

## *Original Paper*

# Design and Application of an Automotive Engine Performance Virtual Simulation Software

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Received: January 18, 2026

Accepted: March 02, 2026

Online Published: March 19, 2026

doi:10.22158/wjeh.v8n2p1

URL: <http://dx.doi.org/10.22158/wjeh.v8n2p1>

### **Abstract**

*"engine performance characteristics" constitutes the core teaching content of the course Engine Principles. Traditional teaching models typically separate theoretical instruction from practical training: theoretical teaching appears abstract due to the lack of dynamic demonstration tools, while experimental teaching is constrained by factors such as the number of equipment sets, space limitations, and safety risks, making it difficult to achieve hands-on operation for every student. Against this backdrop, this paper designs a lightweight virtual simulation teaching software for engine performance characteristics. Focusing on core experimental projects including speed characteristics, load characteristics, and universal characteristics, the software enables students to intuitively and safely explore the dynamic laws governing how engine performance parameters change with operating conditions through parametric modeling and interactive operations. The deep integration of this virtual simulation platform into theoretical classrooms has effectively addressed the challenge of "disconnection between theory and practice. This provides a feasible approach and empirical support for enhancing the effectiveness of theoretical teaching in the vehicle engineering discipline and for the reform of similar courses.*

### **Keywords**

*engine performance characteristics, virtual simulation, visual interaction, teaching software*

## **1. Introduction**

In recent years, with the development of virtual simulation technology, domestic universities have also attached great importance to the application of virtual simulation experiments in teaching. Virtual simulation technology can overcome the limitations of traditional teaching, such as experimental sites, experimental equipment and environmental conditions. In teaching, a "virtual + theory" integrated teaching mode is adopted, which enhances the interest of the class and strengthens students'

participation. Universities such as Jilin University, Shanghai Jiao Tong University and Hubei Automobile Industry College, they have independently developed vehicle virtual simulation experimental platforms integrating "production, education and research". This virtual simulation platform integrates the relevant course experiments of vehicle engineering, including vehicle structure, design, research and performance debugging, etc. Such comprehensive virtual simulation experiment platforms require a high level of theoretical depth and model complexity, and are oriented towards research-oriented teaching models. They have high requirements for students' learning foundation and are difficult to meet the teaching needs of different levels of institutions. Addressing the above issues, and in combination with the university's educational positioning, conditions, teaching objectives, and student learning context, this paper designs a lightweight engine performance characteristics virtual simulation software tailored to the teaching needs of the Engine Principles course at the university. This software realizes the trinity of simulation, analysis and interaction, enriching the application theory of virtual simulation technology in the *Engine Principles* course.

## 2. Engine Performance Characteristics

Automotive engine performance characteristics reveal the evolutionary laws of engine performance indicators as they change with adjusted and operating conditions, providing a theoretical basis for engine matching, calibration, and performance improvement in engineering practice. The core of adjusted and operating conditions can be quantitatively described by the following thermodynamic and combustion formula system.

The heat supply per cycle  $Q$  (kJ) can be expressed as:

$$Q = \frac{\phi_c V_s \rho_0 h_\mu}{\phi_a L_0} \quad (1)$$

where:  $\phi_c$  is volumetric efficiency;  $\rho_0$  is air density under atmospheric conditions ( $\text{kg}/\text{m}^3$ );  $V_s$  is displacement volume ( $\text{m}^3$ );  $\phi_a$  is excess air ratio;  $h_\mu$  is lower heating value of fuel ( $\text{kJ}/\text{kg}$ );  $L_0$  is theoretical air requirement ( $\text{kg}/\text{kg}$ ).

$$P_{me} = \frac{W_e}{V_s} = \frac{\eta_{et} Q}{V_s} \quad (2)$$

Where:  $W_e$  is effective work per cycle (kJ);  $\eta_{et}$  is effective thermal efficiency;  $\eta_{it}$  is indicated thermal efficiency;  $\eta_m$  is mechanical efficiency.

$$P_{me} = \frac{\rho_0 h_\mu}{L_0} \frac{\eta_{it} \eta_m \phi_c}{\phi_a} \cdot \eta_{et} = \eta_{it} \eta_m \quad (3)$$

From Eqs. (1), (2), and (3), the following can be written:

$$P_e = \frac{P_{me} V_s m_i}{120} = K_1 \frac{\phi_c}{\phi_a} \eta_{it} \eta_m n \quad (4)$$

$$T_{iq} = \frac{P_{me} V_s i}{0.00314 \tau} = K_2 \frac{\phi_c}{\phi_a} \eta_{it} \eta_m \quad (5)$$

$$b_e = \frac{3.6 * 10^6}{\eta_{et} h_{\mu}} = K_3 \frac{1}{\eta_{it} \eta_m} \quad (6)$$

where  $K_1$ ,  $K_2$ , and  $K_3$  are proportionality constants.

Based on the above core formulas of thermodynamics and combustion theory, the evolution laws of engine performance indicators with operating parameters can be systematically revealed: The effective power  $P_e$  and torque  $T_{iq}$  vary coupled with engine speed  $n$ , which essentially originates from the synergistic effects of the mean effective pressure  $p_{me}$ , volumetric efficiency  $\phi_c$ , excess air ratio  $\phi_a$ , and effective thermal efficiency  $\eta_{et}$ . The specific fuel consumption  $b_e$  directly reflects the energy conversion efficiency, which is inversely proportional to  $\eta_{et}$  and represents the combined influence of combustion quality and mechanical losses.

By introducing the Woschni heat release model and the Vibe combustion model, the in-cylinder transient heat transfer and combustion heat release processes can be embedded into the above formula system. Furthermore, a multi-physics coupled engine virtual simulation platform can be established in MATLAB/Simulink to realize the quantitative relationship of key performance indicators — including effective power, output torque, and specific fuel consumption — with operating conditions such as engine speed and load, as well as adjusted conditions such as excess air ratio and ignition/injection timing. This enables accurate prediction and optimization of engine power, torque, and fuel economy under various speeds and loads.

### 3. Software Interface and Functions

The virtual simulation software of this design is centered on the teaching objectives of the engine principle course. It follows the design principles of "human-computer interaction, convenient operation, and data interface", and focuses on the research of traditional engine's speed characteristics, load characteristics, and the matching between the engine and the entire vehicle. It realizes the dynamic change process of the engine's characteristic curves.

#### 3.1 Software Interface

The software interface is shown in Fig. 1, which mainly includes three sub-interfaces: speed characteristics, load characteristics, and universal characteristics. Each sub-interface can be switched via tabs on the main interface.



Figure 1. Interface of the Software

Table 1. Composition and Functions of the Simulation Software Interface

No.	Component	Function Description
1	The engine characteristics simulation entrance	Engine type selection, feature analysis dimension switching
2	Experimental variable recording area	Records core control variables for engine characteristic tests
3	Engine performance parameters output area	torque, power, fuel consumption rate, and other parameters, engine core evaluation indicators of power performance and economy, Engine characteristics
4	characteristic curve visualization display area	showing the simulation results of speed characteristic curve and load characteristic curve, and the intuitive expression of engine characteristic curve change law
5	Regulatory regions of the experimental variables	The interactive regulation of experimental variables can meet the regulation of engine speed and throttle opening under different working conditions

### 3.2 Functions of the Simulation Software

#### 3.2.1 Engine Load Characteristics

The engine load characteristic refers to the relationship between engine performance indicators and load variation at a constant engine speed, which is presented in curve form and known as the load

characteristic curve. In the virtual simulation software, load characteristic simulations can be performed separately for gasoline engines and diesel engines. The engine is fixed at a certain speed (e.g.,  $n=2000$  r/min for gasoline engines and  $n=1500$  r/min for diesel engines), and the throttle opening is increased gradually. The experimental variables are recorded in the **experimental variable recording area**. According to the recorded variables, engine performance parameters including torque, power, fuel consumption rate, effective power, and mean effective pressure are calculated in the engine performance parameter area. Finally, the simulation results of the load characteristic curves are displayed in the **visualization display area**, as shown in Fig. 2 and Fig. 3.

From the simulation results in Figures 2 and 3, it can be observed that when the engine speed remains constant, the fuel consumption rate drops sharply as the throttle opening increases. When the throttle opening is around 50%, the fuel efficiency reaches its lowest point. As the throttle opening continues to increase, the fuel consumption curve begins to rise, and the fuel consumption curve changes in a "hook-shaped" manner with respect to the throttle opening. This simulation result is in perfect agreement with the textbook, indicating that this simulation module is effective and can dynamically display the formation process of the curve.

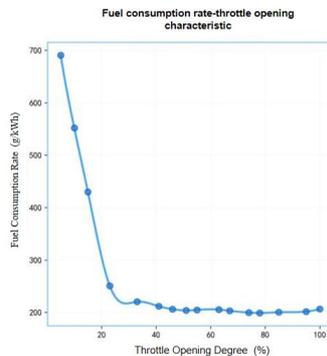


Figure 2. Load Characteristic Curve of Gasoline Engine

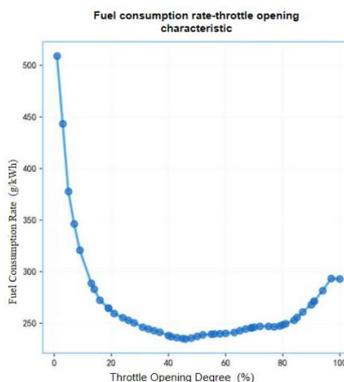


Figure 3. Load Characteristic Curve of Diesel Engine

### 3.2.2 Engine Universal Characteristics

The universal characteristics of the engine can be presented in a single chart, showing engine performance such as fuel efficiency, power output, and engine output torque. The main contour lines are used for representation. In this simulation, the fuel consumption rate curve and power curve are taken as examples. In this virtual simulation software, a group of load characteristic experiments at different speeds are carried out, the experimental variable values are recorded, and the engine performance parameters are calculated. The simulation software automatically fits and generates the universal characteristic curves, as shown in Fig. 6 and Fig. 7.

Based on the simulation results, within the concentric constant fuel consumption curve in the general characteristic diagram, the operating area with the lowest fuel consumption and the best economy can be identified. Figure 4 shows the universal characteristic curve diagram of a gasoline engine. From the simulation results, it can be seen that the innermost isotherm range is the smallest and the color is the darkest. This area has the best fuel economy. The color gradually becomes lighter, the isotherms gradually expand from the inside to the outside, and the economy gradually decreases. Figure 5 shows the universal characteristic curve diagram of a diesel engine. The economic operating area of the diesel engine is larger than that of the gasoline engine.

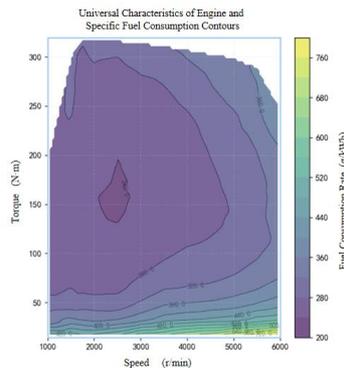


Figure 4. Universal Characteristic Curves of Gasoline Engine

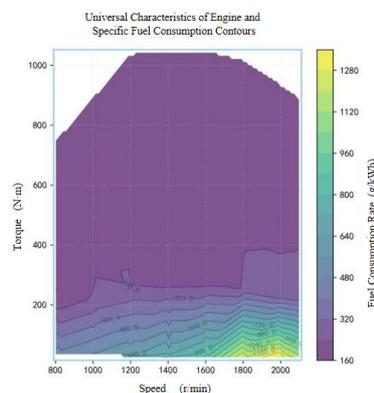


Figure 5. Universal Characteristic Curves

#### 4. Teaching Application and Effects

The course Engine Principles adopts an online-offline blended teaching mode, in which the virtual simulation software is organically integrated into the teaching process.

Before class, teachers assign guided tasks, and students conduct independent exploration using the simulation software on computers. This enables students to intuitively perceive the influences of engine performance parameter variations on power performance, fuel economy and emission characteristics even in self-learning scenarios without direct instructor guidance.

During class, the virtual simulation software supports the deep integration of theory and practice. The teaching breaks away from the one-way lecturing mode: teachers demonstrate software operations combined with key knowledge points and analyze the coupled effects of parameter changes, while students conduct synchronous operations and instant verification. Through simultaneous explanation and practice, as well as virtual-real interaction, students intuitively understand the key and difficult contents, achieving cognitive improvement from phenomenon observation to theoretical internalization.

After class, online expansion is carried out based on the virtual simulation software to consolidate knowledge, cultivate engineering application and innovative abilities. By assigning comprehensive engineering tasks such as engine economy optimization, power performance calibration, and vehicle matching, students are guided to independently adjust engine characteristic parameters and complete simulation training, transforming theoretical knowledge into practical engineering application abilities. Students are required to design virtual schemes adapted to specific vehicle demands based on simulation results, and generate complete simulation reports including curve comparison, data analysis and feasibility demonstration, so as to deepen knowledge application in practical and challenging tasks.

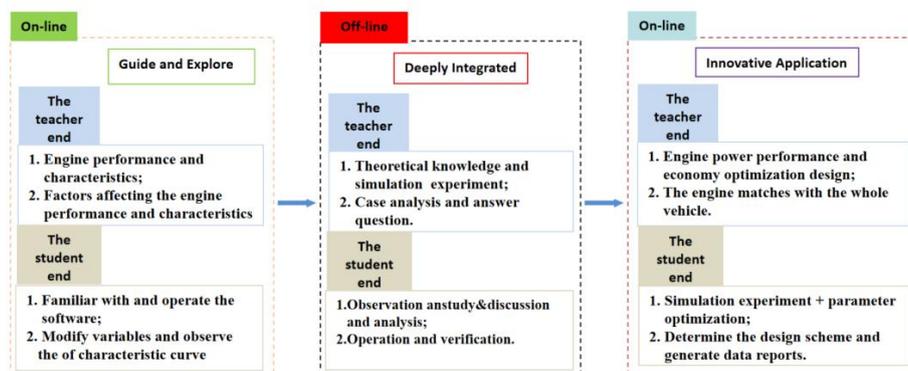


Figure 6. Online and Offline Blended Teaching Mode

This virtual simulation software breaks the traditional teaching model and empowers the entire teaching process. It becomes an important link in building online and offline blended teaching. Online students can use this software for previewing and expansion, which enhances their practical skills and

independent thinking abilities. Offline students actively interact and participate in the classroom teaching, thereby improving the quality of classroom instruction.

At the same time, the virtual simulation software fills the teaching gap of lacking engine bench experiments in the university's vehicle engineering major. It requires no expensive equipment purchase and maintenance costs, and can complete the whole process of characteristic experiment teaching only through a computer terminal, making it a high-quality teaching tool with low cost and high adaptability.

In classroom teaching, the software is used to demonstrate the multi-factor coupling effects, which can quickly transform abstract theories into intuitive phenomena. Students gain a more thorough understanding of the "formation mechanism of engine characteristic curves", and classroom interaction and participation are improved, realizing a dual enhancement of teaching efficiency and quality. In addition, the standardized operation process and visual feedback of the software enable students to think independently even without instructor guidance.

## 5. Discussion

This paper implements the talent cultivation concept of emerging engineering education and the requirements of OBE (Outcomes-Based Education), verifying the feasibility and effectiveness of the engine performance virtual simulation software in curriculum teaching.

As a low-cost teaching tool, this software embodies the core educational value of integrating virtuality with reality. It not only stimulates students' initiative and curiosity but also transforms them from passive recipients of knowledge into active participants in inquiry-based learning. This transformation helps consolidate their theoretical foundation and strengthen their engineering competence.

In future research, the software functions and virtual experiment contents will be continuously enriched. Based on this platform, experimental contents of core professional courses such as Automobile Construction and Engine Principles will be integrated to break through curriculum knowledge barriers and help students construct a systematic and coherent professional knowledge system.

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