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REVIEW ARTICLE

Advancements in Aero Engine Design and Manufacturing Through the Integration of Electronic Computing Technologies: A Comprehensive Analysis

Zhe Luo [1,*]

[1] College of Information Engineering, Shaanxi Institute of International Trade & Commerce, Xi'an 712046, China

Abstract

This study explores the global advancements in Computer-Aided Design (CAD) and Computer-Aided Manufacturing (CAM), focusing particularly on their application in the development of aero engines. It outlines the objectives, implementation stages, and anticipated computer system configurations for integrating CAD/CAM technologies within China's aero engine sector. By examining the current state of these technologies in China, the paper offers a customized approach that addresses both the goals and practicalities of adopting advanced CAD/CAM systems. This paper provides valuable insights into improving precision and efficiency in aero engine design and manufacturing processes in China.

Keywords: Curriculum ideological and Political Education, Information safety, Curriculum system.

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***Corresponding author:**
Zhe Luo
LZhe0628@proton.me

1 Preface

The rapid advancement of computer technology has significantly boosted the global economy and technological progress. Computer-Aided Design (CAD) and Computer-Aided Manufacturing (CAD/CAM), which are closely linked to computer technology, have opened new avenues for industrial modernization, particularly in the aviation industry [1]. Utilizing electronic computers for engine design enables the optimization of engine designs in a short time and at a low cost. Developing engines with high thrust-to-weight ratios is impractical without advanced computer technology, relying solely on traditional methods. It is essential to have a robust computer system, sufficient engineering workstations, and comprehensive system software, application software, and software tools that exceed basic computing capabilities. Equally important is the cultivation of a highly skilled technical team. It is evident that computer technology has profoundly impacted and will continue to influence aero engine design and manufacturing technologies, as well as product performance [2].

2 The development of CAD/CAM technology and its application in engine industry

With the growth of the international economy, CAD/CAM technology has also evolved. In the 1950s, the world's first CAD team was established at MIT in the United States, utilizing the Time Sharing System (TSS) for research. During the 1960s and 1970s, CAD/CAM technology transitioned into practical applications in advanced industrial countries. For instance, General Electric and Pratt & Whitney implemented CAD/CAM technology in the design and manufacture of aero engines. By the early 1980s, CAD/CAM had entered a period of diversification and widespread adoption [3, 11–16]. The hardware used during this time included computers, minicomputers, engineering workstations, and numerous microcomputers with versatile software.

In the mid-1980s, integrated systems emerged, representing highly integrated production systems that utilized all computer control functions for design and production activities. These systems integrated human resources, equipment, materials, capital, and information through computer assistance. Looking ahead to the 1990s, the global economy was expected to undergo significant restructuring [4], and Flexible Manufacturing Systems (FMS) were anticipated to become more widespread. FMS allows for the timely production of various products based on demand, with easy replacement of product varieties, significantly reducing costs and improving product quality. Additionally, the concepts, technologies, and methods of knowledge engineering were projected to be incorporated into CAD, evolving traditional CAD systems into AI-CAD. Concurrently, Computer Integrated Manufacturing Systems (CIMS) were expected to see rapid development and application [5, 17, 18].

The integration of CAD/CAE/CAT/CAM system technology has amassed considerable experience in system composition and usage, reaching maturity. Several prominent aviation industry companies have heavily invested in the application of this technology. For example, Boeing's computer services company invested 600 million in CAD/CAM computer systems in 1985. In 1988, GE Company allocated approximately 1.3 billion to engine engineering development, with a significant portion directed toward computer engineering software development and 20% of the equipment investment devoted to computer hardware. Table 1 presents the CAD/CAM profiles of several major foreign engine companies, and Fig. 1 illustrates the total investment in the global CAD market.

In China, the Ministry of Aeronautics and Astronautics holds a leading position in CAD/CAM technology, particularly within the aircraft industry. However, due to various historical reasons, the development of CAD/CAM in the engine industry has lagged. A project initiated at a meeting in Shenyang in October 1982 was delayed due to investment difficulties and did not commence until 1987. The software and hardware environment in the engine industry also remains underdeveloped. The hardware consists of low-grade VAX machines, the application software is inadequate, there is a shortage of technical personnel, and funding is scarce.

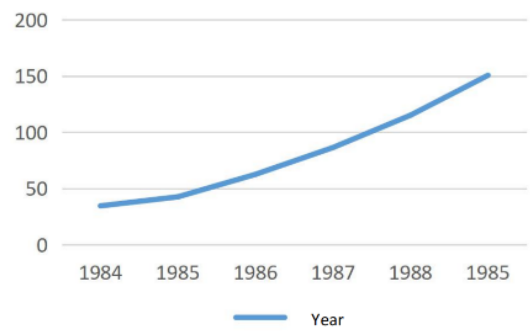

Figure 1. World CAD Market Situation.

Despite these challenges, the existing personnel have demonstrated great enthusiasm, and their collective efforts have resulted in significant achievements. From 1983 to November 1988, Institute 608 of the Ministry of Aeronautics and Astronautics successfully developed a five-coordinate computer-aided manufacturing (TI-CAMSNC) system for titanium alloy integral centrifugal impellers. This system was integrated with the centrifugal impeller CAD system, achieving CAD/CAM integration for the first time in China, and it met international standards of the 1980s. Additionally, Institute 606 of the Ministry of Aeronautics and Astronautics successfully integrated a renowned finite element analysis system with the CAD system, providing a crucial tool for both component design and whole machine design.

3 General goal of computer system in engine industry

Currently, China is undergoing a restructuring and deepening of its economic system, which will have significant implications for its economic and technological development, particularly in the context of international economic changes. In formulating strategic objectives for China's aero engine industry, it is crucial to align national conditions with global technological advancements. This approach should follow the principles of "comprehensive planning, self-reliance, assimilation and application, innovation, and development." By leveraging the strengths of factories, research institutes, and universities, a comprehensive CAD/CAM integrated system can be developed to meet the demands of both large and small engine development.

3.1 Change ideas and adapt to development

In recent years, the concept and scope of Factory Automation (FA) have undergone significant changes. Future international economic competition and cooperation will require enterprises and institutions to focus on market demands, producing high-quality products at competitive prices in appropriate quantities. Production modes should not only consider mass production but also accommodate small batch and multi-variety production or variable batch production.

To adapt to these requirements, continuous and comprehensive scientific management is essential. Strategic decision-making should incorporate Office Automation (OA) to enhance management, optimize resource utilization, invigorate all undertakings, and boost competitiveness and social status. Technologically, transitioning from batch production technology (Automation Technology) to small batch, multi-variety production technology or variable batch production technology necessitates the following actions by the technical department:

- Maintain the advancement of design technology
- Ensure the introduction of new products to the market
- Continuously improve QCD (quality /cost /delivery)

3.2 Objectives

In the long run, and throughout the research, design, and production processes, implementing the principle of considering both military and civilian applications is undoubtedly correct. To this end, the use of computer technology must be widespread, combining general and specific applications, integrating practicality with advanced features, and achieving continuous utility development. General-purpose use facilitates meeting the needs of various environments, technical cooperation, and adapting to multiple production modes.

In summary, the overall goal of China's aero engine development is to establish a technical system that can adapt to changing times and environments, and fulfill the development and production tasks of small batch, multi-variety, short-cycle, low-cost, and high-quality products. This goal is targeted to be achieved by the year 2000, implemented in three stages:

1. During the Seventh Five-Year Plan, build the rudimentary integrated environment and establish the primary CAD/CAE system.
2. In the Eighth Five-Year Plan, focus on solving the overall system structure, integrate the management and engineering systems, and initially build an intermediate CAD system operating on two to three levels of network. Simultaneously, vigorously develop CAM for typical parts and tooling. When establishing the intermediate CAD system, consider future integration with CAM.
3. During the Ninth Five-Year Plan, introduce AI-CAD to build an advanced CAD/CAM integrated system to address CAM needs.

Achieving this goal will elevate the level of computer-aided design and manufacturing technology for aero engines in China to the global standards of the 1980s.

3.3 Computer system configuration of engine industry

3.3.1 Basic requirements of computer configuration

The Engine Corporation of the Ministry of Aeronautics and Astronautics of China is primarily responsible for the development and production of large and medium-sized engines such as WP7, WPS, WP13, and Qianxian aircraft power equipment, as well as small engines like WZ8, WJ9, and WJ5A-1. Their tasks include development, production, and modification, along with pre-research tasks for core components such as advanced compressors, combustion chambers, and turbines. Additionally, they focus on digital electronic tuning, structural integrity, computer-aided design, and other research areas.

To accomplish these tasks, there are five main requirements for computer configuration:

a. CAD Requirements. To build an intermediate-level aero engine CAD system, the computer system must handle the engine CAE and CAD system setup, scheduling operations, data transmission, and database management. It should support large-scale scientific calculations in fluid mechanics, solid mechanics, combustion, and dynamic simulation at high speed. The system should generate spatial grids, flow fields, concentration fields, stress fields, and temperature fields before and after numerical simulations. Additionally, it should facilitate geometric modeling, geometric interference display, simulation assembly and decomposition, drawing, and database construction of complex structures.

b. CAM Requirements. The system should enable NC machining of main engine parts and connect with the CAD system. It should include programming software, tool path display, and simulated cutting for 2-axis and multi-axis NC machining. Moreover, it should interface with NC machining equipment to realize NC machining of main parts.

c. Computer-Aided Tooling Design. The system should support CAD integration for tools, clamps, gauges, and molds for engine parts manufacturing. It must handle geometric modeling, geometric interference display, simulation assembly and decomposition of complex structures, and engineering drawing. It should also support scheduling operations, data transmission, and operation management.

d. Computer-Aided Test and Detection. The system should enable the automatic acquisition, processing, and process control of test data. It must handle comprehensive processing and analysis of altitude-simulated test cells, high-speed data acquisition from ground test rigs and large and medium test equipment, dynamic data acquisition, real-time display of test data, and dynamic analog display metering, detection, and test results.

e. Computer-Aided Management. The system should manage the engine development and production process, providing continuous support for computer-aided management environments as the management level improves in each stage of engine development and production.

3.3.2 Preliminary opinions on computer configuration

Implementing overall planning and step-by-step execution based on the concept of computer network construction and computer configuration arrangement is essential.

The engine industry and its various factories have diverse requirements for computer systems, making it impractical to use a single model to meet all needs. However, without proper planning and control, this could lead to a lack of coordination and resource sharing for design, production technology, hardware, and software within the industry. Therefore, it is crucial to strengthen industry management by implementing overall planning and phased execution.

In the computer development planning for the engine industry, a preliminary approach suggests configuring computers based on the concept of computer network construction within the industry. This includes establishing a three-level computer network in scientific research institutes to create a computer-aided design system. Super minicomputers and workstations should be installed in factories to facilitate research on computer-aided manufacturing of key parts, while all factories should be equipped with super minicomputers and microcomputers for computer-aided management.

The three-level network involves configuring computers according to a three-tier structure: high-speed computers, general-purpose computers, and engineering workstations (including microcomputers). Each level of computer handles different primary tasks to meet the multifunctional requirements of model development and production. This three-level network is the fundamental mode of computer configuration in the engine industry. Each plant will be equipped with one, two, or all three levels of the computer network based on its specific task requirements and the conditions for technological transformation.

The proposed selection scheme is as follows:

For high-speed computers, a small supercomputer is recommended with the following technical specifications: a computing speed of 100-300 million floating-point operations per second (FLOPS), a memory capacity of 500-1000 megabytes, and an external memory capacity of 50-100 gigabytes.

For general-purpose computers, the main technical specifications are: a computing speed of 10-20 million instructions per second (MIPS), a memory capacity of 128-256 megabytes, and an external memory capacity of 50-100 gigabytes.

For engineering workstations, the main technical specifications include a computing speed of 5-5 MIPS, a memory capacity of 4-128 megabytes, and an external memory capacity of 50-100 gigabytes.

4 CADISEN overview

According to the design characteristics of vortex jets, vortex fans, vortex shafts, and propellers, CADISEN will include a set of software modules for tasks such as engine design, analysis, and engineering drawing, enabling data exchange among the design system, subsystems, and modules [6].

The CADISEN system consists of CASSEN (engine engineering analysis software system) and CISSEN (engine integrated environment). CASSEN incorporates all the engineering analysis and design modules required during the engine design process. The control functions provided by the CISSEN system establish the user interface with CASSEN through menus and programming languages. By utilizing the CISSEN geometry system, CASSEN can perform geometric design, engineering drawing, and part drawing functions. The general finite element analysis system is used to analyze complex structures. The data generation and conversion program provided by CISSEN enables data exchange between the database, UF file, and each module. The executive control system is an integrated interactive design system composed of CASSEN, large graphics software, a database system, and a general finite element analysis system. The relationship between the systems in CADISEN is illustrated in Fig. 2 as follows:

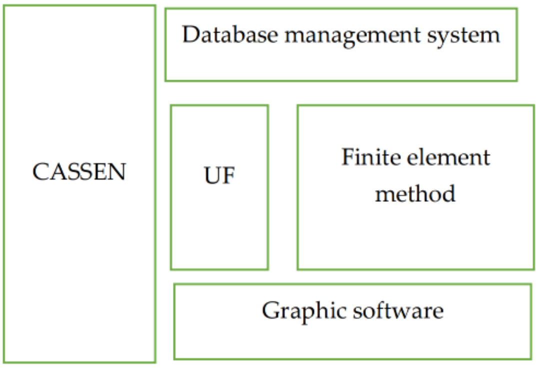

Figure 2

4.1 Function overview of CISSEN system

The CISSEN system is the core of the integration for aero engine CAD with an intelligent architecture, featuring completely modular software. With a standard user interface and a unified interface for external systems, the engineering analysis system is easily integrated. Designed with a robust software engineering environment and standard programming languages, it aims to be as independent of hardware equipment as possible. The system supports distributed processing, adapts to multi-level network computer configurations, utilizes database technology, and enables data sharing. The system comprises several components: the hardware environment, basic software, geometry system, front and back processing, general finite element program, and general external interface.

4.2 Function overview of CASSEN system

The CASSEN system is an integrated design platform for aeroengine design, characterized by multifunctionality, multipurpose capabilities, and standardized human-computer interaction, graphics, optimization, and integration. It can design various engines and incorporate features of vortex jets, vortex fans, vortex shafts, and propellers. The system comprises 13 design systems, such as the engine general system, and 12 databases, including the original standard engine database [7]. Its main functions are as follows:

A. It provides coordination for matching aircraft and engine requirements.

B. It can meet user requirements and perform screening of overall performance parameters under matching conditions.

C. It can conduct design analysis for the entire engine and its individual components.

D. Supported by an integrated environment, each design system can operate independently or in parallel.

E. With the aid of a geometric modeling system, it can complete the design of components, generate proofing drawings, engineering drawings, some axonometric drawings, and provide relevant documents for production and processing.

F. Supported by a general finite element program, it can complete structural analysis of parts.

G. It offers reverse design capabilities for the entire engine, parts, and components.

H. It includes pre- and post-processing functions.

I. It features 12 types of engineering databases that enable data sharing and querying of relevant data.

J. It provides a human-computer interaction function.

5 AI and CAD

Integrating AI with databases can not only enhance the intelligence of databases but also facilitate knowledge management. Introducing AI technology into CADISEN in a planned manner is a significant technical endeavor. Currently, the CAD technology we utilize only supports engineers in the detailed design stage and beyond, offering little assistance during the conceptual and outline design stages. This limitation arises because contemporary CAD systems are confined to algorithmic or deterministic problems [8]. It is well understood that engine conceptual and outline design stages are critical and foundational to the design process. Traditional CAD systems operate on a man-machine dialogue basis, lacking capabilities in synthesis, reasoning, and selection [9], making it challenging to broaden and extend their application scope.

In the process of aero engine design, two types of problems typically arise. The first type involves analyzable problems, where goals can be expressed in specific forms. The second type involves synthesis problems, where goals can only be described by characteristics or behaviors. To address these issues, solutions must operate above the program layer, as computer implementation occurs below this layer. Introducing a knowledge expert system (KES) can enable interactive problem-solving using established models on the computer. Analyzing the aero engine design process reveals the importance of extending the ideas, methods, and technologies of knowledge engineering to CAD [10].

6 Conclusion

Due to the relatively weak computer technology in China's aero engine enterprises, research on CAM has not progressed as extensively as CAD during the Eighth Five-Year Plan period and remains in the foundational stage. Currently, research efforts are focused on auxiliary tooling design, 2-5 axis NC programming, and integral impeller CAD/CAM. Moving forward, these areas will serve as starting points for mastering CAM technology, cultivating talent, gradually expanding research scope, and applying the findings to various parts of NC machining. Additionally, opportunities for collaboration with foreign countries in trunk line power production will be leveraged to apply and develop the MRPH (Production Resource Management System), thereby enhancing factory management quality.

During the Eighth Five-Year Plan period, the development of CAM technology in the industry will be systematically advanced in conjunction with trunk power cooperation and model development, focusing on the auxiliary manufacturing of specific parts. In the Ninth Five-Year Plan period, efforts will be directed towards the development of networking and integrated manufacturing systems.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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Table 1. CAD / CAM profile of three major.

Company name	Software personel	Equipment condition		Integrated system	Application
		Hardware	Software		
GE (USA Evendale)	2000	CRAYX-MP 48 1set IBM3090-400E 2set VAXB600 15set VAXII 785 10set Honeywell 6000 Workstation 300+set All kinds of terminals 4000 set IBM4341, 4381 batch	NASTRAN PATRAN ABAQUS IDEAS INGRES CALMA system Document management system APT4 Proprietary software GDSS MRP	in progress CIMS system work	CAD CAE CAT CAPP MIS CAM MRP
PW (USA HARTFORD)	800	CRAY II 2 set IBM3090 7 set IBM4341 and IBM4381 one batch VAX equipment one batch Workstation 200+ set All kinds of terminals 1000+ set	NASTRAN ABQCS DBMS MARC AD2000 ANVIL5000 CADFEED APT14 ASKA	GDS (General Design System) In progress CIMS	The same as above
RR (England)		Since 1987,£ 25 million was invested to purchase workstations			Shorten the develoment cycle by two years