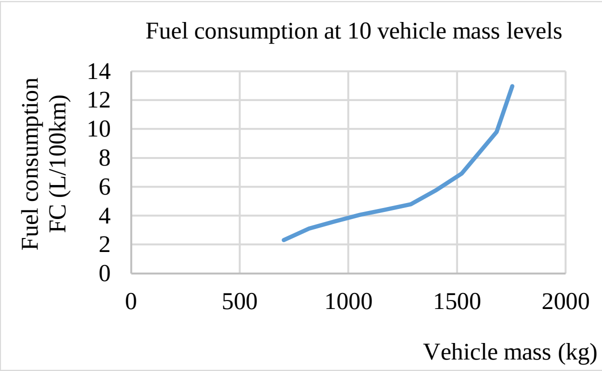


Figure 3.20. Fuel consumption variation as a function of ten different vehicle masses

Based on the data from Figure 3.20, an empirical function describing the relationship between vehicle mass and fuel consumption was determined using the least squares regression method. Due to the nonlinear characteristics of the data, a piecewise function model was developed, in which each segment corresponds to a specific mass range, representing fuel consumption as a function of vehicle mass as follows: $FC = \begin{cases} 0.0035m - 0.15; & m \leq 1300 \\ 0.00002m^2 - 0.045m + 30; m > 1300 \end{cases}$ $(lít/100\ km)$, with a coefficient of determination $R^2 \approx 0.99$.

3.6. PROPOSED SOLUTIONS TO REDUCE FUEL CONSUMPTION BY CHOOSING LIGHTWEIGHT MATERIALS FOR THE BODY.

3.6.1. Material distribution diagram on the vehicle body frame

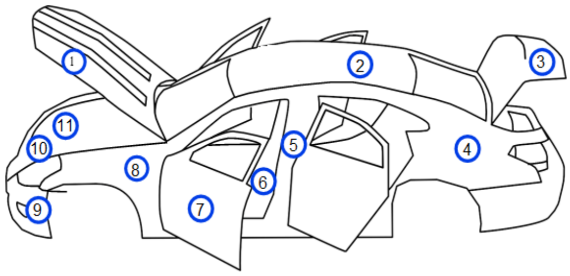


Figure 3.21. Material structure distribution diagram on the car body.

1) Hood: Aluminum; 2) Roof: Low-carbon steel; 3) Trunk lid: Low-carbon steel; 4) Rear side panels: Low-carbon steel; 5) Pillar: Hot-stamped steel 1000-1500 MPa; 6) Vehicle floor: Low carbon steel; 7) Outer doors: Hardened steel, Inner doors: Low carbon steel; 8) Fenders: Medium carbon steel or hardened steel; 9) Front bumper: Plastic; 10) Front grille: Steel 980-1200 MPa or aluminum; 11) Engine compartment: High-strength alloy sheet steel;

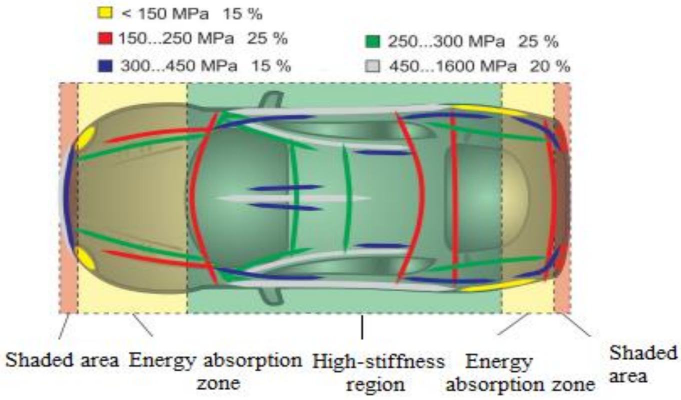


Figure 3.22. Material requirements distribution diagram according to hardness.

- Analyzing the material distribution according to stiffness structure, steel is often used in areas requiring high stiffness, and newer vehicles use ultra-high-strength steel. The main materials in car body shells are steel, aluminum, magnesium, copper, titanium, plastic, and carbon fiber (Figure 3.22).

3.6.2. The possibility of using lightweight materials in the vehicle body frame.

There are many types of lightweight materials used in vehicle frames and bodies, some of the main ones include:

- Composite materials are lightweight, have good rigidity, and are less susceptible to corrosion.
- Polycarbonate (PC) plastic is used to manufacture bumpers, ...

- Polyamide is used to manufacture parts located under the hood of the engine compartment.
- Acrylonitrile Butadiene Styrene (ABS) plastic is used to manufacture parts for the car body and dashboard.
- Thermoplastic alloy PC + acrylonitrile / butadiene / styrene + polyamide (ABS + PA) is used to manufacture interior and exterior decorative parts.
- Polyvinyl chloride (PVC) is used to manufacture protective underlayment for car floors, as an interior lining, and as a covering for electrical cables in vehicles.
- Polypropylene (PP) plastic is used to manufacture car bumpers, battery casings, fuel tanks, and floor mats.
- Polyurethane (PUR) plastic is used to manufacture flexible foam seat cushions, foam insulation panels, elastic tires, automotive suspension bushings, etc.
- Polystyrene (PS) glass fiber polymer is used to manufacture device housings and buttons.
- POM polymer plastic is used to manufacture interior and exterior components, ...
- PMMA (Acrylic) thermoplastic is used in the manufacture of windows and screens.
- Polybutylene terephthalate is used to manufacture fog light housings and bezels, ...
- Polyethylene terephthalate is used to manufacture wiper blades and gear shift housings, etc.

3.6.3. Mass distribution ratio on the vehicle

The vehicle body frame offers the easiest material changes for designers, manufacturers, and operators.

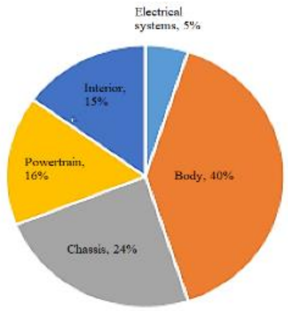


Figure 3.24. Mass distribution diagram on a passenger car.

3.6.4. Criteria for selecting lightweight materials and basis for mass change

Using composite materials with a density of 1600 kg/m³ on the vehicle body frame shows a mass difference ratio compared to sheet steel of 7890/1600 = 4.93.

According to the diagram showing the weight distribution of the chassis, which is approximately 40% of the total vehicle weight, the simulated model will have the weight as shown in Table 3.7.

Table 3.7: Analysis of the simulated vehicle's mass

	Total vehicle weight (kg)	Frame weight ~40% (kg)	Weight of other components (kg)
Original steel body	1170	470	700
CFRP-Epoxy Composite Body	795	95	700

3.6.5. Resistance to motion in the use of composite materials on the shell frame

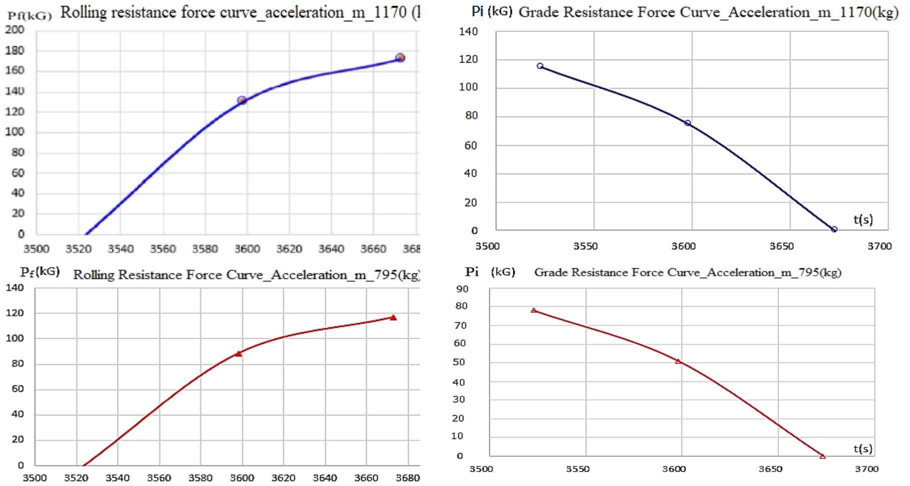
3.6.5.1. Throughout the entire cycle time

CFRP-Epoxy composite chassis is reduced by 55.25 kg, a 32% reduction compared to the original vehicle with a steel chassis. Downhill resistance on vehicles with lightweight CFRP-Epoxy composite chassis is reduced by 39.1 kg, also a 32% reduction compared to the original vehicle with a steel chassis. Aerodynamic drag on both vehicles with lightweight CFRP-Epoxy composite chassis and the original car has the same steel frame and body because the car's aerodynamic structure remains unchanged.

3.6.5.2. During acceleration

The vehicle has a steel frame and body .

The vehicle has a CFRP-Epoxy composite frame and body.



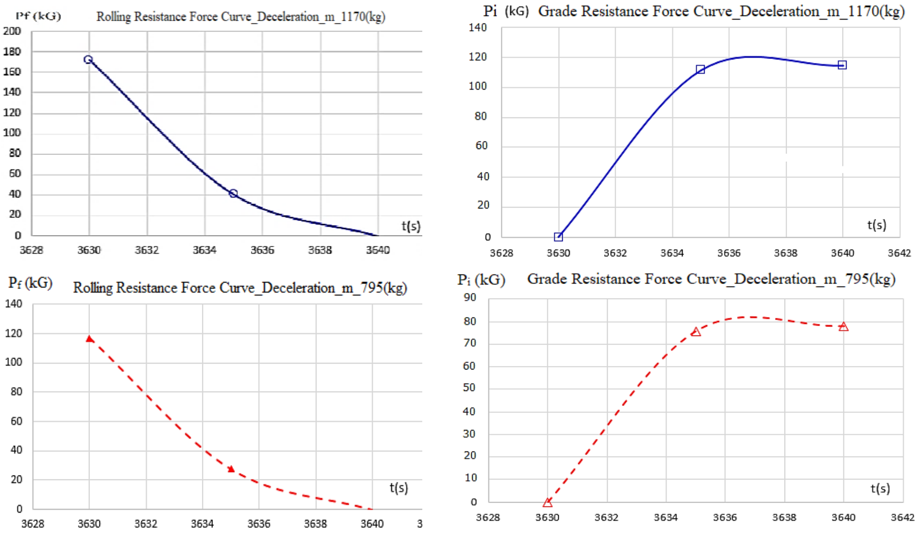
32,05% reduction compared to vehicles with steel frames. 32,1% reduction compared to vehicles with steel frames.

Figure 3.28. Graph of rolling and slope resistance forces during acceleration.

3.6.5.3. During deceleration

The vehicle has a steel frame and body.

The vehicle has a CFRP-Epoxy composite frame and body.



32,05% reduction compared to vehicles with steel frames. 32,05% reduction compared to vehicles with steel frames.

Figure 3.30. Graph of rolling and slope resistance forces during deceleration.

3.7. EVALUATING THE ECONOMIC ASPECTS OF VEHICLES USING LIGHTWEIGHT MATERIALS

The fuel economy of a vehicle, based on YFS (Liters) fuel consumption, is determined by the following equation:

$$YFS = \frac{L(FC1-FC2)}{100} \tag{3.8}$$

Let's assume the vehicle travels 100,000 km per year:

Table 3.8: Fuel economy assessment of the vehicle

a) In the direction of decreasing mass.					
Sign	m11	m22	m33	m44	m55
Weight (kg)	702	819	936	1053	1170
FC (liters/100 km)	2.31	3.11	3.60	4.06	4.41

YFS (L)	2105	1298	808	347	0
SM (VN Dong)	42,100,000	25,960,000	16,160,000	6,940,000	-
b) In the direction of increasing mass.					
Sign	m66	m77	m88	m99	m10
Weight (kg)	1287	1404	1521	1638	1755
FC (liters/100 km)	4.78	5.76	6.92	9.22	12.97
YFS (L)	-374	-1354	-2506	-4812	-8558
SM (VN Dong)	-7,480,000	-27,080,000	-50,120,000	-96,240,000	-171,160,000

CONCLUSION OF CHAPTER 3

Chapter 3 investigates the effect of vehicle mass on resistive forces and fuel consumption using Matlab/Simulink simulations, with real-world speed data processed via Fourier transform to provide reliable input signals for the model.

The results indicate that rolling resistance is directly proportional to vehicle mass, while aerodynamic drag is nearly independent of mass when vehicle geometry remains unchanged. Fuel consumption exhibits a nonlinear dependence on mass and is represented by a piecewise model (linear and quadratic) with a high coefficient of determination ($R^2 \approx 0.99$)

A lightweight solution using CFRP–Epoxy composite materials to replace conventional steel in the vehicle body structure is proposed, achieving approximately a 32% mass reduction. Simulation results show corresponding reductions in resistive forces and significant fuel savings. Economic analysis indicates annual fuel savings ranging from 347 to 2105 liters, equivalent to approximately 7 to over 40 million VND.

These findings confirm the significant impact of vehicle mass on energy consumption and demonstrate the effectiveness of lightweight materials in improving automotive fuel efficiency.

CHAPTER 4: EXPERIMENTAL RESEARCH

4.1. EXPERIMENTAL METHODS FOR DETERMINING FUEL CONSUMPTION IN AUTOMOBILES.

4.1.1. Measurement experiment on a test bench

a) Engine test bench.
b) Chassis test bench.

4.1.2. Direct measurement on a moving vehicle on the road.

Using a disassembled fuel tank, weighed after each test run to determine fuel consumption (Figure 4.1).

The advantages of this method are that it complies with environmental regulations for vehicles, and the cost of the measurement process is more reasonable.

Figure 4.1. How to measure fuel consumption in a road-driving vehicle according to SAE J1321 standard.

4.2. OBJECTIVES, METHODS, AND SUBJECTS OF THE EXPERIMENT

4.2.1. Experiment Objectives

The experiment aimed to achieve the following main objectives:

- Develop an empirical dataset for modeling and analysis.
- Measuring and evaluating the actual fuel consumption of a 2009 Toyota Vios.
- Compare experimental results with simulation models.

4.2.2. Experimental methods

The experiment measured the fuel consumption of a car using a combination of direct measurement, surveying, and calculation methods to determine five parameters.

4.2.3. Experimental subjects

Experiment conducted on a 2009 Toyota Vios.

4.3. EXPERIMENTAL EQUIPMENT

4.3.1. Diagram of the connection of experimental equipment

The fuel consumption testing equipment features internationally standardized measurement modules integrated with additional custom-made modules and specialized software called Kisster, which has been quality-tested and evaluated by the Vietnam General Department of Standards, Metrology and Quality Control.

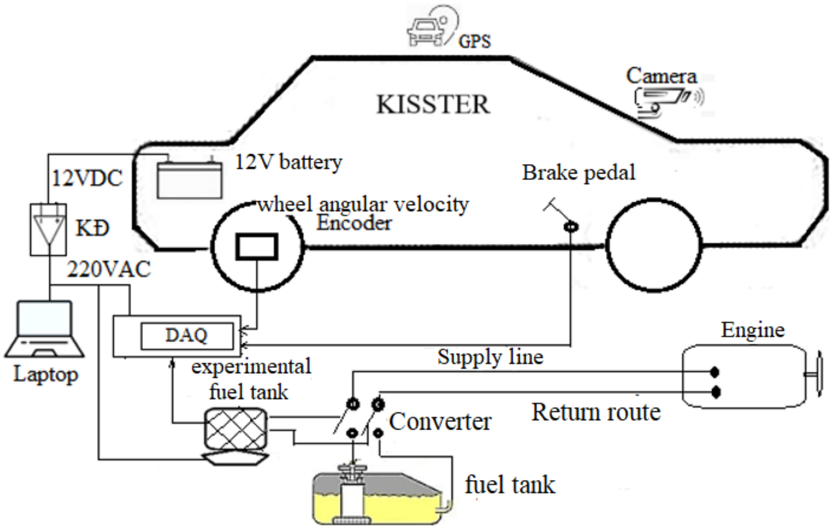


Figure 4.3. Diagram of the experimental equipment connection on the test vehicle.

4.3.2. Laboratory equipment and instruments

- Experiment monitoring team (engine ECU, GPS unit).
- Measuring equipment (electronic scale, frame, connecting cables, data reading software, sensors).

4.4. EXPERIMENTAL PROCEDURE

4.4.1. Developing a test vehicle route

The vehicle's cycle can be composed of several subcycles depending on traffic conditions and operating circumstances, and is implemented in three phases: acceleration phase I, steady-state driving phase, and deceleration phase, to match the simulation as shown in Figure 4.12, where qc_1, qc_2,…qc_n are subcycles, with *n* being the number of subcycles.

Estimated rest time along the way is 6.8 – 4.39 = 2.41 hours

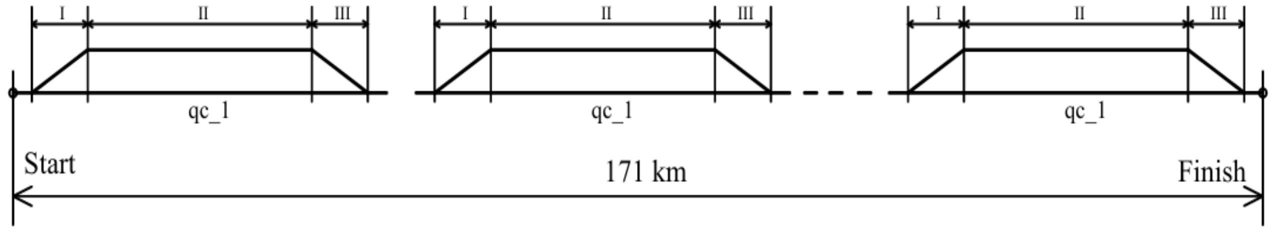


Figure 4.12. Vehicle cycle in the experiment

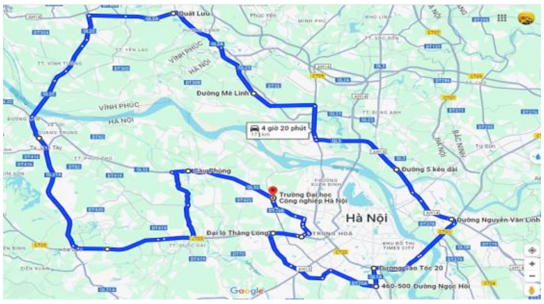


Figure 4.13. First test vehicle route

Figure 4.14. Second test vehicle route

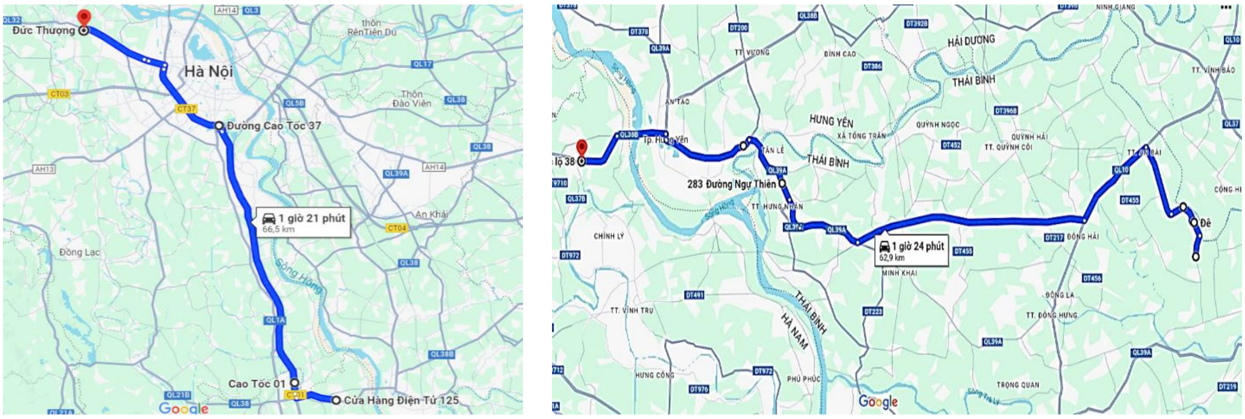


Figure 4.15. Third test vehicle route

4.4.2. Establishing Data Stability Conditions

Using identical brake pedal force and throttle opening data from driving the same vehicle on three different test routes.

a) Brake pedal force

Figure 4.19 shows the magnitude of the force on the brake pedal, with the peaks representing the selected number of brake pedal strokes.

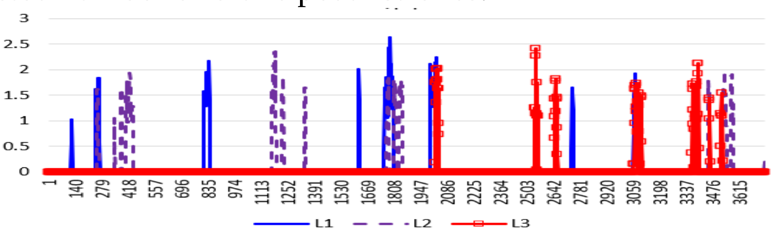


Figure 4.19. Graph of brake pedal force in 3 trajectories

b) Percentage of throttle opening

Figure 4.20 shows the percentage of throttle opening that can approximate the percentage of the driver's pedal use. In the three experimental routes, the percentage values of the driver's pedal use were L1 = 14.76628 (%) , L2 = 14.45064 (%), and L3 = 14.57764 (%) .

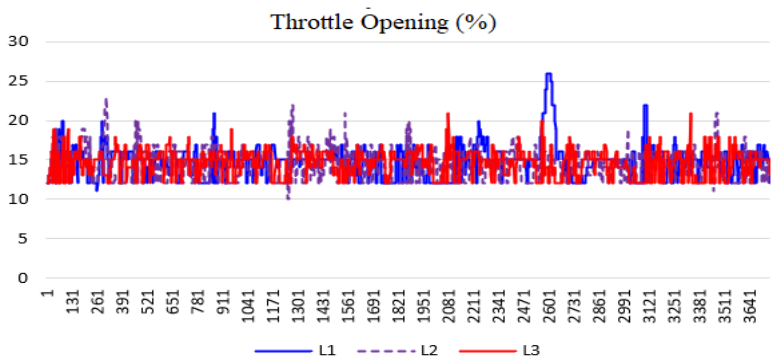


Figure 4.20. Graph of percentage throttle opening in 3 routes

4.5. COLLECTION AND PROCESSING OF EXPERIMENTAL RESULTS

4.5.1. Preparing data files

Input parameters, output parameters, vehicle parameters, equipment parameters, etc., are updated in the software to create data files along with the test vehicle's speed.

The input parameters are set according to the structure of the data logging software .

4.5.2. Implementation Process

Each resulting file shows the starting and ending points, regardless of whether it's an urban road, highway, or rural road.

The initial fuel volume is set as the initial reference (kg), and the throttle level sensor and brake pedal count sensor are displayed on the corresponding software of the measuring device.

Each cycle will have its own results file; the collection of results from all cycles constitutes the vehicle's route.

4.5.3. Experimental Results

4.5.3.1. Real-time data table

- Kisster software records data in Excel spreadsheet format (.xlsx).

1	Thời gian	Vận tốc (km/h)	Áp lực (kg)	Khối lượng (kg)	Bướm ga (%)
30	2024-04-07 05:37:25.016	5.9	0	11.668	16
31	2024-04-07 05:37:25.887	5.9	0	11.668	16
32	2024-04-07 05:37:25.940	8.2	0	11.505	12
33	2024-04-07 05:37:26.803	8.2	0	11.505	12
34	2024-04-07 05:37:26.866	10	0	11.319	16
35	2024-04-07 05:37:27.720	10	0	11.319	16
36	2024-04-07 05:37:27.785	10	0	11.446	18
37	2024-04-07 05:37:28.644	10	0	11.446	18
38	2024-04-07 05:37:28.704	10.3	0	11.416	18
39	2024-04-07 05:37:29.596	12.7	0	11.277	19
40	2024-04-07 05:37:29.634	12.7	0	11.277	19
41	2024-04-07 05:37:30.493	12.7	0	11.277	19

Figure 4.21. Table format of real-time data file results

4.5.3.2. Vehicle speed in the experiment over time.

The vehicle's speed in the experiment is shown in real time (Figure 4.22).

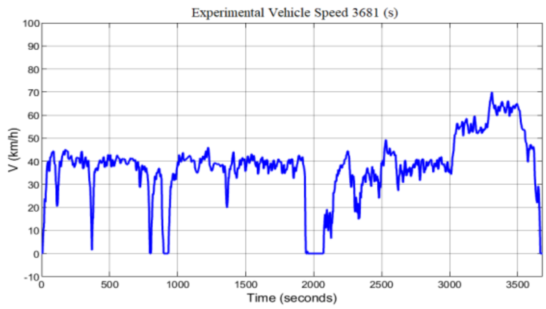


Figure 4.22. Experimental vehicle speed graph

4.5.3.3. Real-time fuel consumption measurement values

- The fuel consumption measured on the test vehicle m_1 = 1170 kg, $FC_{stat\ max}$ = 4.2 (L/100km), is shown in Figure 4.23.

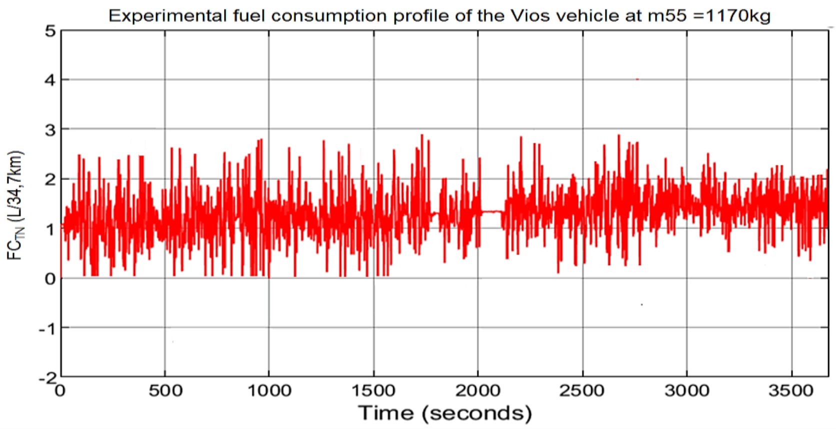


Figure 4.23. Fuel consumption measured on the test vehicle.

4.6. EVALUATION OF EXPERIMENTAL RESULTS

4.6.1. Constructing the regression equation

Actual regression equation

$$y = 5.26 + 34.7x_1 + 1009.03x_2 + 115.5x_3 \qquad (4.2)$$

x_1 : Vehicle speed V (km/h) ;

x_2 : Rolling resistance, slope resistance related to vehicle mass m_i (kg);

x_3 : Aerodynamic drag related to vehicle shape and size P_w (N).

4.6.2. Assessing the reliability of regression coefficients

Use the coefficient of determination R^2 to assess the model's fit; the closer R^2 is to 1, the better the model fits, and the more reliable the regression coefficients are.

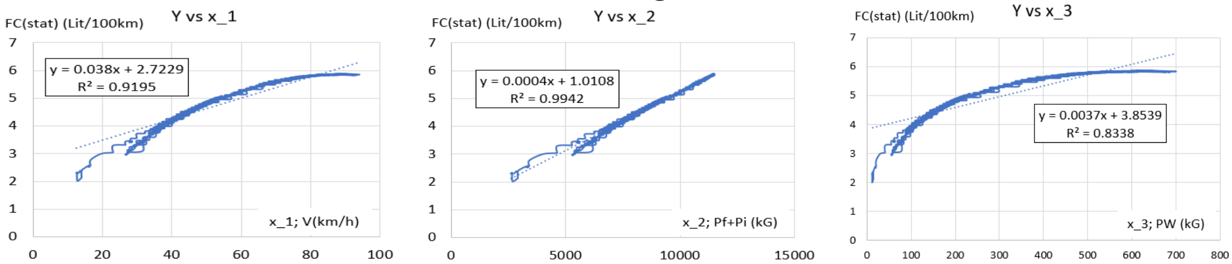


Figure 4.24. Graph showing the relationship determining R^2 of FC_{stat} with x_1, x_2, x_3

4.6.3. Analyzing the influence of factors on FC_{stat}

NCS used Minitab software to analyze the influence of various factors on the results of determining fuel consumption (FC) in automobiles.

- The effect of velocity x_1 on FC_{stat} Y

The correlation function between velocity factor x_1 and factor Y is first-order, and the statistical significance is indicated by a p-value of 0.993 > 0.05, suggesting that x_1 will have a very large influence on Y.

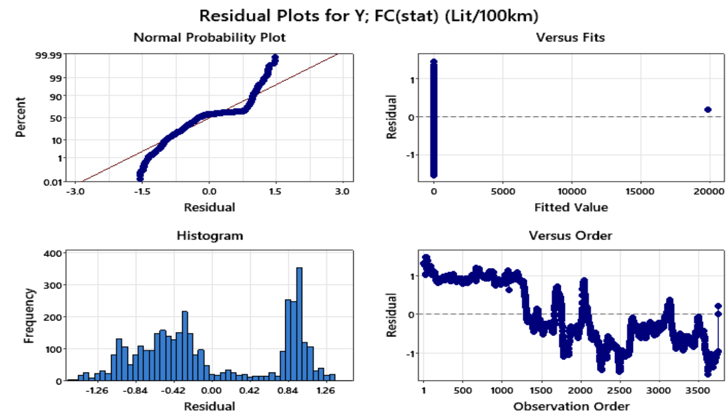


Figure 4.26. Effect of velocity x_1 on Y

- The effect of mass x_2 on FC_{stat} Y

The correlation function of mass factor (in the components of rolling and slope resistance) x_2 to factor Y is a first-order function, statistically significant with a p-value of 0.996 > 0.05, suggesting that x_2 will have a very large influence on Y.

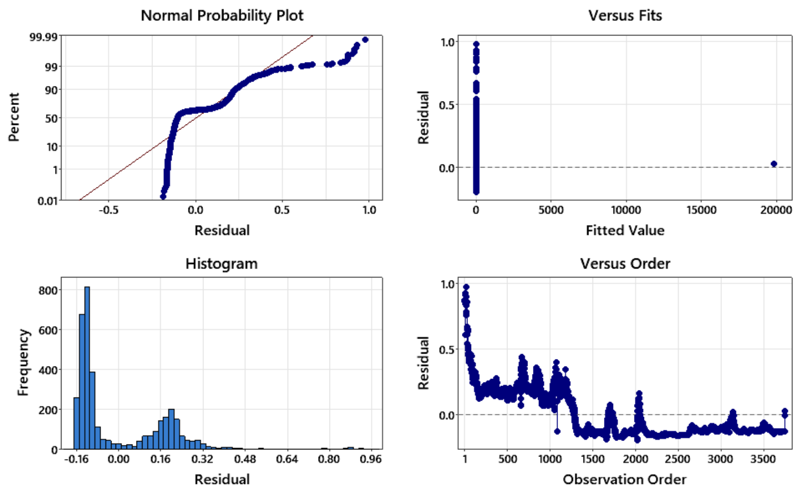


Figure 4.27. Effect of mass x_2 on Y

- Effect of aerodynamics x_3 on FC_{stat}

The correlation function of the aerodynamic factor (vehicle design shape) x_3 to factor Y is first-order, statistically significant with a p-value of 0.988 > 0.05, so x_3 will have an influence on Y, but it will be smaller than x_1 and x_2.

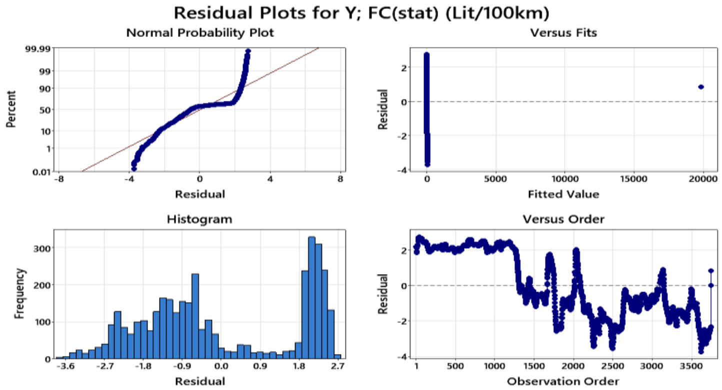


Figure 4.28. Effect of aerodynamic x_3 on Y

- The main influencing factors are qualitatively identified on the Main Effects Plots (Figure 4.29).

As observed from the graph, the slope of the vehicle speed curve is considerably steeper than that of the vehicle mass curve. This indicates that both vehicle mass and driving speed have an influence on the fuel consumption FC_{stat}. A qualitative evaluation suggests that the effect of vehicle speed is approximately 5,6 times greater than that of vehicle mass.

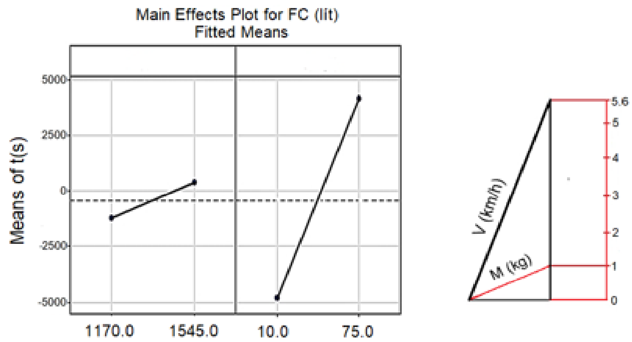


Figure 4.29. The degree of influence of vehicle mass and velocity parameters.

4.6.4. Comparison of experimental and simulation results

4.6.4.1. Basis for comparison

Graduate student selected the experimental route for April 7, 2024, as shown in Figure 4.13 above, with a total distance of 171 km, divided into 5 sub-cycles. The first cycle, covering a distance of 34.7 km, starts from the Hanoi University of Technology and ends at Dong Truc (Lang-Hoa Lac Expressway).

Table 4.2: Summary of test vehicle routes on April 7, 2024

Fuel consumption test on cars, April 7, 2024										
	Cycle 1		Cycle 2		Cycle 3		Cycle 4		Cycle 5	
Content	Data	Result	Data	Result	Data	Result	Data	Result	Data	Result
Departure time	4:12	1 hour	5:37 AM	1h02'	7:02 AM	1 hour	8:27 AM	1 hour	9:52 AM	1h06'
End time	5:12 AM		6:37 AM		8:02 AM		9:27 AM		10:55 AM	
First kilometers	0	34.7	34.7	34.7	69.4	34.7	104.1	34.7	138.8	31.7
Final kilometers	34.7		69.4		104.1		138.8		170.5	
Initial fuel quantity (g)	12,464	1,057	11,391	1,009	10,377	1,025	11,323	1,082	10,232	1,165
Final fuel quantity (g)	11,407		10,382		9,352		10,241		9,067	
Running route	University of Technology - Phung Bridge - Thay Pagoda - Đồng Trúc (Lang-Hoa Lac Expressway)		Dong Truc (CT Lang Hoa Lac) - Son Tay - Vinh Thinh Bridge - Dong Van - Yen Lac		Dong Van (Yen Lac) - National Highway 2A - Me Linh Road - Vo Van Kiet Road		Vo Van Kiet Street - Dong Tru Bridge - Thanh Tri Bridge - Do Muoi Street (Hoang Mai District)		Do Muoi Street (Hoang Mai District) - Ngoc Hoi - Cau To Bridge - Van Khe - Le Trong Tan - Lang Hoa Lac - My Dinh - Trinh Van Bo - Hanoi University of Technology	
Road characteristics	City center, suburbs, highway		The suburbs have slopes.		Suburban		Suburbs, Urban areas		Densely populated urban areas	
Break time	End of first session: 25 minutes		Second attempt ends: 25 minutes		Third attempt: 25 minutes		End of round 4: 25 minutes			

Specifically, the experimental results from the first subcycle were used to comprehensively compare fuel consumption figures between the experiment and the simulation.

There are five basic mathematical methods for comparing experimental and simulation results data, including: (1) Descriptive statistical methods; (2) Measurement of errors using MAE (Mean Absolute Error) indices; (3) Statistical testing methods; (4) Correlation analysis methods using Pearson correlation; (5) Visual methods using one of the graphs.

The thesis selected the Line plot method from Matlab Simulink software (method 5) to obtain visual analysis results and combined them with the key evaluation indicators from the four methods above to compare and evaluate the experimental and simulation results (Figure 4.31).

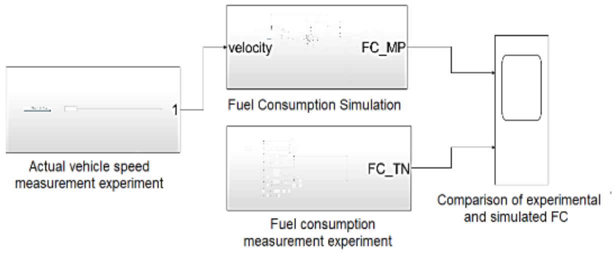


Figure 4.31. Simulink diagram comparing the overall results of experimental and simulation-based FC.

4.6.4.2. Comparison Results

a) Graph showing the comparison results.

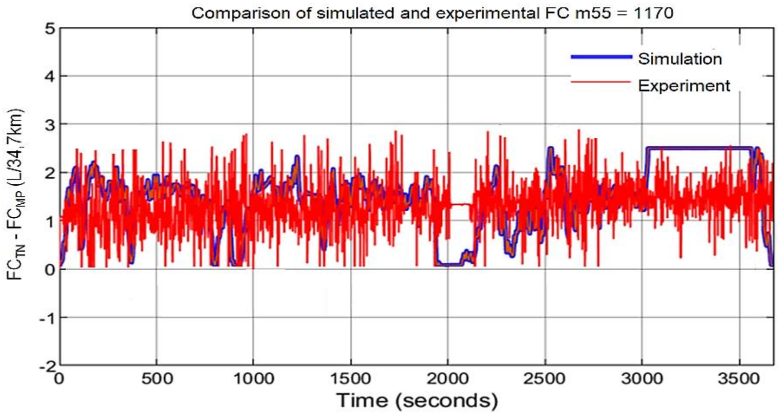


Figure 4.32. Graph comparing experimental and simulation FC results.

b) Simulation results of FC_{MP} fuel consumption.

The standard deviation in the ranges with a mean value of 0–2.48 liters and in the range of 0.80–4.95 liters with a mean value of 2.06 liters both have a standard deviation of 0.42 liters.

The data are stable with a low coefficient of variation CV = 20.03%.

The distribution is slightly skewed to the right (skewness = 0.36), with no negative values.

The graph conforms to the pattern of high Kurtosis (4.04) with a sharp peak and few outliers at the tail.

Comment: The simulation data is of good quality and stable, and the predictions will match the actual physical measurement signals.

c) Results of the FC_{TN} fuel consumption experiment

FC_{TN} has a mean value of 0–2.62 liters with a standard deviation of 1.07 and in the range of 6.84–9.77 liters with a standard deviation of 1.69 liters. Thus, the total standard deviation is 1.69 – 1.07 = 0.62, a difference of 0.2 compared to 0.42 of the simulation.

The data is unstable with a high coefficient of variation (CV = 66.03%) due to the presence of many variable parameters in the experiment, generating signal noise.

The distribution shows a large right-skew (skewness = -0.16), with many negative values (14.085/659.043 values), accounting for 5.68% of the total signal due to noise. However, this percentage is acceptable in mechanical measurements.

The graph shape is flatter than a normal distribution with low Kurtosis (0.14).

Comment: The experimental data contains noise; the negative values clearly indicate the influence of the measuring sensors or the fluctuations of the fuel in the tank. Based on this, recommendations are made regarding the selection of measuring sensors and signal normalization in the experiment.

d) Comparative comments between FC_{MP} and FC_{TN}

- Average value: Within the average value range of FC_{MP} 2.48 liters and FC_{TN} 2.62 liters, there is a difference of +0.14 liters, calculated as a percentage: (2.62 – 2.48) / 2.48 × 100% = 5.65%. Thus, the difference between FC_{TN} and FC_{MP} is 5.65%.

- Stability σ: FC_{MP} has σ_{MP} = 0.42 liters (stable) and FC_{TN}: σ_{TN} = 1.07 liters (unstable). Thus, FC_{MP} has a stability level 2.5 times higher than FC_{TN}.

- Measurement errors in the experiment: Mean absolute error MAE = 0.98 liters. Mean square error RMSE = 1.22 liters.

- Statistical test results: T-test: p-value < 0.001 indicates high statistical significance. Mann-Whitney U: p-value < 0.001 shows that all differences are statistically significant.

- Correlation analysis: Pearson r = 0.934 indicates high correlation, ensuring reliability. Spearman index ρ = 0.95 shows strong hierarchical correlation, and the very high homogeneity CCC = 0.720 suggests that the two datasets are close together and strongly correlated.

4.6.4.3. Comparison of results in reduced volume

Table 4.3: Summary of experimental results from April 14, 2024 with m44 = 1053 kg

Fuel consumption test on a car, April 14, 2024										
	Cycle 1		Cycle 2		Cycle 3		Cycle 4		Cycle 5	
Content	**Data**	**Result**	**Data**	**Result**	**Data**	**Result**	**Data**	**Result**	**Data**	**Result**
Departure time	4:02 AM	1 hour	5:27 AM	1h02'	7:55 AM	1 hour	8:20 AM	1 hour	9:45 AM	1h06'
End time	5:02 AM		6:29 AM		7:55 AM		9:20		10:51	
First kilometers	0	34.7	34.7	34.7	69.4	34.7	104.1	34.7	138.8	31.7
Final kilometers	34.7		69.4		104.1		138.8		170.5	
Initial fuel quantity (g)	12,488	0.974	11,516	0.974	10,546	0.93	11,683	0.948	10,735	1,103
Final fuel quantity (g)	11,514		10,542		9,616		10,735		9,632	
Running route	University of Technology - Phung Bridge - Thay Pagoda - Dong Truc (Lang-Hoa Lac Expressway)		Dong Truc (CT Lang Hoa Lac) - Son Tay - Vinh Thinh Bridge - Dong Van - Yen Lac		Dong Van (Yen Lac) - National Highway 2A - Me Linh Road - Vo Van Kiet Road		Vo Van Kiet Street - Dong Tru Bridge - Thanh Tri Bridge - Do Muoi Street (Hoang Mai District)		Do Muoi Street (Hoang Mai District) - Ngoc Hoi - Cau To Bridge - Van Khe - Le Trong Tan - Lang Hoa Lac - My Dinh - Trinh Van Bo - Hanoi University of Technology	
Road characteristics	City center, suburbs, highway		The suburbs have slopes.		Suburban		Suburbs, Urban areas		Densely populated urban areas	
Break time	End of first session: 25 minutes		Second attempt ends: 25 minutes		Third attempt: 25 minutes		End of round 4: 25 minutes			

The results of the comparative test run in cycle 1 showed that the car traveled 34.7 km in 1 hour, with a fuel consumption of 0.974 kg FC = 1.35 liters. Compared to the original weight (m55), a 10% reduction in weight resulted in a 7.8% reduction in fuel consumption, and compared to the simulation, it was 7.2%. Thus, the difference of 7.8 – 7.2 = 0.6% is due to driving skill and external factors.

CONCLUSION OF CHAPTER 4

Chapter 4 presents the experimental study on fuel consumption measurement of the Toyota Vios, including the design and fabrication of the measuring device, the development of the experimental driving cycle, data acquisition and processing, and result evaluation. The direct on-road measurement method was selected in accordance with the SAE J1321 standard and adapted to Vietnamese traffic conditions. After fabrication, the measuring device was calibrated and verified to ensure the accuracy and reliability of the collected data.

The experimental results show that fuel consumption increases with the increase in vehicle mass, which is consistent with both theoretical predictions and simulation trends. A comparison between the simulation and experimental results shows an average deviation of 5.65%, demonstrating a high level of agreement. For the case of a 10% reduction in vehicle mass, fuel consumption decreased by 7.8% in the experimental results and by 7.2% in the simulation results, with a difference of only 0.6%.

These results have validated the reliability of the FC_{stat} model, the FC equation, the experimental driving cycle, and the developed measurement system, while also confirming that vehicle mass is a significant factor affecting fuel consumption. This provides a scientific basis for vehicle mass reduction solutions aimed at improving fuel efficiency in practical applications.

GENERAL CONCLUSIONS AND FUTURE RESEARCH DIRECTIONS OF THE THESIS

The dissertation entitled “Research on the Influence of Five-Seat Passenger Car Mass on Fuel Consumption” has clarified the relationship between vehicle mass and fuel consumption through theoretical analysis, modeling, simulation, and experimental studies conducted on the Toyota Vios. The results indicate that rolling resistance varies proportionally with vehicle mass, whereas aerodynamic drag is almost independent of vehicle mass when the vehicle shape remains unchanged.

Based on the analysis of multiple vehicle mass levels, the dissertation establishes the variation law of fuel consumption with respect to vehicle mass. Due to the nonlinear characteristics of the data, a piecewise model is employed to describe this relationship, achieving a high coefficient of determination ($R^2 = 0.99$). Specifically, fuel consumption is expressed as: $FC = \begin{cases} 0.0035m - 0.15; & m \leq 1300 \\ 0.00002m^2 - 0.045m + 30; & m > 1300 \end{cases} \ (L/100\ km)$

The dissertation has also designed and fabricated a real-time fuel consumption measurement device and developed an experimental driving cycle suitable for Vietnamese traffic conditions. The comparison between simulation and experimental results shows an average deviation of 5.65%; for the case of a 10% reduction in vehicle mass, the deviation between experimental and simulation results is only 0.6%, thereby confirming the reliability of the model and the research methodology.

In addition, the dissertation proposes a vehicle mass reduction solution through the use of CFRP-Epoxy composite materials, contributing to the reduction of motion resistance forces, lower fuel consumption, and improved energy efficiency. The research results have both scientific and practical significance in the design and development of fuel-efficient and low-emission vehicles.

Directions for further research:

Due to time constraints and research limitations of the thesis, the measurement system could only be implemented on 5-seater passenger cars. Therefore, the doctoral candidate proposes the following directions for further research:

- To further expand the study by investigating the combined effects of vehicle mass and other influencing factors under actual operating conditions on the fuel consumption of passenger cars.
- To investigate fuel consumption across multiple vehicle models.
- To study and evaluate the durability and production cost of vehicle body structures made from composite materials.
- To further improve the measurement system so that it can be widely applied to various vehicle types in research and practical applications.

SCIENTIFIC PUBLICATION

[1]. Ngo Quang Tao, Nguyen Thanh Quang (2024), “Influence of kinematic parameters on fuel consumption in cars”, *Proceedings of the 2024 4th International Conference on Electrical, Computer, Communications and Mechatronics Engineering (ICECCME)*, Male, Maldives, 1–6. DOI: 10.1109/ICECCME62383.2024.10796898.

[2]. Ngo Quang Tao, Nguyen Thanh Quang (2025), “Analysis relationship between mass and lightweight materials on the body to resistance forces of the car moving”, *Advances in Engineering Research and Application. ICERA 2024. Lecture Notes in Networks and Systems*, Vol. 1611, 100–107. https://doi.org/10.1007/978-3-032-03859-3_10.

[3]. Ngo Quang Tao, Nguyen Thanh Quang, Le Van Anh, Pham Minh Hieu, Le Duc Hieu (2024), “Analysis of effect of rolling resistance coefficient on automobile fuel consumption”, *HaUI Journal of Science and Technology*, 60(5), 216–218.

[4]. Ngo Quang Tao, Nguyen Thanh Quang, Le Van Anh (2025), “Relationship Between Rolling Resistance and Deformation Energy of Car Tires”, *Proceedings of the 4th Annual International Conference on Material, Machines, and Methods for Sustainable Development (MMMS2024)*, Vol. 1: *Advanced Materials and Manufacturing Technologies*, 281–287. https://doi.org/10.1007/978-3-031-93816-0_34.