Journal of Contemporary Educational Research, 2025, Volume 9, Issue 2
http://ojs.bbwpublisher.com/index.php/JCER
ISSN Online: 2208-8474
ISSN Print: 2208-8466

Reform Practice of CDIO Teaching Mode Based on the Digital Engine Structure Principle

Kai Qu, Zhenmin Zhuang*, Kehai Dong, Liang Zeng, Yufeng Wang, Jinfei Li

Naval Aviation University, Yantai 264001, Shandong, China

Corresponding author: Zhenmin Zhuang, zzmxgd@foxmail.com

Abstract: With the continuous advancement of computer and information technology, education and teaching methods have undergone profound changes. Addressing the challenges in the Engine Structure Principle course—such as its highly practical nature, complex principles, and difficulty in student comprehension—a simulation program for the engine oil supply regulation system was developed using digital technology. This paper analyzes key factors affecting engine fuel supply, including tank pressure, engine inlet total temperature, and fuel viscosity. By encouraging inquiry-based learning, the approach enhances students' understanding of theoretical knowledge, improves teaching efficiency, and yields positive learning outcomes. Additionally, the CDIO (Conceiving-Designing-Implementing-Operating) teaching framework is integrated into the course, strengthening students' ability to apply knowledge comprehensively and collaborate effectively in teams.

Keywords: Digitalization; Turbojet engine; Fuel supply regulation; CDIO

Online publication: March 7, 2025

1. Introduction

With the rapid advancement of modern high-tech weaponry and equipment, missiles have become increasingly prevalent in modern warfare due to their flexibility and precision. To extend missile range, the cruise-stage engine typically employs low-fuel-consumption, compact turbojet or turbofan engines as its power source. Therefore, mastering the structural principles and operational processes of turbojet and turbofan engines—particularly the regulation of their oil supply systems—is crucial for proper use, maintenance, and enhanced combat support capabilities.

The Engine Structure Principle course covers the fundamental structure and maintenance of various missile power systems and serves as a core component of training for engine major students. Classified under Equipment Structure Principle education, the course involves complex theoretical and practical concepts, particularly in the case of turbojet and turbofan engine oil supply systems. Traditional teaching methods primarily rely on multimedia demonstrations, supplemented by a limited number of physical engine components for hands-on learning. However, the absence of modern teaching tools makes it difficult for students to grasp essential concepts, such as the internal structure, working process, and functional principles of engines, leading to ineffective learning outcomes.

To address the theoretical challenges in engine principle instruction, a simulation program for the engine oil supply regulation system was developed using digital technology. The program analyzes critical factors influencing fuel supply, such as tank pressure, engine inlet total temperature, and fuel viscosity. This approach deepens students' theoretical understanding, enhances teaching efficiency, and optimizes learning outcomes. Furthermore, to improve students' ability to apply knowledge comprehensively and work collaboratively, the CDIO teaching framework [1-4] was incorporated into the classroom, fostering engagement, problem-solving skills, and teamwork.

2. Development of a simulation program for the engine oil supply regulation system based on digital technology

The simulation of the engine oil supply regulation system is closely aligned with the operational processes of turbojet engines. Therefore, based on the characteristics of components such as compressors and turbines, a dynamic model was developed. This model integrates the rotor motion equation, flow balance equation, and pressure balance equation, following the principle of component matching. Various iterative solutions were then applied to solve the equations.

The accuracy of the mathematical model is critical for simulating the engine's working process. The model must effectively reflect the oil supply regulation mechanisms under different operating conditions. Given specific working parameters—such as flight altitude, Mach number, and engine speed—the system iterates the engine compressor boost ratio and turbine pressure drop ratio based on power balance and airflow equilibrium across components. Subsequently, error analysis is conducted to ensure that the direct parameters align with design accuracy. Once validated, the computed boost ratio, pressure drop ratio, and other relevant parameters are used to determine engine oil supply, thrust, and other performance metrics. The model's computational process is illustrated in **Figure 1**.

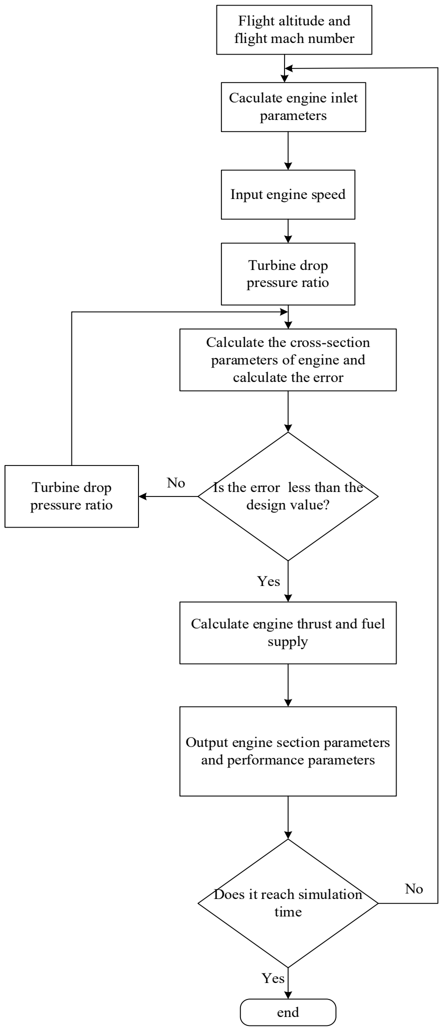

Figure 1. Flow chart of steady-state engine solution

The engine system model is composed of the fuel system model and the engine model, and the simplified sub-model relationship is shown in **Figure 2,** where $p(t)$ is the pump pressure at the t moment and $q(t+1)$ is the oil supply at the $t+1$ moment.

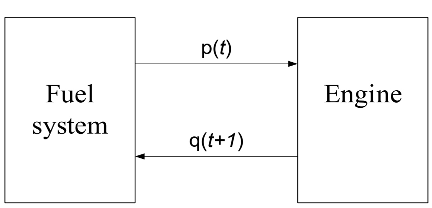

Figure 2. Schematic diagram of sub-model relationships in the system model

In the whole mathematical model, the nozzle flow at time t is first obtained from the engine model. The fuel is burned in the combustion chamber and drives the engine rotor to rotate. At the same time, the main shaft of the engine is connected to the pump shaft of the fuel pump through the gear. The rotation of the fuel pump generates the pump pressure and the fuel flow at time $t+1$ is obtained by the model of the oil supply regulating system.

According to the schematic diagram of the fuel system of a turbojet engine, a model of the fuel system was built, and the principle of the model was shown in **Figure 3**. The system includes bypass pipeline, differential pressure valve, metering valve, electronic fuel controller, oil filter, relief valve, nozzle, and other components.

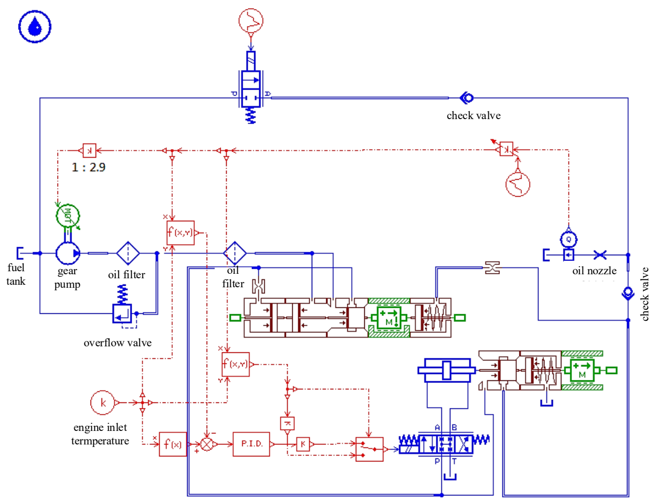

Figure 3. Schematic diagram of oil supply system

Set the temperature to 25°C, the fuel tank pressure to 3 bar, and the simulation time to 20s, and draw the simulated fuel flow curve and speed curve according to the simulation results, as shown in **Figures 4** and **5**.

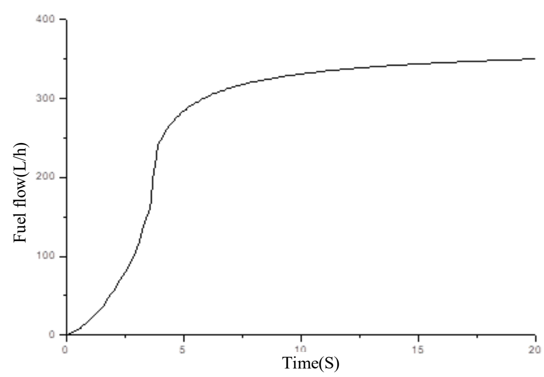

Figure 4. Fuel flow curve of fuel system

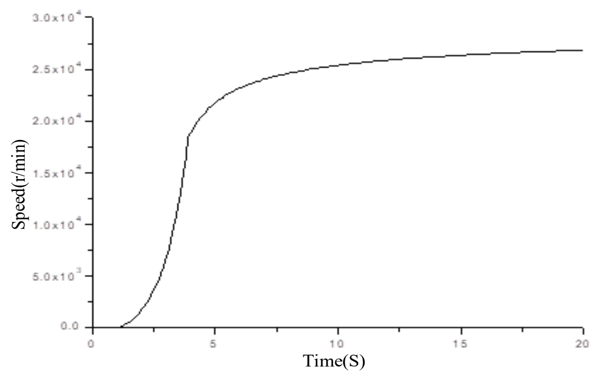

Figure 5. Fuel system speed curve

3. Influence of key parameter changes on turbojet fuel supply regulation

3.1. Influence of fuel tank pressure on engine fuel supply regulation

During engine operation, variations in fuel tank pressure affect the engine's performance. To analyze this impact, fuel tank pressures of 3.0 bar, 3.2 bar, 3.4 bar, 3.6 bar, and 3.8 bar were selected. A fuel regulation model was established to conduct simulation calculations under identical environmental and fuel system conditions. To facilitate comparative data analysis, the engine fuel flow curve and engine speed curve for different fuel tank pressures were plotted within the same coordinate system, as shown in **Figures 6** and **7**.

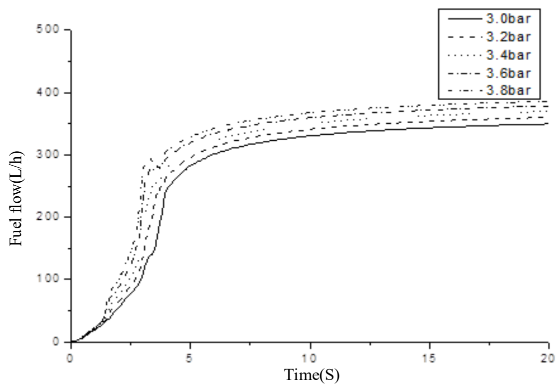

Figure 6. Engine fuel flow curve under different fuel tank pressures

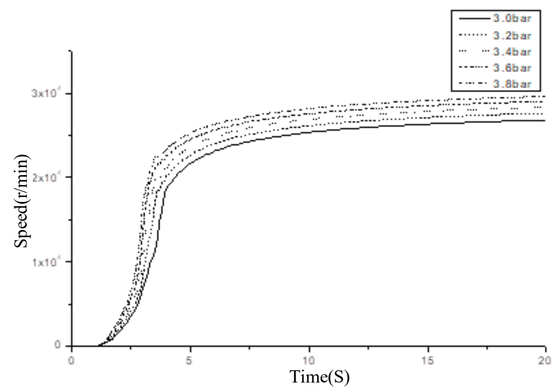

Figure 7. Engine speed curve under different fuel tank pressures

As illustrated in **Figures 6** and **7**, engine performance varies with fuel tank pressure. Within a certain range, an increase in fuel tank pressure reduces the time required for the engine speed to stabilize while also increasing both engine speed and fuel flow. Taking a fuel tank pressure of 3.0 bar as the baseline, it was observed that higher fuel tank pressure results in greater fuel flow and engine speed. Specifically, at a fuel pressure of 3.3 bar, fuel flow increases by 10.44%, while engine speed rises by 10.39%.

3.2. Influence of total engine inlet temperature on engine fuel supply regulation

Changes in the total temperature of the engine inlet also influence engine performance. To investigate this effect, inlet temperatures of 5°C, 10°C, 15°C, 20°C, and 25°C were selected. A fuel supply adjustment model was developed, and simulations were performed under consistent environmental and fuel system conditions. The resulting curves are presented in **Figures 8** and **9**.

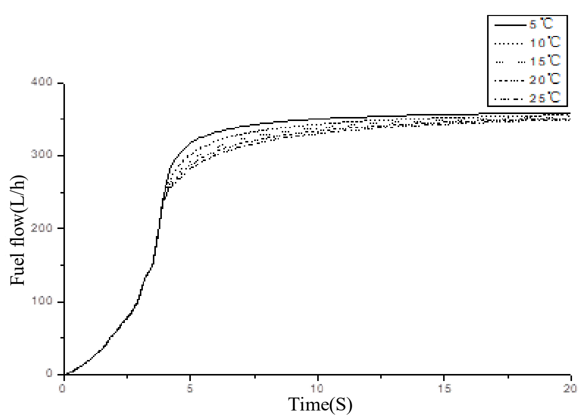

Figure 8. Engine fuel flow curve at different outlet temperatures

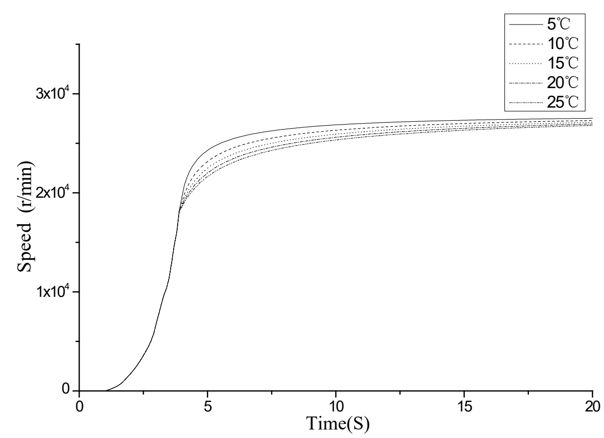

Figure 9. Engine speed curve at different outlet temperatures

Figures 8 and **9** show that variations in total engine inlet temperature affect the time required for the engine to reach equilibrium. Within a certain range, higher inlet temperatures lead to an extended adjustment time, while both engine speed and fuel flow decrease slightly at equilibrium. Using an inlet temperature of 25°C as a reference, it was found that higher temperatures correlate with lower fuel flow and engine speed, though the overall impact remains minor. When the total inlet temperature is 5°C, fuel flow and engine speed increase by 2.69% and 2.67%, respectively.

3.3. Influence of fuel viscosity on engine fuel supply regulation

Fuel viscosity also affects engine performance. To examine this factor, fuel viscosity values of 51 cP, 56 cP, 61 cP, 66 cP, and 71 cP were selected while maintaining all other conditions constant. Simulations were conducted using a turbojet fuel system model, and the resulting fuel flow and engine speed curves are shown in **Figures 10** and **11**.

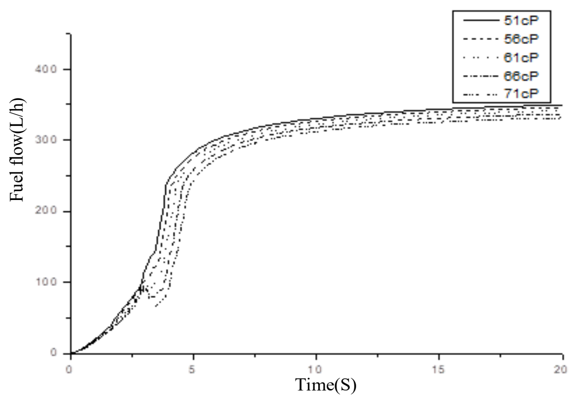

Figure 10. Engine fuel flow curves under different fuel viscosities

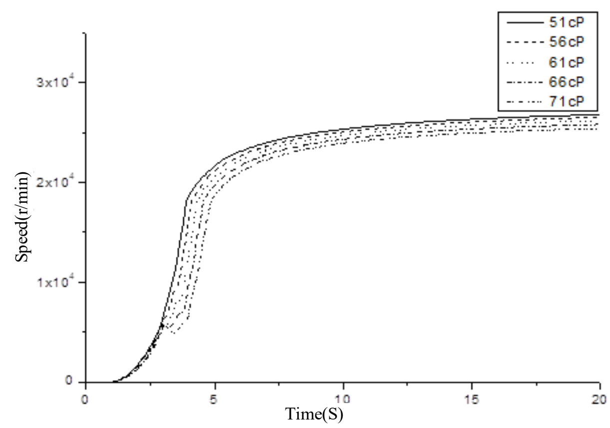

Figure 11. Engine speed curve under different viscosities

Figures 10 and **11** indicate that fuel viscosity has a measurable impact on engine performance. As viscosity increases, fuel flow and engine speed gradually decrease, though the rate of change diminishes over time. Using a fuel viscosity of 51 cP as a reference at 20 seconds, it was observed that higher viscosity results in lower fuel flow and engine speed. At a viscosity of 71 cP, fuel flow decreases by 5.21%, while engine speed declines by 5.22%.

Using a validated fuel system model, simulations were conducted to evaluate the effects of varying fuel tank pressure, total engine inlet temperature, and fuel viscosity on engine performance. Based on the comparative analysis of engine fuel flow and speed curves, the following conclusions were drawn:

(1) Effect of fuel tank pressure: Increasing fuel tank pressure within a certain range shortens the time required for the engine speed and fuel flow to stabilize, leading to higher equilibrium values of both parameters.

(2) Effect of total engine inlet temperature: As inlet temperature increases within a certain range, the time required for engine speed and fuel flow to stabilize extends, while both parameters decrease slightly at equilibrium.

(3) Effect of fuel viscosity: Higher fuel viscosity results in lower fuel flow and engine speed, with the rate of decrease slowing as viscosity increases.

4. Reform practice of CDIO teaching mode based on digitalization

In traditional classroom teaching, the focus is primarily on explaining principles and configuring components. Although multimedia tools such as images and videos can be incorporated to enhance visualization, students still engage in passive learning, resulting in poor learning outcomes and an inability to apply knowledge comprehensively.

By leveraging digital technology, the fuel regulation model integrates theoretical calculations with principle demonstrations, thereby improving learning efficiency. Furthermore, when combined with hands-on practical teaching, it stimulates students' intrinsic motivation for learning. Throughout the learning process, students transition from theoretical knowledge in textbooks to real-world applications, deepening their understanding of engineering theories and principles while enhancing teaching effectiveness. While this approach meets students' cognitive needs and improves classroom teaching quality to some extent, it does not sufficiently foster teamwork skills, which are essential for training modern military talent.

After multiple teaching practices, the CDIO [5-8] curriculum framework—conceived as Conceive-Design-Implement-Operate based on project or product development—was introduced into classroom instruction. This teaching philosophy emphasizes "learning by doing," a concept rooted in Dewey's educational theory, which critiques traditional schooling and advocates pragmatism. Dewey emphasized students' instincts and interests, asserting that "learning by doing" involves acquiring knowledge through experience and practice, linking school-based learning with real-life activities. He argued that experiential learning is superior to passive listening, aligning with fundamental cognitive principles [9-12].

With the adoption of this teaching model, students' enthusiasm has significantly increased. Driven by project-based tasks, they have shifted from passive learners ("I have to learn") to active participants ("I want to learn"). Within the curriculum knowledge framework, theoretical research, structural principles, and design processes are systematically integrated, enabling students to "see while learning," "do while learning," and "apply while learning." The synergy between digital technology and the CDIO approach effectively stimulates students' desire to learn and yields positive learning outcomes.

Between 2020 and 2024, the CDIO teaching model has been applied to the Engine Structure Principles course for students in relevant majors. The reform efforts have focused on strengthening students' ability to apply knowledge comprehensively, enhancing teamwork and collaboration skills, and incorporating self-assessment and peer evaluation to foster autonomy and competency. To create an engaging learning environment, instructors established a supportive teaching platform. At the beginning of the course, students were voluntarily grouped into teams of four to five members, each led by a team leader selected through open competition to ensure fairness and transparency. Once selected, team leaders assigned tasks based on the project implementation plan proposed by the instructor, considering individual abilities and preferences. Each team member was given clear deadlines and performance expectations, ensuring structured and effective project execution.

5. Evaluation of the teaching effect of CDIO courses based on digitalization

After five years of teaching reform practice, a questionnaire survey was conducted among missile engine majors who had participated in the CDIO teaching model. The results showed that the majority of students held a generally positive attitude toward the teaching reforms under the CDIO framework. Approximately 91% of students believed that the CDIO concept could be effectively applied to teaching engine structure principles and that the CDIO curriculum reform model was worth promoting. These findings indicate a strong level of student recognition and approval of the course reforms.

As technology and educational paradigms continue to evolve, teachers should actively adapt their perspectives and teaching methods to meet the learning needs of the new generation of students. The traditional instructor-led "one-way transmission" teaching model is no longer well received by students, whereas a student-centered, skills-oriented approach is highly favored.

Through the reform process, approximately 94% of students reported that the CDIO teaching model enhanced their ability to apply knowledge comprehensively and improved their communication skills. Additionally, around

96% affirmed that the model effectively fostered teamwork skills. Communication and teamwork are among the most critical competency indicators in the CDIO framework, highlighting the feasibility and effectiveness of this teaching approach. Therefore, the instruction of engine structure principles should move beyond an exam-focused approach and instead emphasize quality education aimed at developing students' communication, collaboration, and practical problem-solving skills.

A comparative analysis of students' theoretical assessment results under the traditional teaching method and the CDIO model revealed a significant improvement in academic performance among those using the CDIO approach. On average, students following the CDIO model achieved notably higher scores, particularly in theoretical analysis and comprehensive calculation questions, with an approximate 25% increase. This demonstrates that students' ability to apply theoretical knowledge comprehensively has improved significantly. They not only grasp theoretical concepts but also integrate them with specific equipment applications, linking prior coursework in a coherent manner, thereby enhancing their problem-solving capabilities.

Furthermore, instructors of subsequent courses, particularly those supervising undergraduate graduation projects, reported that students who had participated in the CDIO reform demonstrated stronger practical problem-solving abilities, greater hands-on skills, improved language expression, and superior teamwork capabilities compared to their peers. These strengths were especially evident in graduation projects, with many being rated as outstanding theses. The teaching reforms have enhanced students' classroom engagement, effectively strengthened their learning abilities, cultivated critical thinking habits and overall competencies, and laid a solid foundation for their future professional roles.

Disclosure statement

The authors declare no conflict of interest.

References

[1] Gu P, Shen M, Li S, et al., 2008, From CDIO to EIP-CDIO: Exploration of Engineering Education and Talent Training Model in Shantou University. Research of Higher Engineering Education, 41(3): 12–20.

[2] Wang T, Cheng W, 2010, Research and Practice of Innovative Engineering Talent Training Model Based on CDIO. Higher Engineering Education Research, (1): 28–32.

[3] Liu Z, 2006, Foundation of Modern Military Simulation Technology, National Defense Industry Press, China.

[4] Wang G, 2009, Interpretation and Thinking of CDIO Engineering Education Model. China Higher Education Research, 2009(5): 86–87.

[5] Gong S, Hong C, 2009, CDIO: The Classic Model of Engineering Education in MIT. Science and Technology Higher Education Research, 28(4): 116–119.

[6] Mei Y, Liang G, Lin Y, et al., 2014, The Practice of CDIO Teaching Mode in the Teaching Reform of "Hydraulic and Pneumatic Transmission" Course. Journal of Guiyang University (Natural Science Edition), 9(4): 71–77.

[7] Jason P, David T, Alan R, et al., 2021, Developing CDIO Practitioners: A Systematic Approach to Standard 10. Procedia Manufacturing, 38: 680–685.

[8] Ahmed S, Monther A, 2022, The Impact of CDIO's Dimensions and Values on IT Learner's Attitude and Behavior: A Regression Model Using Partial Further Squares. Heliyon, 8: e11433.

[9] Svante G, 2017, Automatic Control Education in a CDIO Perspective. IFAC PapersOnLine, 50-1: 12161–12166.

[10] Zhang L, Jie J, Zhu W, 2021, Exploration and Practice of Automatic Control Principle Teaching Reform Based on

OBE-CDIO Concept. Journal of Higher Education, 36: 128–131.

[11] Meng YY, Jia CH, Liu M, 2021, Research on Talent Cultivation of Applied Undergraduate Colleges Based on CDIO Engineering Education Concept Under New Engineering Background. Journal of Higher Education, 36: 152–155.

[12] He XK, Yao J, Shen Y, et al., 2021, Discussion and Reform of Energy and Power Engineering Curriculum System Under CDIO Mode. China Modern Educational Equipment, 23: 121–123.