面向21世纪普通高校双语适用教材

# 现代设计方法

（英文版）

# Advanced Design Methods

Advanced Design Methods

湖南大学　张维刚　钟志华　编著

机械工业出版社
CHINA MACHINE PRESS

面向21世纪普通高校双语适用教材

（英文版）

# 现代设计方法

# Advanced Design Methods

湖南大学　张维刚　钟志华　编著



机械工业出版社

本书是一本专门为高校机电类专业双语教学而编写的英文教材，概述性地介绍了当今时代发展起来的一些先进设计方法，重点介绍了有限元法、优化设计方法以及可靠性工程理论和方法等。每一章在理论方法的介绍之后都列举了一些应用实例，目的在于使学生以英语思维的方式了解不同于传统的现代设计方法，并能应用这些理论和方法来解决工程实际中的相关问题。为了便于读者阅读和理解，每章末尾都附有一定的疑难点注释，全书最后附有专业词汇表。

本书为高校机电类专业双语教材，同时也可作为科技英语爱好者的专业英语阅读教材以及机电行业工程技术人员和高级专业管理人员的参考书。

**图书在版编目（CIP）数据**

现代设计方法/张维刚等编著. —北京：机械工业出版社，2005.1
书名原文：Advanced Design Methods
面向21世纪普通高校双语适用教材
ISBN 7-111-15395-2

Ⅰ.现… Ⅱ.张… Ⅲ.机械设计—高等学校—双语教学—教材
Ⅳ.TH122

中国版本图书馆CIP数据核字（2004）第104255号

机械工业出版社（北京市百万庄大街22号 邮政编码100037）
责任编辑：赵爱宁 版式设计：冉晓华
封面设计：陈 沛 责任印制：洪汉军
北京瑞德印刷有限公司印刷·新华书店北京发行所发行
2005年1月第1版第1次印刷
787mm×1092mm 1/16·9印张·222千字
定价：15.00元

# 前　言

先进设计方法的重要性，在现代社会中受到高度而广泛的关注。机电工程技术方面的高级专业人才不了解现代设计方法的基本思想、理论及其作用是不可思议的。随着全球经济一体化的快速推进，深入了解和掌握现代设计方法对一名工程设计师或者一个现代企业在国际激烈的商业竞争中获取胜利是非常有利的。基于上述原因，我们编写了这本英文教材，一方面是为了帮助学生掌握现代设计方法的相关理论和知识，另一方面也是为了提高他们的科技英语水平，使他们成为当今社会需要的高素质复合型人才。

根据本课程几年双语教学的实际经验，我们在编写本教材时注重了以下几点：

(1) 在概述基础上突出重点　由于现代设计方法涉及到的内容相当广泛，并且还在不断地发展变化，因此不可能也没有必要在一本教材中详细介绍和讨论现代设计方法的全部内容。考虑到本书是中国学生阅读的科技英文教材及绝大部分学生的接受能力，本教材只选择并详细介绍了几种相对成熟的、在工程实际中得到广泛应用并产生了重大影响的代表性方法，包括有限元法、优化设计方法及可靠性工程理论方法等；同时为使学生有一个全面的概括性了解，本书第一章对目前最新的多种设计方法作了概要介绍。

(2) 注重全书的整体性及各章的独立性　作为一本教材，本书各主要章节采用了统一的写作风格和模式，即首先在介绍理论与方法的基础上，再通过实例说明其实用性，这样可使得读者对现代设计方法的认识更加全面深刻；同时，各章之间又相互独立，每一章都是从不同侧面来考虑产品特性设计时所应用到的理论和方法，这样十分方便教师根据学生的兴趣以及他们的知识背景作出教学计划安排和内容取舍。

(3) 既注重理论的系统性和科学性，又注重方法的实用性　考虑到本教材的适用对象，书中在重点介绍几大现代设计方法时，力求系统、完整地反映该方法的基本理论和思想，但又不刻意追求理

论和方法的深度和广度，以能达到实用为主要目的，从而能较好地引发学生的学习兴趣，避免使学生因教材内容枯燥、深奥而出现厌学和畏难情绪。

由于本书是为中国读者编写的英文书籍，因此除了文章内容本身的上述特点外，还考虑到一些自学读者，如科技专业英语爱好者、企业工程师或设计师等自学的需要，尽量少用或不用复杂、深奥的英文词汇和语句，以使他们能够较容易地阅读和学习。对于一些必需的专业词汇，读者可参考本书末尾附录的词汇表。当然，本书也可作为机电产品设计方面高级专业管理人员的参考用书。

本教材的出版是为配合我国普通高校开展双语教学而作出的一种积极响应和尝试，希望它能为我国普通高校双语教学的发展和繁荣提供有益的经验和借鉴。由于编者水平有限，书中难免存在不妥或错误之处，恳请各位专家、学者和广大读者批评指正，同时也向本书中参考引用到的书籍文献资料的作者致意！

编 者

2004 年 7 月于湖南大学

# Contents

Chapter

# 1

# An Introduction to Advanced Design Methods

## 1.1 General Description

It is needless to say, design activities have significant meaning for human society, and we could not live well if there were no designs, for any kind of innovation activities depends on design. In reality, design activities cover a wide range, such as mechanical design, architecture design, cloth design, etc. All these designs have had a long history and created the great civilization of Human world. However, different kinds of designs have different theories, ideas and methods. In this book, discussions will only be confined to mechanical and electronic designs.

Design develops with time, and we often use "traditional design" and "modern design" to indicate the design in the past and the design at present respectively[1]. The biggest difference between them is whether computers are used or not.

Before the technology of Computer Aided Design (CAD) came to use, traditional design could only rely on manual works, thus it not only cost too much time, but also constrained the designers' brains[2]. Moreover, traditional design drawings could only be in two dimensional patterns and it was very hard to directly show design results to engineers or clients, thus the judging, evaluating and improving of the design results became very difficult. However, after CAD technology came to use, much of the design work can be done by computers, designers can quickly obtain information from calculated results, and it be-

comes easier and easier for design data to be modified, copied, stored or transferred[3]. What is more, the most important thing is that three-dimensional computer figures can directly reflect the design results, as well as make physical engineering data visualized, such as stress field, velocity field, temperature field, etc.[4], thus it is very convenient for engineers to evaluate, optimize or analyze the corresponding design.

For an engineering problem, traditional design relied on analytical method to solve the problem with lots of assumptions or simplifications, which was because of the mathematical tool limits other than the engineering requirement[5]. Today, with the development of Computer Aided Engineering technique, complex engineering problems can be solved with high accuracy, provided that the computer capacity is enough[6]. Just because of the strong power of CAE technique, those designs considered impossible before can be conducted now, such as the vehicle crashworthiness simulation design[7], as shown in Figure 1.1.

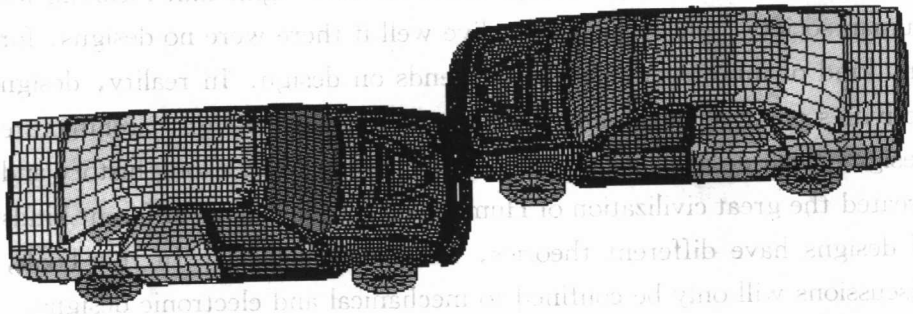

**Figure 1.1** Vehicle crashworthiness calculation by computer

CAD and CAE techniques can be regarded as a kind of revolution corresponding to traditional design methods, i.e., CAD replaces manual drawing, and CAE replaces analytical calculation. Besides CAD and CAE techniques, advanced design methods also include some other modern design ideas, such as product's optimization, product's reliability engineering, etc. Product's optimization is to achieve an objective under some conditions, while reliability engineering is to study the probability that components, products, or systems will perform their designed-for functions without failure in specified environments for desired periods under specified conditions[8].

With the development of society, economy, science and technolo-

gy, people will demand more and more functions for products, thus more and more design regulations and methods will be continuously improved or developed further.

## 1.2 Main Contents of Advanced Design Methods

In this book, three main contents will be discussed in three chapters respectively, i.e., the theories of finite element method for computer aided engineering, theories and applications of optimization of design, and theories and methods of reliability engineering. In order to make readers have a quick view about the three main contents, let us briefly introduce them first in the following sections.

### 1.2.1 Finite Element Method

Finite element method is the basis of Computer Aided Engineering. In this chapter, basic ideas and relative theories are introduced first by using constant strain 3-node triangular element, which include the basic equations, elastic plane problems with strain-displacement relation, strain-stress relation, and equilibrium equation. The methods and steps for finite element analysis are fully discussed. In general, finite element analysis by using displacement method always contains three main steps, i.e., discretization of the structure, element analysis, and global analysis. These three steps are discussed in sequence, and after each step, examples are given out to help understanding.

### 1.2.2 Optimization of Design

Optimization of design is to make a design achieve some special objectives such as minimum weight, minimum material cost, etc., and the way of optimization is numerical method. Generally, for an engineering problem, optimization steps are as follows: ① establish a mathematical model for the problem; ② select a kind of optimization numerical method; ③ solve the model and obtain a best group of design parameters.

As to the mathematical model, the general form, design variables, constraints, and objective functions have been fully discussed, which can make the readers have a basic knowledge about optimization of de-

sign. The detailed contents include mathematical bases, iteration searching algorithms and penalty functions. Finally some application examples are given out.

### 1.2.3 Reliability Engineering

Reliability is a kind of quantitative measure of the integrity of a designed component, product or system[9]. In other words, reliability is the probability that components, products, or systems will perform their designed-for functions without failure in specified environments for desired periods under specified conditions. Reliability engineering provides the theoretical and practical tools by which the probability and capability of components, products, or systems can be specified, predicted, designed or tested.

Reliability prediction is one of the important part of reliability design, while reliability and failure rate are the most important contents that reliability engineering needs to study.

Scientific and technological advances produce or form more and more complex products and systems, which are always expensive to build, and even more expensive if they fail to operate as designed[10]. Reliability evaluation takes on an ever increasing importance. The emphasis placed on product's quality and reliability further stresses the need for studying, quantifying and innovating to improve the reliability of engineering systems.

## 1.3 Developing Trend of Advanced Design Methods

As mentioned above, design methods develop with the progress of society, economy, and technology. Today, many new emerged design methods, ideas or techniques, such as innovation design, concurrent design, green product design, intelligent CAD, and inverse design, etc. have caused much attention and discussion. The very reason is because they are very effective in energy saving, environment protecting, and product performance improving. However, they are still in their primary developing stages, and in order to make readers have a brief recognition about them, several typical methods of them will be introduced in the following sections.

### 1.3.1 Innovation Design

Innovation is the key feature of any designs. Without innovation, the world would not be so colorful. At present, the product market is becoming more and more competitive, thus innovation is much needed and will become the best approach for an enterprise to win in the competition.

In mechanical manufacturing industry, product's innovation can be divided into two kinds. One is the product's outside form innovation without important new techniques, such as package change, styling change, color change, etc.[11]; the other is internal innovation with new important technique, such as new material, gene technique, high speed chips, etc[12].

The innovation concept covers a wide range, and it can be a great invention or just a new electrical product. By studying the rules of innovation, it is found that human's ability of creation can be trained definitely[13], thus it is very important to conduct innovation education consciously and scientifically, so as to make people exert their innovating capacities at a different levels and thereby make contributions to the progress of the civilization of human beings.

### 1.3.2 Intelligent CAD

The design itself is a kind of intelligentized activity. In other words, it is actually a dealing or operating with knowledge. At the traditional design stage, the intelligent part of work during the design process was undertaken by human specialists; while at modern design stage, the intelligent part of work is done by specialist system, and this kind of design is Intelligent Computer Aided Design (usually called ICAD). When it comes to the advanced design stage, the intelligent work will be done by human and computer together, which is the so called Integrated Intelligent CAD system ($I_2$CAD)[14]. The differences between $I_2$CAD and ICAD are as follows:

1) Generally, ICAD deals with the design confined to one field, while $I_2$CAD deals with multi-field design;

2) ICAD simulates an individual specialist's deducing process, while $I_2$CAD simulates a group of specialists' deducing and deciding ac-

tivities;

3) ICAD still belongs to the field of ordinary design, while $I_2$CAD can be considered as innovation design.

The key techniques of intelligent design lie in the following 5 "Hows":

1) How to establish a reasonable and valid model to express design knowledge;

2) How to conduct concurrent design for multi-schemes;

3) How to co-operate and deal with for multi-specialist systems;

4) How to re-design and learn by itself;

5) How to integrate relative design information.

### 1.3.3 Design for Manufacturing

A study shows that in reality, large number of designs cannot become goods finally due to many reasons, of which the most important reason is that the designed products are very difficult to make, or the manufacturing cost is very high, thus the technique of design for manufacturing is very important for designs to become successful products eventually.

The techniques of design for manufacturing cover a wide range, which lie in the following items:

1) Parts or components are made with reasonable cost;

2) Parts or assemblies can be ported;

3) Product quality can be checked;

4) Product performance can be tested;

5) Parts or assemblies can be maintained.

At present, most products' development process is step by step. What the designers think about is how to realize the product's performance, other than the product can be manufactured or not[15], thus the product development fails in the end.

The theories and methods of design for manufacturing can be taken as a tool for designers to evaluate a product's manufacturing characteristics or its manufacturing economy during the process of design stage. Generally, the key techniques of design for manufacturing have relations with the following items: computer aided conceptual design, product manufacturing evaluation method, concurrent design process model-

ing, techniques of design and test, etc.

### 1.3.4 Green Product Design

After 1970's, the global environment crisis has become severer and severer due to industrial pollutions. In order to enhance the protection of environment, the global industrial product strategy should turn to green trend, i.e., the industry should develop with little or no pollution to the environment, produce rubbish as little as possible, and have a reasonable use of the resources that the Earth can provide. Just because of this, the green product is also called the environmental conscious product[16]. How can we judge whether a product is green product or not? The answer mainly lies in the following items:

1) The material which the product is made of should have no bad effect on environment;

2) The design should have a consideration for the product to be recycled;

3) The design should have a consideration for the product to be ported.

Today, the green product design is very important for an enterprise to take part in the competition in the world market, thus, the key techniques for this kind of design have to be studied well. In general, green product design should consider the environment, the resources on the Earth, and the materials for the product, etc.

## 1.4 Summary of Advanced Design Methods

The characteristics of advanced design methods can be summarized as follows:

**1. Expansion of Design Fields**

Traditional designs were confined to product design only, while modern designs involve in product planning, customer requirements analyzing, product manufacturing, maintenance, price, recycle and quality, etc.

**2. Computer Used in Design**

Traditional design has been replaced by computer aided design, and the application of computers in design fields has been developing from

the early engineering analysis and calculating to the modern optimization, solid model building, design process supervising and virtual manufacturing, simulation, etc., thus the design process has been greatly shortened with design quality improved at the same time.

**3. Intelligentizing of Design**

In the traditional design, the creative works depended on designers completely, while in modern design, intelligentized specialist systems are used to do part of the creative works which completely depended on human to do before.

**4. Visualization of Design Methods**

In the traditional design, the shape of a product or a component could only be seen after it was made out, while in modern design, due to three dimensional prototype technique, simulation and virtual manufacturing, a product or a component's shape can be watched before it is made out, thus the design results can be easily improved or optimized, this can be as shown in Figure1.2 and Figure 1.3.

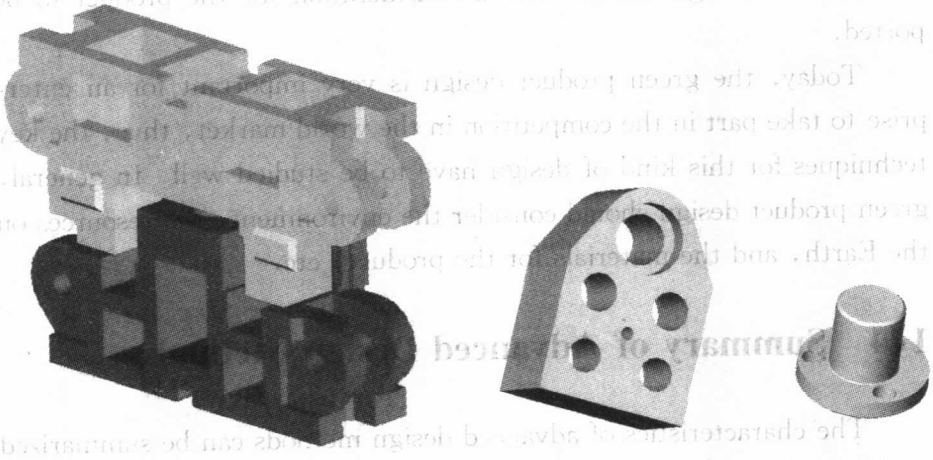

**Figure 1.2** Components designed by computer

**5. Accurate and Powerful**

In the traditional design, loads and stresses were considered to be concentrated[17], and the way to improve product's reliability could only be by increasing the design safety factor, but in reality, loads and stresses are usually distributed, and increasing the design safety factor is not always effective for improving product's reliability, thus modern designs concern about the distributing characteristics of loads and stress-

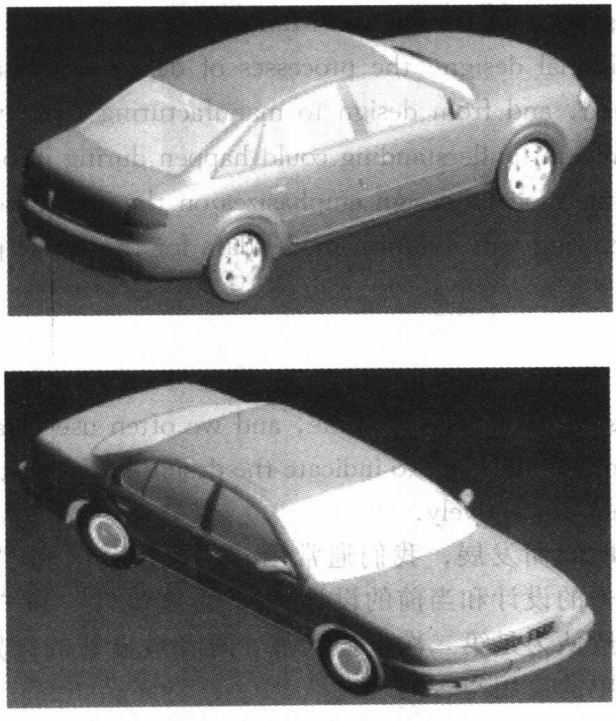

Figure 1.3 Vehicle body designed by computer

es, and by using the powerful tool of finite element method, product's real working status and final result can be accurately simulated and obtained respectively, furthermore, modern design can predict a product's reliability according to probability and statistic theories.

**6. Multi Dynamic Variables Optimization**

Due to limitations of design methods, traditional design could just do static analysis and deal with few variables in general, while modern design can take concerns about multi dynamic factors, such as load spectrum, load changes, etc., thus optimization can be conducted with multi dynamic variables.

**7. Environment Protecting Consciousness**

Since the human living environment has been destroyed seriously by the development of modern industry, today's products should be designed for environment, i.e., the pollutions to the environment due to product's running should be as little as possible, and the hurt to human bodies should be reduced to a lowest degree, therefore, the design for environment has become a main developing trend of modern designs.

**8. Integrating of Design and Manufacturing**

In traditional design, the processes of design and manufacturing were separated, and from design to manufacturing there were several processes, thus misunderstanding could happen during information transfer[18]; while modern design emphasizes on the integration of design and manufacturing with uniform model data for the whole process.

## 注释

[1] Design develops with time, and we often use "traditional design" and "modern design" to indicate the design in the past and the design at present respectively.

设计随时间而发展，我们通常用“传统设计”和“现代设计”来分别指过去的设计和当前的设计。（“传统设计”和“现代设计”的分割点一般认为是第二次世界大战，两者最显著的区别是计算机技术在设计中的应用与否。）

[2] but also constrained the designers' brains.

而且限制设计师的思维。（这句话的意思是由于设计方法和手段的限制，设计师在设计时不能很好地发挥大脑的作用。）

[3] and it becomes easier and easier for design data to be modified, copied, stored or transferred.

设计数据的修改、拷贝、存储或传递变得越来越容易。（这是因为设计是通过计算机来进行的，它对数据的处理当然比人工方便、快捷而且准确得多。）

[4] the most important thing is that three-dimensional computer figures can directly reflect the design results, as well as make physical engineering data visualized, such as stress field, velocity field, temperature field, etc., …

最重要的是三维计算机图形能直接反映出设计结果，并且能使工程物理数据可视化，比如应力场、速度场、温度场等，……（设计结果的可视化是现代设计方法的一个最重要和最有用的特征之一，这里的“field”是“场”的意思。）

[5] For an engineering problem, traditional design relied on analytical method to solve with lots of assumptions or simplifications, which was because of the mathematical tool limits other than the engineering requirement.