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Teaching and Evaluation Reform of "Aircraft Dynamics and Control" Course Aimed at Cultivating Innovation Ability

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Abstract

In response to the new demands for technological innovation and talent development in the aerospace sector, the "Aircraft Dynamics and Control" course urgently requires deepening teaching reforms. Currently, the course faces core challenges such as the separation of undergraduate and postgraduate education, a monolithic teaching model, and a disconnect between theory and practice. To address these issues, this paper proposes a five-dimensional integrated reform framework. This framework features an innovative undergraduate-graduate integrated curriculum system, the development of a new practice-oriented textbook, a deep integration of micro-lectures and project-based teaching, the alignment of professional education with value cultivation, and a data-driven evaluation system. By establishing a closed-loop mechanism of "goal setting - multiple evaluations - continuous improvement", this study provides a systematic curriculum reform pathway to effectively enhance the engineering practice and innovation capabilities of academic postgraduate students in Aerospace Science and Technology.

Keywords

Curriculum Reform; Innovation Ability; Integrated Undergraduate and Graduate Education; Blended Teaching; Ideological and Political Education in Courses.

1. Introduction

In recent years, the scale of postgraduate enrollment has gradually expanded, making it a crucial pathway for cultivating high-quality and innovative talents, as well as a primary driver of high-quality economic and social development. Since 2012, the Journal of Academic Degrees & Graduate Education and the Graduate Education Research Center of Beijing Institute of Technology have conducted annual national satisfaction surveys on graduate education. Statistical data indicate that the issue of insufficient innovation ability among university graduate students is prominent, with engineering graduate students reporting the lowest satisfaction rates regarding the practicality of curricula and the innovativeness of research training [1].

This challenge is particularly pronounced in the aerospace sector, where rapid advancements in cutting-edge aerospace technologies—led by information technology—and numerous critical bottlenecks demand that graduate students in related fields possess more sophisticated interdisciplinary knowledge structures and practical innovation capabilities to meet industry needs. However, traditional training models for aerospace graduate students fall short in fostering practical skills and innovative capacities. Urgent reforms and enhancements are needed, particularly in areas such as the incorporation of cutting-edge content in core specialized courses, the rationality of curriculum systems, the practicality of coursework, and research training [2].

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2. Current Status and Teaching Challenges of the Course

“Aircraft Dynamics and Control” is a core course for postgraduate students majoring in Aerospace Science and Technology, as stipulated in the Core Curriculum Guide for Academic Degree Postgraduate Programs. The course content encompasses applied mechanics and control theory, covering key topics such as flight vehicle motion modeling, flight performance and stability & control characteristics analysis, and control law design. It serves as the theoretical foundation for aircraft design, testing, demonstration and validation, training, and operational applications. However, with the advancement of technologies such as hypersonic vehicles and intelligent swarm control, most graduates, due to weak practical skills, struggle to directly participate in the engineering design tasks of employers and require a lengthy adaptation period. Therefore, the reform of this course must meet the new demands for innovative talents brought by aerospace technology advancements, building a bridge connecting fundamental theories with engineering practice for students. Currently, the teaching challenges in this course are primarily concentrated in five areas:

(1) The fragmentation of the knowledge system. The theoretical framework of the course content lags behind the development of modern aerospace science and technology, control science and engineering, and related interdisciplinary fields. Furthermore, undergraduate and postgraduate education are separated, lacking vertically integrated design. There is a high degree of overlap in content between undergraduate and graduate courses with insufficient continuity, manifesting as insufficient depth in fundamental theories at the undergraduate level, while postgraduate courses redundantly cover basic content and lack advanced topics.

(2) The lack of practical experience. The course covers a broad range of topics and rich knowledge points, creating a supply-demand imbalance with the limited number of class hours. Moreover, current textbook contents are outdated, lacking sufficient engineering examples and concrete computational cases and their corresponding code implementation. Meanwhile, due to the absence of physical experimental platforms, practical components cannot be fully implemented, leaving students to engage primarily in theoretical discussions without hands-on experience. So the engineering orientation and comprehensiveness of the course teaching are insufficient.

(3) The singularity of teaching methods. Due to the complexity and abstract nature of aerospace motion, the course is highly theoretical, involves numerous formulas, and features intricate derivations, making it challenging to teach. Classroom instruction primarily relies on PowerPoint presentations combined with chalkboard writing, a unidirectional, "cramming" approach that results in low student engagement.

(4) The limitation of course evaluation methods. The simplistic reliance on written exams or final reports overlooks the cultivation of innovative thinking during the process-oriented teaching. The limited teaching and assessment approach results in courses lacking depth, leading students to rely on rote memorization, and fails to provide a sense of achievement, and makes it difficult to motivate students.

(5) The disconnect between values education and professional education. The integration of ideological and political education into courses often remains at the level of "case collages", failing to align precisely with professional competency development or achieve deep integration [3].

Therefore, emphasis should be placed on the diversification and multi-dimensional development of the course to foster new ideas for reconstruction. This paper aims to promote the holistic unification of students' knowledge, abilities, thinking, and competencies. Guided by the fundamental principles of "strengthening foundations, emphasizing interdisciplinary approaches, and enhancing practice applications," it proposes a systematic solution that

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provides both theoretical justification and a practical paradigm for the transformation and upgrading of this course.

3. The Core Framework of the "Five-Dimensional Integration" Teaching Reform

3.1. Vertical Reconstruction of the Knowledge Chain to Build an Integrated Undergraduate-graduate Curriculum System

Undergraduate programs at aerospace institutions typically offer courses related to "Flight Mechanics" and "Flight Control". Therefore, in reshaping the graduate-level course "Aircraft Dynamics and Control", it is necessary to break down the barriers between undergraduate and postgraduate education, embodying the philosophy of "integrated design, long-term cultivation, progressive advancement, and innovation-focused development." Innovations should be made in the coherence and integration of teaching content to advance the depth and breadth of this course series, enhance teaching effectiveness for diverse student groups, achieve effective transition between the two educational stages, and facilitate the systematic training of students' knowledge and abilities [4].

To this end, communication with teachers of relevant undergraduate courses must be strengthened to form a teaching team, clarify the boundaries and transition points between undergraduate and postgraduate curricula, and establish a three-tiered knowledge system encompassing foundational, comprehensive, and innovative components. The undergraduate stage focuses on mathematical modeling and classical control (e.g., transfer function analysis); the postgraduate stage deepens modern control theory (e.g., LQR optimization, H∞ robust control); the integration strategy involves streamlining repetitive content (e.g., rigid-body flight dynamics fundamentals) and introduces new "cutting-edge topics" (e.g., advanced UAV dynamics and control technologies). The course content structure is shown in Figure 1.

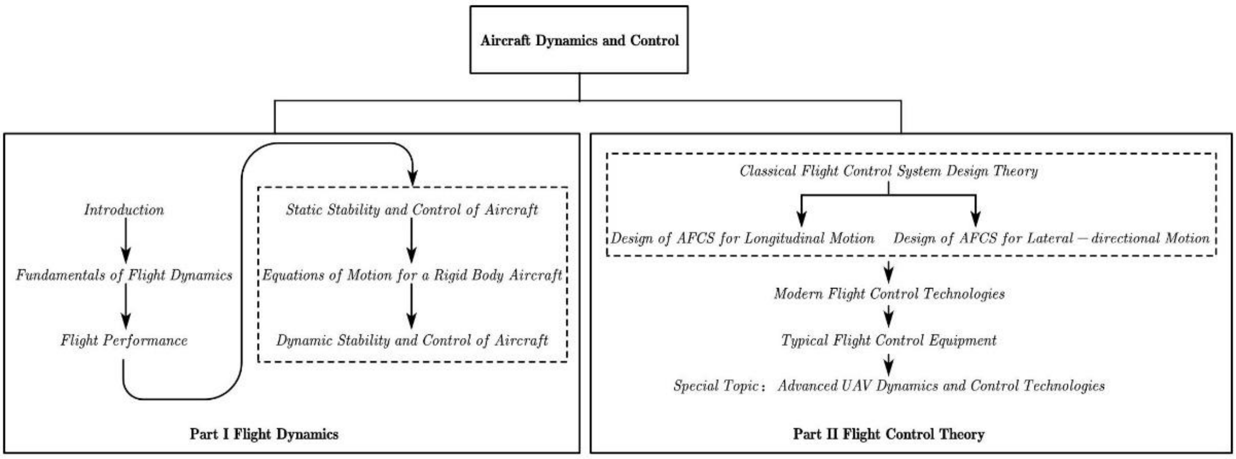

Figure 1. Course Content System of "Aircraft Dynamics and Control"

3.2. Incorporating Simulation Examples to Develop a New type of Practice-Oriented Code book

Leveraging MATLAB's powerful capabilities in computation, simulation, and control system analysis and design for aerospace applications, each chapter emphasizes hands-on examples with accompanying code to enhance the textbook's practicality and interactivity. Moreover, simulation analysis facilitates the concretization of abstract knowledge, deepens students' understanding of fundamental principles, and enhances the appeal of teaching [5]. For instance, in the dynamics chapter, content on using software to linearize the dynamics equations of specific aircraft can be added. In the section on stability and control characteristics analysis, content could be added on using software to perform typical motion mode simulation analysis.

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In the flight control principles chapters, cases studies using software to design aircraft autopilots for each channel can be incorporated. The parameters for different aircrafts are provided in an appendix, enabling students to engage in hands-on practice by referencing the sample program code in the textbook and applying the method to similar scenarios.

Furthermore, a flight simulation platform is constructed using "MATLAB/Simulink + Flight Gear flight simulation software+ Control joystick." Students with strong comprehensive skills and an interest in research and development can offline modify the aircraft model and controller parameters on the platform, operate the aircraft to conduct flight simulations, thereby verifying the impact of the flight control system on flight quality and gaining an intuitive experience.

3.3. Blended Teaching Design with Micro-Lectures and Project-Based Learning

The course “Aircraft Dynamics and Control” is characterized by its extensive content and limited class hours, a contradiction commonly reported by universities. Within the limited class hours, it is difficult to thoroughly cover all knowledge points solely through teacher lectures. How to enhance teaching efficiency and ensure teaching effectiveness remains a problem that needs to be addressed. An effective approach is to utilize micro-lectures and online teaching platforms by providing QR codes at relevant knowledge points within each chapter. These QR codes link to online micro-videos explaining the concepts. In this way, valuable class time can be saved, allowing more focus on deriving and explaining key content. Simultaneously, the "code-integrated textbook" can provide multimedia videos or simulation animations at abstract knowledge points for students to view, thereby aiding their comprehension of the concepts. In summary, while resolving the conflict between class hours and the volume of knowledge, the online teaching space greatly expands the temporal and spatial dimensions of the course. It also aligns with contemporary learning trends characterized by visual content, fragmented schedules, and mobile accessibility, catering to the digital-native identity of today's college students. And it serves as a crucial supplement to traditional classroom teaching.

On the other hand, the project-driven teaching model adopts a flipped approach where instructors distribute topics based on course content and provide partial references, while students engage in self-directed learning through open seminars. Instructors guide, evaluate, and supplement the process as needed. This approach fully enhances student participation and sense of achievement, cultivating their abilities in data collection, literature review, research analysis, and presentation skills. For example, the entire aircraft design process is broken down into key stages—such as concept design and aerodynamic calculations, six-degree-of-freedom modeling, flight quality analysis, and controller design—each designated as an innovative open-ended practical project for a related chapter. Students are required to conduct simulation experiments using mainstream software in aircraft design and analysis, thereby enhancing their practical and innovative capabilities.

3.4. Alignment of Professional Education with Value Guidance

From the perspective of the course content, “Aircraft Dynamics and Control” course not only provides a professional foundation and broad knowledge but is also closely related to the frontiers of national aerospace technology development. It serves as a natural vehicle for promoting the "spirit of serving the country through aerospace endeavors." Therefore, proactive efforts are made in the course's values education integration. The goal is to ensure that the values education content is "close to the times, close to the profession, and close to the students." By thoroughly exploring ideological and political themes—such as outstanding figures, exemplary achievements, social hot topics and cutting-edge developments in global aerospace—a case repository is constructed. This enables knowledge transmission and value guidance to resonate with each other effectively.

3.5. Data-Driven Process Learning and Evaluation System

This course effectively integrates big data technology with precision teaching methodologies. Centered on the teaching community and utilizing learning data analytics, it addresses the differentiated learning performances of students across three phases of pre-class, in-class, and post-class and implements precision teaching throughout the entire process. This approach not only promptly address students' learning difficulties and shortcomings through tailored instruction but also promotes teachers' reflective activities on their teaching, achieving mutual improvement in both teaching and learning.

During implementation, to ensure the comprehensiveness of teaching data and overcome challenges such as the difficulty of offline data collection, small collection volumes, and text-based data types, data from online teaching platforms is fully utilized. This established an integrated online-offline teaching big data collection model, truly meeting the data capacity requirements of precision teaching from the source. The course adopts a "1-3-1" process-oriented teaching model, wherein each chapter features one learning task module, three instructional modules, and one chapter test module. The instructional modules encompass the micro-lectures, extracurricular knowledge presentations, and interactive activities.

Leveraging the platform's big data enables learning analytics for the process teaching. It allows for precise monitoring of students' self-directed learning and the online teaching process, understanding the degree of knowledge mastery, tracking students' learning status in real-time, analyzing student learning behaviors, learning outcomes, and teacher s' teaching behaviors, and making timely adjustments to effectively enhance teaching quality.

4. Summary

The curriculum reform of "Aircraft Dynamics and Control" adheres to the core principles of "student-centered learning, outcome-oriented education, and continuous improvement." Vertically, it breaks down the boundaries between undergraduate and postgraduate education to construct a tiered knowledge chain; by combining virtual and practical applications, it emphasizes hands-on experience, using micro-lectures to tackle theoretical difficulties and project-based teaching to enhance innovation capabilities. Also, it integrates ideological and political education into case analysis and technological evolution to achieve value guidance. In the future, this course will be guided by the OBE philosophy, advancing toward cross-disciplinary integration within aerospace, industry-education collaboration, and university-enterprise partnerships. It will continuously deepen big data evaluation and analysis. Only through systematic reform can we cultivate the interdisciplinary innovative talents needed to support the strategy of building a strong aerospace nation.

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