

Design and Exploration of the Virtual Simulation Experiment Project on Principles of Aviation Engines

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Abstract: The fundamentals of aero-engine design are based on thermodynamic cycles as a core element. They illustrate the methods of component matching and operating-condition coupling. Although this topic has strong theoretical and engineering significance, its practical implementation is challenging because constraints related to cost, energy consumption, and safety requirements must be taken into account. Because internal flow fields are invisible, students tend to focus on memorizing formulas rather than developing a complete and integrated understanding. Based on these educational objectives, this paper systematically examines the development of virtual simulation experiments for aero-engine principles. The experiments adopt student-centered and outcome-oriented methods, naturally integrating theoretical learning with practical exploration. The practical components are arranged according to the engine's operating workflow, and the experiments are organized into several layered modules that focus on different components of aero-engine systems. Therefore, it is necessary to construct a teaching approach that helps students understand the overall system and aligns with the requirements of modern engineering education. Based on these educational objectives, this paper systematically examines the development of virtual simulation experiments for aero-engine principles. The experiments adopt student-centered and outcome-oriented methods, naturally integrating theoretical learning with practical exploration. The practical components are arranged according to the operating workflow of the engine, and the experiments are organized into several layered modules focusing on different components. By combining component analysis, system integration, whole-engine testing, and flight-condition simulation, a closed-loop teaching model can be established: "theory-guided learning → three-dimensional cognition → parameter interaction → result analysis → evaluation report → continuous improvement." With the support of 3D visualization and real-time simulation, students can independently adjust key parameters and clearly observe their effects on engine performance. Although virtual simulation cannot completely replace actual engine experiments, it can serve as an effective bridge between classroom learning and engineering practice. This approach enables students to gradually progress from theoretical knowledge to engineering analysis and innovative design.

Keywords: The principles of aero-engine; Virtual simulation; Experimental teaching; Teaching design

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1. Introduction

With the recent advances in information technology and virtual reality, technologies such as 3D visualization, real-time simulation computing, and virtual simulation have been increasingly introduced into engineering education. Experimental teaching has become an indispensable part of practical teaching in higher engineering education. Therefore, the Ministry of

Education's guidelines on national virtual simulation experiment teaching projects emphasize the importance of integrating advanced information technology with experimental teaching.

These initiatives should adhere to the fundamental task of fostering virtue and cultivating talent. They should adopt a competency-based educational approach, follow the principles of "student-centeredness, outcome orientation, and continuous improvement," and make full use of available information technologies. By expanding both the scope and depth of experimental content, these technologies provide a solid policy and methodological basis for reforming experimental teaching in courses on aero-engine principles^[1].

Large-scale and complex engineering systems, such as aero-engines, are characterized by high cost, high risk, irreversibility, and difficulty in replication. Therefore, virtual simulation is not merely a temporary substitute for physical experiments, but an effective teaching tool that helps students visualize internal processes, manipulate key parameters, perform calculations, and clearly explain engineering concepts^[2].

This paper, entitled "Design and Exploration of a Virtual Simulation Experiment Project on Aero-Engine Principles," systematically discusses the necessity of project development, teaching objectives, system architecture, and experimental content. It also presents the simulation models, implementation methods, evaluation framework, and application prospects, thereby providing a comprehensive explanation of the technical implementation of the project.

Furthermore, the paper analyzes various aspects of virtual simulation teaching and explores their alignment with educational goals and engineering competency development. The purpose is to establish a well-rounded experimental design framework suitable for aviation universities, aircraft power engineering programs, and related curriculum reforms^[3].

2. Description of the overall design of the experimental project

The engine design discussed in this paper is based on the typical virtual simulation experiment project for aero-turbojet/turbofan engines, and therefore naturally leads to the question of "how air is". The text explains how the quantity is converted into thrust upon entering the engine, then goes on quite naturally to discuss six major points: structural understanding, energy conversion, component features, matching constraints, general engine performance, and the purpose of discussing flight conditions is to find out how to enable students to. By watching the engine's operating process and properly adjusting the relevant parameters by analyzing performance curves, determining fault boundaries, and writing experimental reports in a virtual environment, one can naturally and systematically learn the overall working mechanisms of aero-engines. Since the course is mainly intended for majors in flight technology, it makes sense to say that the fields of transportation, aircraft power engineering, and aircraft design engineering, and therefore can naturally be used as a practical module for general purposes.

Because the text refers to aviation courses, engineering training programs, and prerequisite courses for graduate students, it is natural to say at the instructional level that junior students should concentrate on structural understanding and fundamental principles, while senior students are eligible to proceed to component matching, performance analysis at non-design points, and fault diagnosis. Since people engaged in innovation training have this foundation, they can properly build on it. Discuss the topics of model extension, control strategies, and data-driven analysis. Since the system can naturally be divided into four layers, it is proper to first discuss the first layer. The instructional objectives layer specifies what is to be learned regarding knowledge, skills, and. The first layer is the competency goals layer, and the second layer is the experimental tasks layer. Experiments are described that serve to investigate the principles, component characteristics, integration matching, and overall engine performance. The third layer is properly called the simulation model layer, in which thermal cycle models, component characteristic models, thrust models, fuel consumption models, surge boundary models, and flight environment models are all included^[4].

The fourth layer is the platform support layer, so it is natural to mention its functions: 3D visualization, human-machine interaction, data recording, and online evaluation. The text has experimental reporting, resource-sharing functions, and begins from the point of view of learning. Students first look at intake ports, fans, the compressor, combustion

chamber, turbine, nozzle, and accessories, which are all mentioned. Use 3D models to study the systems, and thereafter measure the variations of pressure, temperature, flow rate, and efficiency in the single-component experiments. First, determine the power balance between the compressor and turbine, as well as the relation between nozzle area and flow rate from matching experiments, and then proceed naturally to a thorough analysis of flight performance. The effect of altitude, speed, throttle conditions, and ambient temperature is discussed. The parameters of engine thrust, fuel consumption, surge margin, and exhaust temperature. At the same time, performing full-engine experiments ^[5].

Table 1. Design of the virtual simulation experiment module for aeroengine principles

Module	Core Task	Main Interaction Parameters	Expected Learning Outcomes
Understanding the principles of propulsion	Observe the processes of air intake, compression, combustion, expansion, and nozzle acceleration.	Engine Type, View Mode, Station Display	It demonstrates the fundamental mechanism of how thrust is generated.
Component Property Testing	Analyze the performance of the intake passage, compressor, combustion chamber, turbine, and nozzle.	Pressure ratio, efficiency, fuel flow rate, and nozzle area	Can explain the trend of component parameter changes
Integration and Matching Experiment	Research on compressor-turbine power balance and overall flow constraint of the system	PC, Tt4, A8, Revolution Rate	Can determine whether the match is valid
Overall Machine Performance Tests	Comparison of thrust and fuel consumption rates under different flight conditions	Height, Mach number, throttle position, ambient temperature	Capable of analyzing performance at non-design points
Fault Boundary Experiment	Identify boundary conditions such as surge, overheating, and insufficient thrust.	Intake distortion, throttle variation, and nozzle mismatch	Capable of conducting fault cause analysis

3. Design of experimental teaching objectives

The engine design discussed in this paper is based on a typical virtual simulation experiment project for aero-turbojet and turbofan engines. Therefore, it focuses on the fundamental question of how air entering the engine is converted into thrust. The experiment explains this process through six major aspects: structural understanding, energy conversion, component characteristics, matching constraints, overall engine performance, and flight-condition analysis.

The purpose of introducing flight-condition analysis is to enable students to systematically understand the overall working mechanisms of aero-engines in a virtual environment. By observing the operating process of the engine, adjusting relevant parameters, analyzing performance curves, determining fault boundaries, and writing experimental reports, students can develop a more comprehensive understanding of aero-engine principles.

Since the course is mainly intended for students majoring in flight technology, transportation, aircraft power engineering, and aircraft design engineering, it can be used as a general practical teaching module. For aviation-related courses, engineering training programs, and prerequisite courses for graduate students, different instructional levels should be designed according to students' academic backgrounds. Junior students should focus on structural understanding and fundamental principles, while senior students can proceed to component matching, off-design performance analysis, and fault diagnosis. Students involved in innovation training can further explore model extension, control strategies, and data-driven analysis.

The system can be divided into four layers. The first layer is the instructional objectives layer, which specifies the expected learning outcomes in terms of knowledge, skills, and competencies. The second layer is the experimental tasks layer, which includes experiments on engine principles, component characteristics, integration matching, and overall engine performance. The third layer is the simulation model layer, which includes thermodynamic cycle models, component characteristic models, thrust models, fuel consumption models, surge boundary models, and flight environment models ^[4].

The fourth layer is the platform support layer, which provides functions such as 3D visualization, human-machine interaction, data recording, online evaluation, experimental reporting, and resource sharing. From the perspective of the learning process, students first observe the intake, fan, compressor, combustion chamber, turbine, nozzle, and accessory systems through 3D models. They then study the variations in pressure, temperature, flow rate, and efficiency through single-component experiments.

In matching experiments, students first determine the power balance between the compressor and turbine, as well as the relationship between nozzle area and flow rate. They then proceed to a comprehensive analysis of flight performance. During full-engine experiments, the effects of altitude, flight speed, throttle setting, and ambient temperature on engine thrust, fuel consumption, surge margin, and exhaust temperature are analyzed^[5].

4. Experimental content and task module design

The experimental content is divided into five modules, each of which can operate independently or be combined to form a complete experimental sequence according to the course progression^[6].

Module 1 focuses on the fundamental principles of propulsion. Through 3D animation, students observe the entire process in which air enters the engine through the intake passage, is compressed by the compressor, heated in the combustion chamber, expanded through the turbine to produce work, accelerated through the nozzle, and finally converted into thrust. According to NASA Glenn's public educational materials, in a jet engine, the turbine extracts energy from high-temperature gas to drive the compressor through a shaft, while the remaining energy is accelerated through the nozzle to generate thrust^[7]. This module helps students clearly understand the energy conversion process: the chemical energy of fuel is first converted into the internal energy of the gas, and then further converted into shaft work and the kinetic energy of the exhaust stream.

Module 2 deals with component characteristic experiments. In this module, students work with sub-modules such as the intake duct, compressor, combustion chamber, turbine, and nozzle. By adjusting parameters such as inlet Mach number, compressor speed, fuel flow rate, turbine inlet temperature, and nozzle throat area, students study the total pressure recovery coefficient, pressure ratio, efficiency, temperature rise, expansion ratio, and outlet velocity of different components. The combustion chamber section introduces the structures of annular combustion chambers, tubular combustion chambers, and tubular-annular combustion chambers, followed by an explanation of their characteristics. In the combustion chamber, high-pressure air mixes with fuel and burns, causing a significant increase in the temperature of the working fluid, while an associated pressure loss also occurs^[8].

Module 3 is devoted to integrated matching experiments. The components of an aero-engine do not operate independently. The turbine's output power drives the compressor, while the nozzle flow capacity influences both the turbine back pressure and the overall engine mass flow rate. According to NASA Glenn's documentation on compressors and turbines, the matching relationship between components is essential for stable engine operation. From the matching results, students can understand that the turbine work output must match the power required by the compressor. This relationship is analyzed in terms of compressor pressure ratio, turbine inlet temperature, turbine efficiency, and nozzle flow capacity^[9]. In this module, students adjust variables such as compressor pressure ratio, turbine inlet temperature, and nozzle throat area on the virtual platform, check whether the engine operates stably, and compare thrust and fuel consumption rates under different matching configurations.

Module 4 focuses on engine performance testing. Under given flight altitude and speed conditions, students adjust the throttle setting and ambient temperature to examine their effects on engine thrust, fuel consumption rate, exhaust temperature, and rotational speed. The project includes mission profiles for different flight phases, such as takeoff, climb, cruise, high-altitude high-speed flight, and low-temperature high-altitude flight. By considering different altitudes and flight conditions, students can understand that engine performance is not fixed but varies dynamically with external atmospheric conditions and flight dynamics.

Module 5 is the fault and boundary recognition experiment. Since teaching safety is a primary concern, this module is implemented in virtual form to simulate operating conditions that are unsuitable or unsafe to trigger in real experiments. The module includes typical fault and boundary scenarios such as compressor surge, intake distortion, combustor flameout, turbine overheating, and nozzle area mismatch. Students are required to identify fault indicators from performance curves, describe parameter changes, analyze the causes of faults, and propose appropriate corrective measures^[10]. The purpose of this module is not to teach students how to repair a specific engine model, but to cultivate an engineering mindset that enables them to infer system conditions from abnormal parameter changes.

5. Discussion of three-dimensional visualization and the design of interactive interfaces

A visually rich virtual simulation experiment should not be limited to attractive graphics. Instead, images, data, and interactive elements should all contribute directly to the learning objectives. This paper proposes that the interaction interface should be designed around four core dimensions: structural visualization, process visualization, data visualization, and fault visualization.

For structural visualization, the platform should provide a complete 3D engine model. Through exterior views, cross-sectional views, exploded views, and individual component views, students can rotate, scale, hide, or display the engine casing in a transparent manner. This allows them to examine the rotor, stator, combustion chamber flame tube, turbine guide vanes, nozzle, and shaft assembly. Since turbofan engines contain both inner and outer flow paths, these flow paths should be clearly defined and displayed.

The platform should also clearly explain the sources of core engine thrust and fan thrust. Process visualization is intended to show variations in air pressure, temperature, and velocity. Therefore, the platform should use colors, arrows, and dynamic particles to represent changes in flow parameters. When the airflow enters the compressor, the color can gradually shift from cool tones to warm tones, indicating a rise in temperature.

In the combustion chamber, the processes of fuel injection, ignition, and high-temperature gas formation should be clearly presented. The airflow passing through the turbine drives blade rotation and produces shaft work, while the airflow passing through the nozzle accelerates to form a high-speed jet^[11]. Therefore, **Figure 1** provides a schematic diagram explaining the operating principles of a turbojet or turboprop engine.

For data visualization, the interface should display both key operating parameters and performance curves. When students change parameters such as compressor pressure ratio, turbine inlet temperature, diffuser ratio, nozzle area, or flight altitude, the platform should update thrust, fuel consumption rate, surge margin, exhaust temperature, and rotational speed in real time. The interface should not only present individual values, but also provide a comparative analysis of different operating conditions and curve overlays. By supporting multiple simulation scenarios, the platform can help students develop quantitative analytical skills.

For fault visualization, the platform should detect abnormal conditions such as approaching surge thresholds, exceeding temperature limits, and nozzle mismatches. In such cases, the platform should provide warnings rather than direct answers. The optimal design is to allow students to first observe abnormal curves and parameter changes, and then guide them to identify the causes of these abnormalities. Failure mechanisms can be explained through prompts or case-based guidance. This approach ensures experimental safety while preserving space for inquiry-based learning^[12].

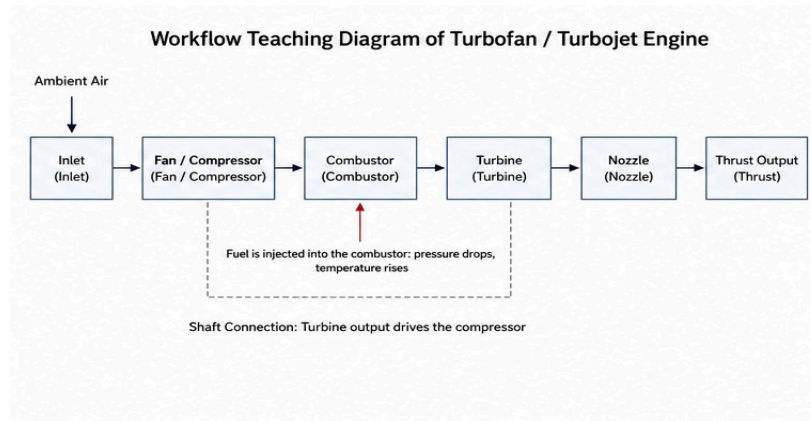


Figure 1. Schematic illustration of the operating process of a turbojet/turboprop engine.

6. Design of the teaching implementation process

The virtual simulation experiment on aircraft engine principles should be integrated into the comprehensive curriculum rather than treated as an isolated hands-on session. Therefore, this paper proposes a structured teaching process consisting of **pre-class preparation, classroom demonstration, student experiments, data analysis, report writing, and improvement based on feedback.**

In the pre-class preparation stage, the instructor provides students with materials on the basic structure of the engine and the Brayton cycle. The course also includes the derivation of the thrust equation and an experimental procedure manual. Before experimenting, students are required to complete a foundational assessment. The purpose of this assessment is not to increase students' workload, but to ensure that they have mastered the basic concepts before entering the experimental stage, thereby avoiding the problem of virtual experiments becoming aimless clicking activities.

In the classroom demonstration phase, the teacher explains the operating process of the engine under typical working conditions and then raises several guiding questions: Why does an increase in compressor pressure ratio not always lead to optimal performance? Why does thrust change with altitude under the same throttle setting? Why can turbofan engines achieve better fuel efficiency in commercial transport aircraft? These questions guide students' attention from visual representations to the underlying physical principles of the phenomena.

In the student experiment phase, students carry out both prescribed and open-ended experiments according to the task manual. Prescribed experiments are designed to achieve basic teaching objectives, such as identifying five major components, recording results under three different compressor pressure ratios, and comparing thrust changes at two different flight altitudes. Open-ended experiments allow students to design their own experimental schemes, such as finding a fuel-efficient operating solution under given mission conditions or analyzing why certain parameters approach the surge boundary.

In the data analysis phase, students export experimental data, draw parameter-performance curves, and conduct comparative analyses. Teachers should make it clear that all conclusions must be based on experimental data and objective evidence. Instead of simply quoting theoretical concepts^[13], students should explain the relationship between parameter changes and engine performance based on the simulation results.

In the report submission phase, the platform generates partial raw data and operational records. Students are then required to add explanations of the underlying principles, curve analysis, fault diagnosis, and conclusions. This process helps students transform simulation operations into structured engineering analysis.

In the feedback and refinement phase, teachers analyze common problems revealed by platform statistics and students' reports. Based on these findings, they can adjust subsequent teaching content, improve the design of experimental tasks, and provide targeted guidance for students.

7. Description of the design for the assessment and evaluation system

The evaluation system for virtual simulation experiments should move away from a single outcome-based assessment and adopt a more process-oriented, comprehensive, and developmental approach. According to the relevant virtual simulation courses of Nanjing University of Aeronautics and Astronautics, the grading criteria generally include several parts, such as understanding operating principles, conducting component characteristic experiments, performing integration and matching experiments, and completing whole-system performance tests, each with different weightings^[14]. Based on this framework, this paper further proposes a more refined evaluation scheme.

Pre-class preparation accounts for 10% of the total assessment. This part requires students to watch instructional videos, complete assigned learning tasks, take preparatory quizzes, and review experimental safety protocols. These activities help students acquire the necessary background knowledge before conducting the experiments.

Experimental procedures account for 30% of the assessment. This part evaluates whether students have completed the prescribed interaction steps, set the parameters correctly, recorded the required data accurately, and identified the components and their positions properly. In the virtual environment, the platform can automatically record students' operational processes, thereby reducing the workload of teachers in manual verification.

Data analysis accounts for 25% of the assessment. This part includes curve plotting, data comparison, parameter sensitivity analysis, and physical interpretation. It is designed to clarify the distinction between "having observed the experiment" and "having understood the experiment"^[15].

Comprehensive analysis accounts for 20% of the assessment. This part focuses on problems such as surge, overheating, insufficient thrust, increased fuel consumption rate, and their overall implications. Since the core issue is the compatibility relationship within the system, students should be guided to analyze and explain the parameter chains behind the observed phenomena, rather than simply giving answers such as "system alarm."

Innovation and expansion account for 15% of the assessment. This part includes the independent design of experimental protocols, the proposal of optimization suggestions, and the application of experimental results to real aero-engineering problems^[16]. For graduate students or students participating in innovation training programs, additional tasks such as model derivation, code simulation, data processing, and digital twin applications can also be incorporated.

8. Analysis of the teaching features and innovations of the experimental project

Compared with traditional teaching methods, the virtual simulation experiment project on aircraft engine principles presented in this paper has several clear and notable advantages. First, it adopts a progressive learning approach that guides students from individual components to component integration and then to whole-system analysis. Instead of exposing students to a complex engine system all at once, this approach follows the cognitive development process from simple to complex concepts. It is also well aligned with the knowledge structure of the aero-engine principles course and students' natural learning progression.

The project emphasizes parameter interaction and engineering boundaries. Many teaching software programs merely display animations and do not provide students with a real sense of conducting experiments. In this project, however, students can observe changes in engine performance by adjusting key parameters such as pressure ratio, temperature, flow rate, cross-sectional area, velocity, flight altitude, and boundary conditions. Through interaction and result feedback, students can perform repeated experiments and understand how engineering performance is affected by changes in constraint conditions. **Figure 2** illustrates the relationship between parameter interactions and result feedback.

The project also highlights the integration of virtual and physical teaching resources. It can be combined with engine disassembly models, sensor data acquisition experiments, and on-campus aviation training facilities. Students first learn about the internal structure of the engine through the virtual platform. They then use physical training facilities to observe the external configuration, disassemble components, and read instrument data. Finally, they return to the virtual platform

to analyze whole-system performance. This teaching method makes full use of both physical experimental data and virtual simulation analysis.

Another advantage of virtual simulation is its openness and safety. Hazardous operating conditions can be explored in the virtual environment before students interact with physical equipment. This allows students to study abnormal conditions and boundary cases without creating safety risks. At the same time, the platform records not only final results, but also students' learning processes, operational steps, and problem-solving methods. Teachers can therefore judge whether students have conducted effective exploratory learning and whether they have improved their solutions through error correction.

Process evaluation is also beneficial for cultivating students' engineering research habits. Because data must support students' conclusions, they are encouraged to analyze problems, verify assumptions, and explain results based on evidence. This process helps students develop a more rigorous engineering mindset.

Finally, the model has strong scalability. It can be extended from basic turbojet engine design to high-bypass-ratio turbofan engines, variable-cycle engines, hybrid-electric propulsion systems, and engine health management. This scalability is highly relevant for aviation universities, as it supports the development of a comprehensive curriculum system rather than a single isolated course.

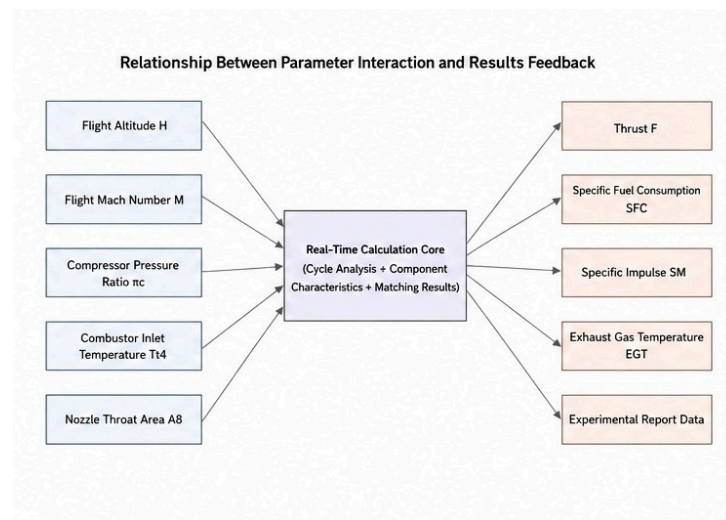


Figure 2. Relationship between parameter interactions and result feedback.

9. Conclusion

Because the course on Principles of Aero-Engine Engineering is highly abstract and engineering-oriented, traditional experimental teaching methods are often constrained by equipment limitations, cost, safety, and visualization challenges. In particular, internal engine flow processes are difficult to observe directly, component characteristics are hard to analyze in isolation, and compatibility relationships under extreme operating conditions are difficult to reproduce in physical experiments. Therefore, virtual simulation provides an effective solution for teaching aero-engine principles.

Based on the theme of "Design and Exploration of a Virtual Simulation Experiment Project on Aero-Engine Principles," this paper proposes a development framework guided by student-centered learning, outcome orientation, integration of virtual and physical environments, practical application, and continuous improvement. The framework consists of teaching objectives, experimental tasks, simulation models, and platform support. On this basis, the paper designs experimental modules covering propulsion principles, component characteristics, integration and matching, overall engine performance, and fault and boundary scenarios. It also systematically discusses model representation, 3D interaction, instructional workflows, and evaluation systems.

The practical significance of this project lies in the fact that virtual simulation does not replace real engine testing. Instead, it transforms experimental content that is difficult to observe, operate, replicate, or access in real-world conditions into visual, interactive, reproducible, and evaluable learning tasks. In this way, virtual simulation serves as an effective bridge between theoretical teaching and engineering practice.

The project is designed to help students develop a comprehensive understanding of aero-engine systems, progressing from component structures to the complete engine system. It enables students to learn about engine performance and related principles in a safe virtual environment, understand how parameter variations affect thrust, fuel consumption rate, surge margin, and exhaust temperature, and gradually improve their abilities in data analysis, engineering judgment, and innovative design.

In the future, digital twins, artificial intelligence, real-test-bed data, and mixed reality can be further integrated into the platform. These technologies can support the construction of a more intelligent, reliable, and advanced experimental teaching system for aero-engines, thereby contributing to the cultivation of new-generation aviation engineering talents.

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References

- [1] Yu K, Xu J, Ge J, 2021, On the Importance of Virtual Simulation Experiments in Aeronautical Engine Education: A Case Study of Nanjing University of Aeronautics and Astronautics’ Virtual Simulation Platform for Aeronautical Engine Principles. *Higher Education Journal*, 7(16): 5.
- [2] Zhang G, Yang Q, Huang R, et al., 2019, Development and Exploration of a Virtual Simulation Experimental Teaching Project for Cylinder Wear Diagnosis in Aviation Piston Engines. *Journal of Anyang Institute of Technology*, 18(6): 4.
- [3] Li C, Liu Y, 2008, Design and Simulation Analysis of a Virtual Prototype for Small Aviation Engines. *Mechatronics*, 14(12): 40–42.
- [4] Ma Y, Fang P, Guo X, et al., 2024, Research and Practice on the Development of a Virtual Simulation Experimental Teaching System for Aeroengine Maintenance. *Science Education Journal (Electronic Edition)*, (34): 4–6.
- [5] Zheng X, Li Z, Han Y, et al., 2023, Development of a Virtual Simulation Experiment Course for Aeroengine Test Operations. *Proceedings of the Fifth National Symposium on Education and Teaching in Aerospace Engineering Majors at Higher Education Institutions*, Beijing.
- [6] Guo X, Liu Y, Li Y, et al., 2020, Practice and Application of Virtual Simulation Experiments in Aviation Gas Turbine Engine Teaching. *Education and Teaching Forum*, (16): 2.
- [7] Gao Y, Zhong X, Xu Z, et al., 2008, Design of a VR-Based Virtual Teaching Experiment System for Aviation Engines. *Journal of System Simulation*, 20(11): 6.
- [8] Shi X, Qiu F, Shi C, et al., 2020, Design and Development of a VR-Based Virtual Experimental Platform for the WS-6 Turbojet Aircraft Engine. *Computer Knowledge and Technology: Academic Edition*, 16(1): 3.
- [9] Liu Z, Gao W, Zhang L, 2013, Development and Application of a Virtual Teaching Experiment System for Aviation

- Engines. Value Engineering, 32(11): 2.
- [10] Hu H, Wang F, Zheng Y, et al., 2022, Development of a Low-Cost Digital Classroom Hardware and Software System and Design of a Virtual Simulation Course for Aviation Engines. Digital Technology and Applications, 40(10): 151–155.
 - [11] Guo Q, Zhao H, Yan G, 2014, Application and Reflections on Virtual Experiments in Aeronautical Engine Education. Journal of Civil Aviation University of China, 32(6): 5.
 - [12] Liu H, Wang Y, Shang F, et al., 2021, Model- and Data-Driven Design of Virtual Simulation Experiments for Transonic Compressor Stall/Buzz in Aeroengines. Experimental Technology & Management, 38(11): 212-217.
 - [13] Liu Z, Gao W, Zhang L, 2013, Development and Application of a Virtual Teaching Experiment System for Aviation Engines. Value Engineering, 32(11): 181–182.
 - [14] Ma K, 2022, Research on Interactive Design and Optimization of Virtual Assembly for Aeroengines Based on Virtual Reality Technology, thesis, Southeast University.
 - [15] Wang H, Tian Y, Li Z, 2019, Research and Application of Aviation Engine Simulation Technology Based on Virtual Ergonomics. 2019 (4th) China Aviation Science and Technology Conference, Beijing.
 - [16] Zhou Q, 2026, Research and System Implementation of Virtual Simulation Technology for High-Altitude Simulation Test Platforms of Aeroengines, thesis, University of Electronic Science and Technology of China.

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