江苏高校省级外国留学生英文授课精品课程配套教材

Modern Engineering Graphics (Exercise Workbook Included)

现代工程图学

(含习题集)

主　编　王静秋　卢　敏　贾皓丽

西南交通大学出版社
·成　都·

Introduction

This book was compiled based on the latest National Standards. It consists of 8 chapters, including The Graphic Language for Design and Communication, Fundamentals of Projection, From 3D Objects to 2D Drawings, From 2D Drawings to 3D Solids, Representation of Drawing, Standard Parts and Commonly Used Parts, Detail Drawings and Assembly Drawings.

This book includes an exercise workbook. Additionally, modern educational technology and information technology are used to realize 3D animation and model display through QR code to help students understand the key points of knowledges.

This book is suitable for bilingual teaching for foreign students of mechanical and related majors in colleges and universities. The applicable lecturer hours are 32-120. It can also be used by engineering technicians and self-study readers of related majors.

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现代工程图学（含习题集）

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Foreword

The “Engineering Graphics” course of Nanjing University of Aeronautics and Astronautics is a National Excellent Course and a National Excellent Resource Sharing Course. The course construction and teaching reformation of engineering graphics have achieved fruitful results, and won the second prize of National Higher Education Teaching Achievement Award twice, in 2001 and 2005 respectively.

The book has the following characteristics:

(1) Briefly introduce advanced design technology. This book focuses on the overall requirements of higher mechanical engineering education on the knowledge, ability and quality of professional personnel training. According to the training objectives and course positioning, design process, innovative design, computer-aided design, etc., are introduced in this book, which plays an enlightening role and paves the way for the study of subsequent chapters.

(2) Arrange the teaching content according to the rule of visualized thinking. This book organically integrate and optimize the conventional contents, such as “projection of basic solid” “three views of composite solid” “pictorial drawings”, and arrange them into two chapters “from 3D objects to 2D drawings” and “from 2D drawings to 3D solids”, which is conducive to the cultivation of students’ thinking ability.

(3) Strengthen the theoretical foundation and emphasize practical application. As a required technical course for mechanical or related majors, this book has a strong foundation of projection theory to cultivate students’ spatial thinking ability; at the same time, it also pays great attention to practice ability. The textbook provides rich examples of mechanical drawings, and closely combines the projection theory with the reading and drafting of mechanical drawings.

(4) The illustrations are rich and exquisite. Take “drawing” as the core, in the part of descriptive geometry, the illustrations are pictorial drawings in the form of wireframe and rendering, which is easy to understand; A step-by-step diagram is used to explain the process and steps of reading and drawing, which is helpful to improve learning efficiency; In the engineering drawing part, very rich illustrations are also provided; Some knowledge points are displayed in the form of 3D model and animation through QR code to help students understand easily.

(5) The courses corresponding to this book are provincial-level excellent courses in English. The course website is https://mooc1.chaoxing.com/course/228674208.html.

The participants in the compilation of this book are as follows: Wang Jingqiu (foreword, chapter 1, chapter 3, chapter 4, chapter 5, chapter 6, appendix A, part of exercise workbook), Lu Min (chapter 7, chapter 8), Jia Haoli (chapter 2, appendix B and part of exercise workbook).

The book was written based on many references and their authors are highly appreciated. Thanks to many others who helped a lot in the course of the book publication.

Due to various limitations, this book may contain mistakes. All suggestions and criticisms from readers are welcome.

Authors

2022-06

Contents

Chapter 1 The Graphic Language for Design and Communication

Objectives

After studying the material in this chapter, you should be able to:

(1) Identify uses of the graphics language.

(2) Explain why standards are important.

(3) Describe the stages of the design process.

(4) List the basic components of a computer-aided design (CAD) system.

(5) Explain features common to most CAD software.

The design, development, manufacturing of engineering and products are the basis of human life and the direct motivation for the progress of human civilization.

A new product, machine or system may first appear in the mind of the engineer or designer before it realizes. This original concept is usually placed on paper or displays as an image on a computer screen. It is then communicated to others by graphics language in the form of freehand sketches (Fig.1.1), technical instrument drawings or computer drawings/models (Fig.1.2, Fig.1.3). During the process of communication, the graphics has the characteristics of visualization, intuition and conciseness. Therefore, engineering drawing is a common language used by designers, engineers and other technicians in the engineering field to record, express and communicate. Both facility in freehand sketching and ability to work with instrument/computer-controlled drawing techniques require a thorough knowledge of the graphics representation.

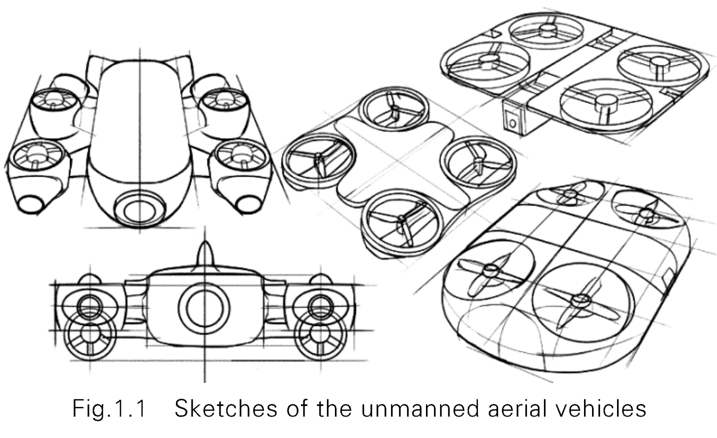


Fig.1.1 Sketches of the unmanned aerial vehicles

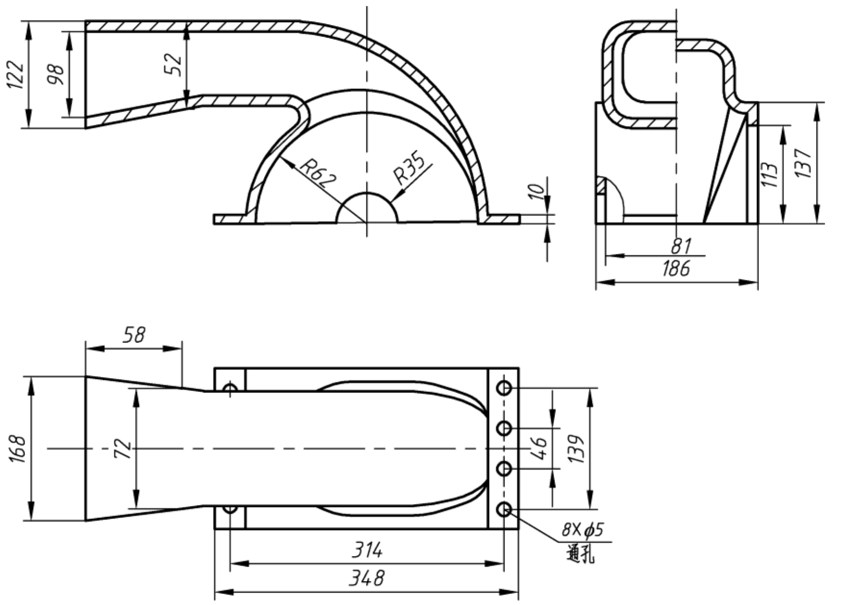


Fig.1.2 Engineering drawing

Fig.1.3 3D computer model

1.1 The Graphic Language

Although people around the world speak different languages, a universal graphic language has existed since the earliest of times. The earliest forms of writing were through picture forms, such as the Egyptian and Chinese hieroglyphics, as shown in Fig.1.4 and Fig.1.5. Those characters and shapes were drawn on rocks, ground and other surface to address their basic communication needs. Surprisingly, the Naxi nationality in Yunnan province of China has an endangered alphabet as shown in Fig.1.6, called Dongba, which is one of the pictographic writing systems still in use today. Therefore, graphic representation is the oldest type of written expression and is understood all over the world.

As time went on, graphic representation has been developed along two distinct lines, artistic picture and technical drawing.

Artists began to use sculptures and paintings to express aesthetic, philosophy or other abstract ideas.

Fig.1.4　Egyptian hieroglyphics

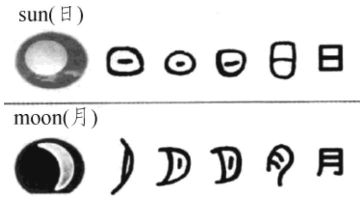


Fig.1.5　Chinese hieroglyphics

Fig.1.6　Naxi, Dongba, the pictographic writing characters

Engineers used technical drawings as tools for expressing design ideas, it is the communication method used in all branch of technical industry. Fig.1.7 shows the plan view for a design of a fortress engraved on a stone tablet, which is perhaps the earliest known technical drawing in existence. It is well known that Leonardo da Vinci used drawings to record and communicate with others. His ideas for mechanical designs and many of these drawings are still in existence (Fig.1.8).

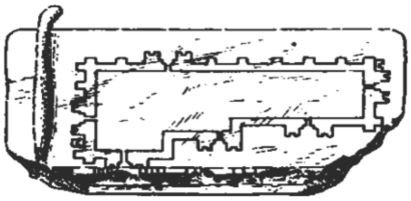


Fig.1.7　Plan view of a fortress

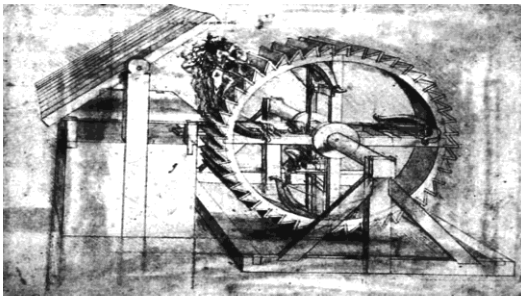


Fig.1.8　A design by Leonardo da Vinci

Fig.1.9 shows the plan layout of an imperial city in Zhou Dynasty in China. Fig.1.10 shows a 3D drawing made in Song Dynasty of China, about 1086 A.D., it shows the structure and components of an astronomical clock tower. At that time, a book called *atlas*（《图谱略》）also pointed out “非图无以作室，非图无以制器”, which means “you can’t make a house or a device without a drawing”, indicating people at that time have already realized that a drawing was not only used for communication, but also a guide for manufacturing and production. Another book, called *Construction Rule*（《营造法式》）, pointed out “没有规矩，不成方圆” means “without compasses and rulers, it is impossible to draw circles and squares accurately”, indicating that people have realized the importance of drawing tools. In early AD, Roman architects were already skilled at drawing architectural designs. They used ruler and compasses to draw elevations, plans and perspectives. During the Renaissance, it became a way to draw a three-dimensional (3D) object with a two-dimensional (2D) pictures using many views. In the 18th century, the rise of the Industrial Revolution led to new forms of design and communication. An accurate and universally accepted communication tool was needed between design and production.

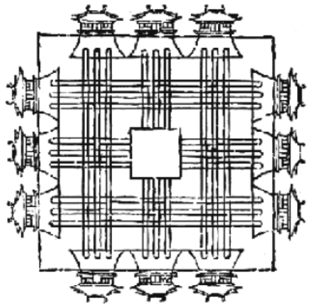


Fig.1.9　Plan view of an imperial city

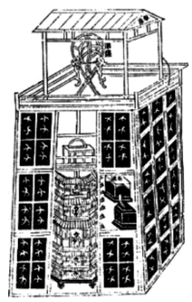


Fig.1.10　Pictorial drawing of a device

1.1.1　Descriptive geometry

Gaspard Monge (1746-1818) is considered as the "inventor" of descriptive geometry, which is the science of graphic representation and solution of spatial problems. His book, *Descriptive Geometry*, published in 1795, is regarded as a milestone from experience to science in graphic technology. Monge developed the principles of projection (A view of an object is known technically as a projection) that are now still the theoretical basis of technical drawing. Descriptive geometry described projection principles to solve spatial geometric relations. It has two important purposes, one is how to project 3D object into 2D drawings, another is how to visualize the 3D solid from 2D views, as shown in Fig.1.11.

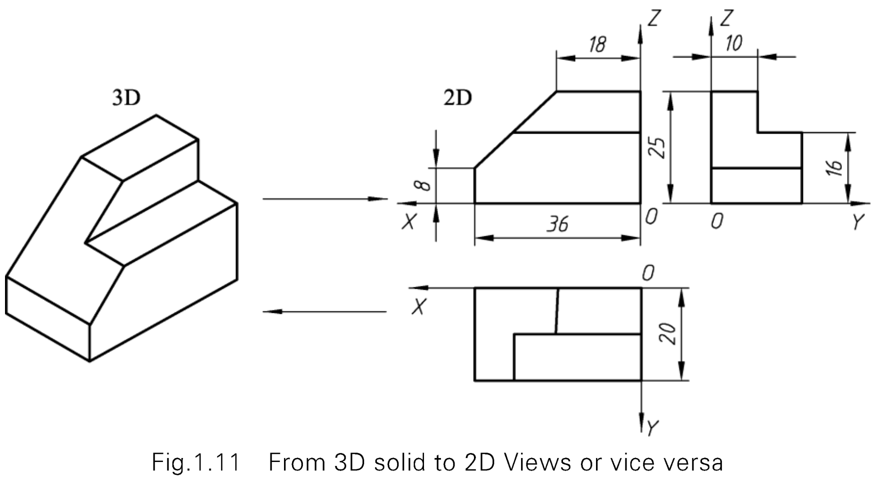


Fig.1.11　From 3D solid to 2D Views or vice versa

1.1.2　Technical drawing

"One picture is worth of a thousand words" said Confucius, a famous ancient educator in

China. Even highly developed word languages are inadequate for describing the size, shape and relationship of physical objects. For every manufactured object, there are drawings that describe its shape and size completely and accurately, communicating the design concept to manufacturing. For this reason, drawing is also called the language of industry.

Technical drawing, also known as engineering drawing, is a broad term that is rightly applied to any drawing used to express technical ideas. In short, it is used to provide graphic or image-oriented information technology. Technical drawings can take many forms: idea or concept sketches, design sketches, lay-out drawings, detail drawings, assembly drawings, etc. To prepare these drawings, designers use either drafting instruments, such as triangles, compasses, templates or computer-aided design/drawing (CAD) systems.

Technical drawings used in the field of mechanical engineering are mainly mechanical drawings which is one of the important technical documents used for technical communication and production guidance. There are drafting standards for mechanical drawings. Certain drawing techniques and conventions should be adopted.

1.1.3 Drawing standards

Throughout the long history of technical drawing, many conventions, terms, abbreviations and practices have come into common use. It is essential that different designers use the same rules due to the drawings serve as reliable means of communicating design ideas.

Technical drawings and engineering drawings are subject to several universally recognized sets of standards. These provide guidelines for presenting drawings, helping to facilitate communication between different teams, including those who speak different languages.

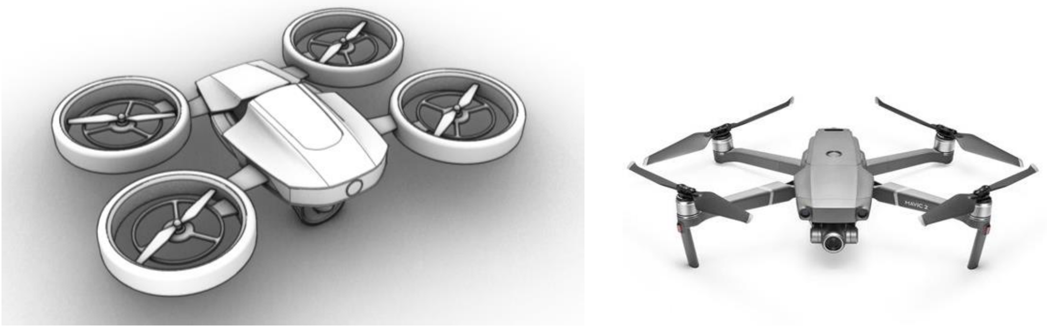
The International Organization of Standardization (ISO) was established in 1946. One of its committees, ISO TCIO, was formed to deal with the subject of technical drawings. The standards established by this committee, have been adopted by most countries, making technical drawing a truly universal language.

The Standardization Administration of China (SAC) is the organization that set the standards for China. The standards used throughout this textbook reflect the current thinking of the SAC committee. These standards apply primarily to mechanical drawings such as detail drawings and assembly drawings. Keep in mind that one needs to follow these standards whether preparing or interpreting technical drawings, and regardless of whether the drawings are made manually or by computer (CAD).

1.2 Drawing and Engineering Design Process

Engineering design is an effective way to solve existing problems by stimulating people's creative thinking and applying scientific principles, experience according to objective needs. The organized and orderly approach to solving problems is known as the design process. Different types of technical drawings have a specific function in the engineering design process. For example, freehand sketches capture and document the ideation process. Later in the design process, CAD models and computer drawings capture the design and specify the details necessary for manufacture.

Engineering design is a complex thinking process in which there are opportunities for innovation and invention. It requires designers to have a clear understanding of the function and performance of the final product, imagine and create new design ideas, and express the design ideas accurately through engineering drawings or 3D models. The 3D models shown in Fig.1.12 represent two products designed from the concept sketches shown in Fig.1.1.



(a) (b)

Fig.1.12 3D models

Design is the ability to combine ideas, scientific principles, resources and existing products to a solution of a problem. This solution to a problem is what we call the design process. The design process of a successful product is leading to manufacturing, assembly, marketing, service and many other activities. The innovative or improved design of products generally includes five stages, as shown in Fig.1.13.

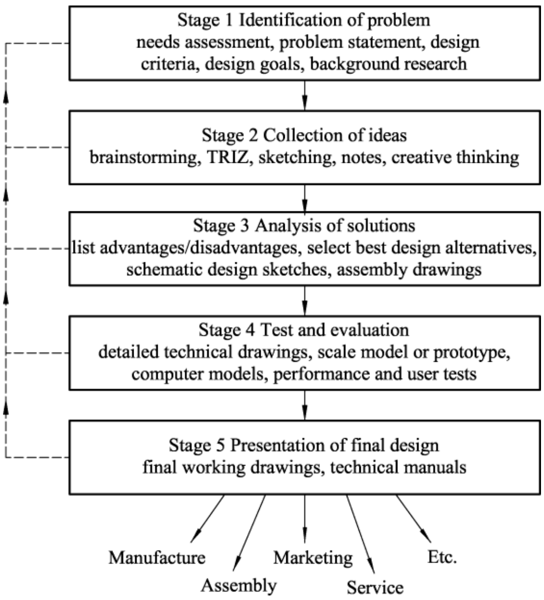


Fig.1.13 Design Process

Ideally, the design moves through these stages, but if a particular stage proves unsatisfactory or new information becomes available, it may be necessary to return to a previous stage and repeat the process as indicated by the dashed line.

Stage 1: Identification of problem

The design activity begins with the identification of a problem, the determination of a need and the customer for a product. Designers must understand the needs of users who will be interested in the product. It is important that the designer identify the end user, design criteria, design goals before design process.

Background research of a design is necessary. Compromises are involved in any design process, as all of the designer's original requirements may not be met. Any product is subject to economic considerations, safety, manufacturability, aesthetic and social constraints. It is important for the designer to approach the design process knowing that compromises may have to be made.

Engineering design problems may range from simple, inexpensive light switches to more complex problems associated with the needs of space exploration. For example, the widely used beverage can with pull tab is very simple and safe to open (Fig.1.14), but the production tools require considerable engineering and design effort. Also shown in Fig.1.15, the Boeing 777 aircraft is an example of a complex design, and was completely modeled using 3D CAD graphics, it was a landmark of paperless design and production in modern manufacturing in the 1990s.

Fig.1.14 Pull–tab can opener

Fig.1.15 Boeing 777 aircraft

At the stage of problem identification, designers can not only realize the necessity of solving problems through design, but also obtain enlightenment through certain problem induction. Information about the identified problem becomes the basis for a problem proposal. Following approval of the proposal, further aspects of the problem are explored. Available information related to the design is collected, and parameters and guidelines for time, cost and function are determined, within which the designers will work.

The parameters or information of a design problem established at this stage will become the basis for the design concept and idea at the next stage.

Stage 2: Collection of ideas

At this stage, brainstorming and TRIZ theory (theory of inventive problem solving) are all effective ways to expand design concepts and ideas. Many ideas are collected, reasonable and otherwise-for possible solutions to the problem. The ideas are broad and unrestricted to be the latest or unique solutions. The ideas may come from individuals or groups. The more ideas collected, the greater the chance of finding one or more ideas suitable for further refinement.

1. Brainstorming method

An innovative design team is important in the creative design process. It is usually composed of people with different experiences, such as designers, production technicians, marketing personnel, etc. People's creative thinking, especially intuitive thinking, can be brought into full play when stimulated. Therefore, the most commonly used creative method in teams is brainstorming.

Brainstorming is a group creativity technique by which efforts are made to find a conclusion for a specific problem by gathering a list of ideas spontaneously contributed by its members. People are able to think more freely and they suggest as many spontaneous new ideas as possible. All the ideas are noted down and after the brainstorming session the ideas are evaluated. Fig.1.16 shows the output of brainstorming on how to crush lemons.

The first and most important principle of successful brainstorming is not to criticize others' ideas. The second principle is to provide as many new ideas as possible. This is not the time to be conservative. Crazy or absurd-looking ideas may lead to a more practical and innovative idea. The third principle is to integrate the ideas generated in the brainstorming session into a specific design. The goal of brainstorming is to produce surprisingly innovative product designs, rather than familiar and orthodox product ideas.

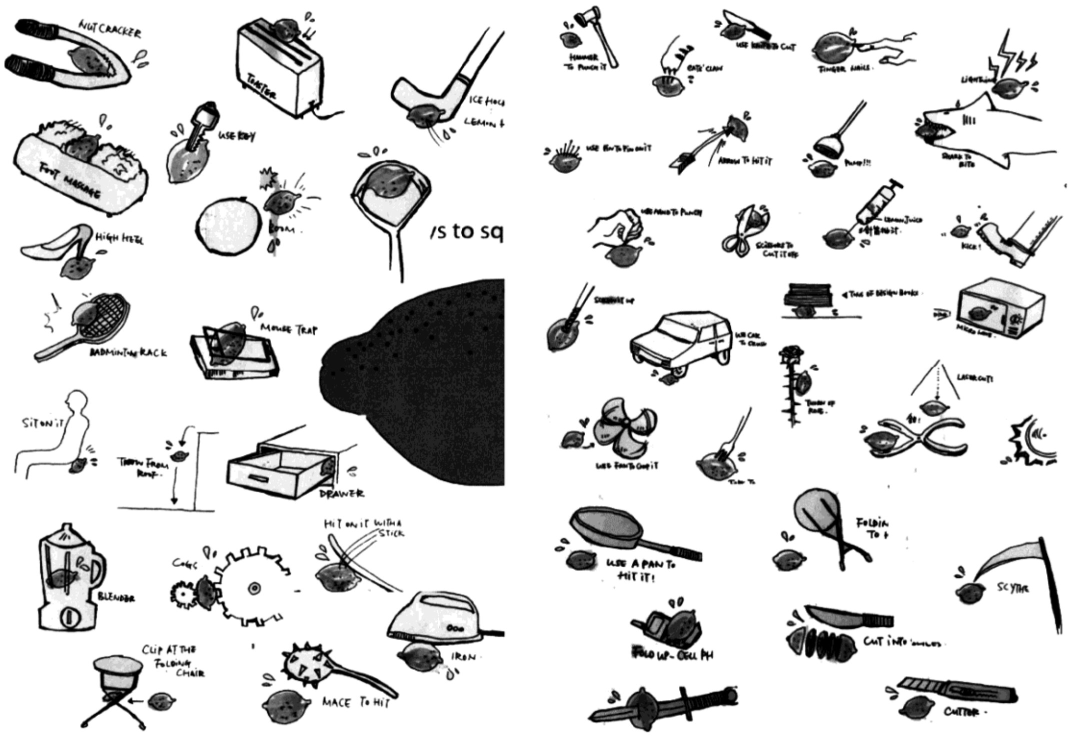


Fig.1.16 Brainstorming on ways to crush lemons

2. Invention problem solving (TRIZ)

TRIZ, literally: "theory of inventive problem solving" is the evolutionary step in creating an organized and systematic approach to problem solving. In another description, TRIZ is "a problem-solving, analysis and forecasting tool derived from the study of patterns of invention in the global patent literature". It was developed by the Soviet inventor Genrich Altshuller and his colleagues, beginning in 1946. Altshuller studied over 200,000 patent files to identify patterns of technological innovation. He discovered that the evolution of a process is not a coincidence. Rather it is governed by certain objective laws or “principles” suggesting that inventiveness and creativity can be learned. TRIZ is not based on psychology, but technology.

TRIZ theory points out that the scientific principles and laws sought by innovation exist objectively, and a large number of inventions and innovations are based on the same principles and will be repeatedly applied in subsequent inventions and innovations, but the technology fields are different. Therefore, there are theoretical basis and rules for innovation. The core content of TRIZ is 40 innovation principles and eight patterns or lines of technical systems evolution.

For example, TRIZ’s seventh innovation principle is to save space by placing small objects inside large, hollow objects, such as Russian nesting dolls (Fig.1.17), telescopic antennas, sliding doors, etc.

Fig.1.17 Russian Nesting Dolls

One of the eight patterns of technical systems evolution in TRIZ system is called dynamization, it suggests that any technical system during its evolutionary process makes a transition from a rigid to a flexible structure. Fig.1.18 shows the evolution of the three products: measuring scale, computer keyboard and cutting tool. They all follow the evolution law from rigidity to flexibility. According to these evolution laws, people can predict the future development direction of products and technical systems.

Fig.1.18 Trend of increasing dynamism

Therefore, TRIZ is a scientific method for creation. Using this theory can speed up the process of creation and invention, and get high quality innovative products.

All sources of ideas should be explored, such as technical literature, reports, design and technical journals, patents and existing products. Inspiration can even come from the user of an existing product, who can provide suggestions for improvement.

The value of ideas is not evaluated at this stage. All notes and sketches are signed, dated and retained for possible future patent proof.

Stage 3: Analysis of solutions

The various design concepts in the preceding stages are carefully considered and selected to integrate into one or more possible compromise solutions. Once a number of possible solutions to the design problem are created, it is necessary to choose which one is best. At this point, the best solution is carefully evaluated and simplified as much as possible, making it easier to manufacture, repair and even dispose of.

After the design is refined, the selection of suitable materials and motion problems should be studied. What source of power is to be used? What type of motion is needed? Is it necessary to translate rotary motion into linear motion or vice versa? Most of these problems can be solved graphically using schematic design sketches in which various parts are shown in skeleton form. For example, pulleys and gears are represented by circles, and a path of motion by centerlines.

Usually, the schematic sketch is followed by an accurate instrument or CAD drawing, as shown in Fig.1.19, showing actual sizes so that proportions and fits can be clearly represented. At this time, the actual size and fit of each part are designed with the aid of engineering standard manuals, experimental data and other empirical information. For parts working at high speed, high load and under special requirements and environment, stress analysis and detailed calculation are also required. To show how the parts are fit together, special attention should be paid to the simplicity and practicality of object movement and installation in an assembly drawing. Costs should be kept in mind. Standard parts should be used whenever possible. Because no matter how perfect a product is, it must sell at a profit; otherwise the time and development costs will have been a loss.

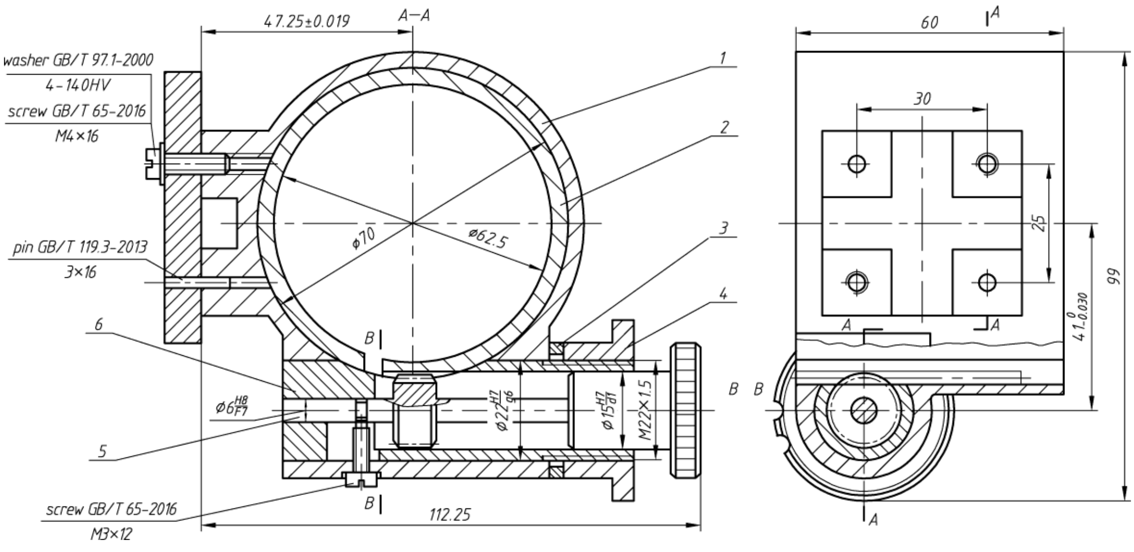


Fig.1.19 Assembly drawing of the throttle valve

Stage 4: Test and evaluation

Normally, at this stage, a scale model is constructed to study, evaluate and refine a design. A full-size working model made to final specification is known as a prototype. The goal of a prototype is to have a physical model of the answers to the challenges that the designers have already specified and discussed during the concept/idea stage. The prototype is analyzed, tested, and improved where necessary, and the results are recorded on the revised sketches and working drawings.

A 3D CAD model is an accurate model generated by a computer. It can not only provide the same level of information as a physical prototype, but also avoid the great expense for a physical prototype. The Boeing 777 aircraft is an example of a very complex system that was entirely modeled in 3D CAD.

Fig.1.20 shows all the parts and the prototype of unmanned aerial vehicles based on the concept sketch shown in Fig.1.1.

(a) The model of each part

(b) Prototype of unmanned aerial vehicles

Fig.1.20　3D CAD model and prototype

If the model or prototype does not work out, it may be necessary to return to the previous stage and select a different solution, and then prototype and test that solution again.

Stage 5: Presentation of final design

There are many ways to present the final design, often varying depending on the audience. For an engineering audience, the presentation may include circuit diagrams, blueprints, and other technical materials such as operating manuals. A presentation for a sales team might focus on the capabilities of the final product and how it compares to other products in the marketplace. A presentation for the general public might emphasize how to use the product, as well as the production of marketing materials.

To manufacture a product, a final set of working drawings (detail drawings and assembly drawings) shall be made, checked, and approved.

Detail drawings are made for each part to be manufactured. The necessary views are drawn, complete dimensions and notes are added so that the drawings will describe those parts completely. Fig.1.21 shows the detail drawing of a shaft.

An assembly drawing is also created showing all the parts go together and the working principle in the complete product.

Unaltered standard parts such as bolts, nuts and screws do not require a detail drawing but are shown conventionally on the assembly drawing and listed with specification in the parts list.

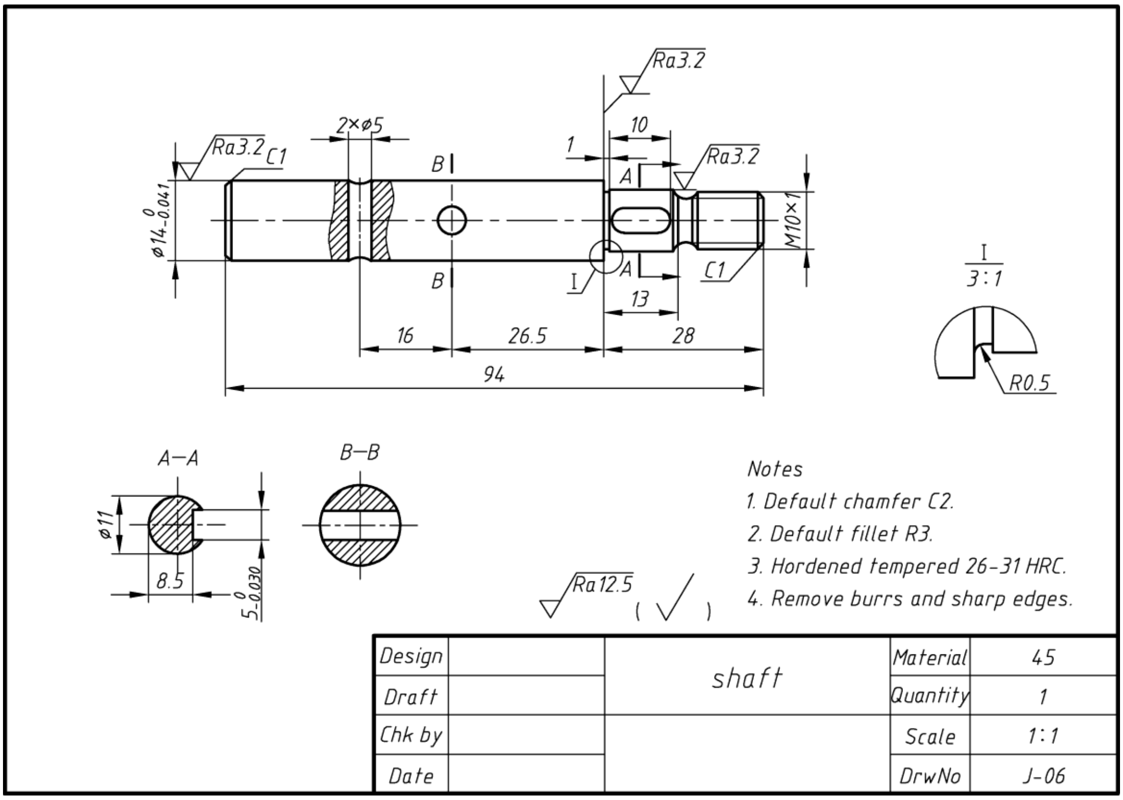


Fig.1.21 A detail drawing

1.3 Introduction to Computer-Aided Design

In the design process, the sum of all practical technologies that use computer as tools to help engineers design is known as computer-aided design (CAD). CAD is technology for design and technical documentation, which replaces manual drafting with an automated process. CAD technology integrates the thinking and comprehensive analysis ability of designers with the fast, accurate and easy revision characteristics of computers, which accelerates the design speed of products and improves the design quality.

Some other terms, such as computer-aided manufacturing (CAM), computer-integrated manufacturing (CIM), computer-assisted engineering (CAE), finite element analysis (FEA), and numerical control machining (NCP) are often used in conjunction with the term “CAD”. The single concept that these terms refer to is the use of computer and software to aid the designer or drafter in the preparation and completion of a task. All terms together describe the use of computer in the total design and manufacturing process, from design to production, publishing of technical material, marketing and cost accounting.

As a new technology, CAD began in the early 1960s and has a history of more than 60 years. At present, CAD technology has entered the practical stage and is widely used in machinery, electronics, aerospace, shipbuilding, automobile, construction and other fields. Moreover, CAD technology is developing towards standardization, integration, networking and intelligence.

1.3.1 CAD system

A complete CAD system consists of hardware and software, as shown in Fig.1.22. High-performance hardware and powerful software are necessary to get the optimum performance of CAD.

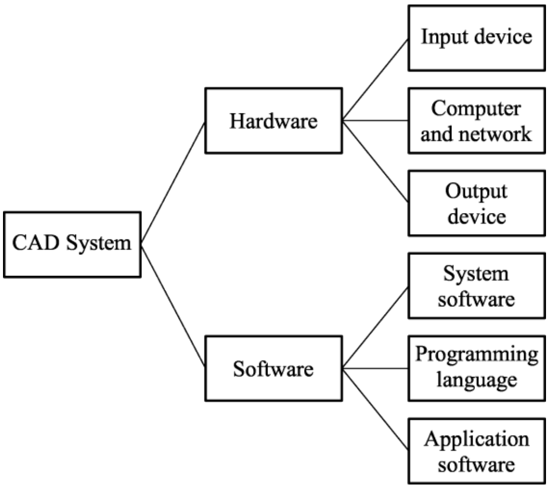


Fig.1.22 CAD system

The hardware for a typical CAD system is made up of various pieces of physical components including the computer system, graphics display, input devices (mouse or tablet), output devices (plotters, printers), storage devices and other specialized equipment.

The software of a CAD system consists of the programs and instructions that permit the computer system to operate. The typical software components of a CAD system are the system software, the programming language, and the application software.

The system software is a type of computer software that is designed for running the computer hardware parts and the application programs. It is the platform provided to the computer system where other computer programs can execute.

The other category of computer software is the programming language that is used by the programmers to write their programs, scripts, and instructions which can be executed by a computer. The use of programming language is in developing applications, and many other programs.

The third category of software is application software that is designed for the users to perform some specific tasks such as drawing a layout. For all these requirements there required a specific software for each type and that specific software that is designed for some specific purpose is known as application software.

1.3.2 2D CAD software and 3D CAD software

A CAD software consists of one or more application modules.

2D CAD software is a computer-aided design program that allows designers and engineers to create two-dimensional drawings, drafts, and plans thanks to a suite of shapes, layers, commands, and tools tuned to simplify the process. Unlike 3D CAD software, which allows users to create a 3D model, 2D CAD restricts dimensional manipulations to the *X*-axes and *Y*-axes.

The advent of 3D CAD software made it apparent that a 3D model could assist not only in the manufacture of the part but also, along with its three-dimensional database, in testing the design with finite element analysis programs, in developing technical manuals and other documentation that combine illustrations of the design with text from word processing programs, and in marketing (for which the 3D solid models can be used with a rendering and animation program).

The core of a 3D CAD system is the construction of 3D solid model of products. For this solid model, people can observe it from different perspectives, or change the display scale, so it is more convenient to change the design. The CAD system can also automatically generate engineering drawings based on this three-dimensional solid model. At present, 3D CAD system has developed from early solid modeling to feature modeling and constraint based modeling. 3D CAD system provides strong support for parts design, assembly design, mold design and numerical control simulation of products.

Some of the more popular CAD software suitable for professional engineering is the AutoCAD family of software, available from AutoDesk (Fig.1.23); Creo Parametric, available from Parametric Technology Corporation (PTC) (Fig.1.24); CATIA, available from IBM and CAXA etc. These software can complete sophisticated large-scale CAD projects that can be integrated with other common tools including word processors and all of them are also capable of sharing data with each other in a variety of forms. All the above software now provides a somewhat consistent user environment from one to another.

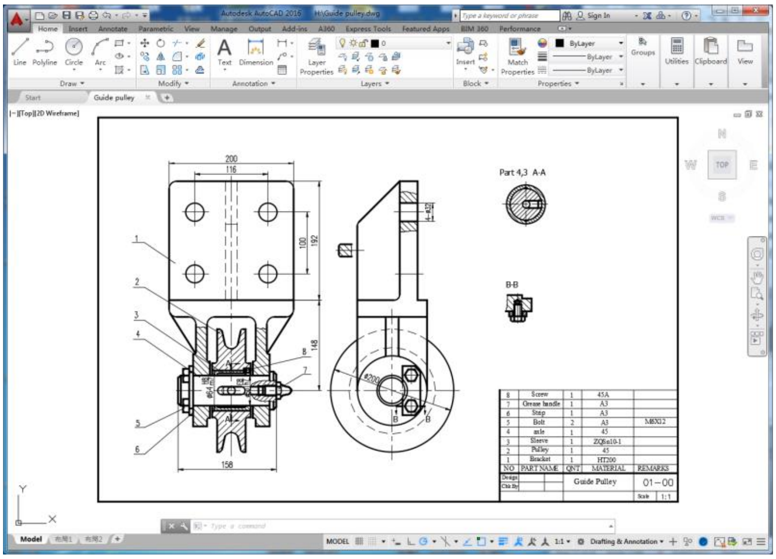


Fig.1.23 Typical screen from AutoCAD software

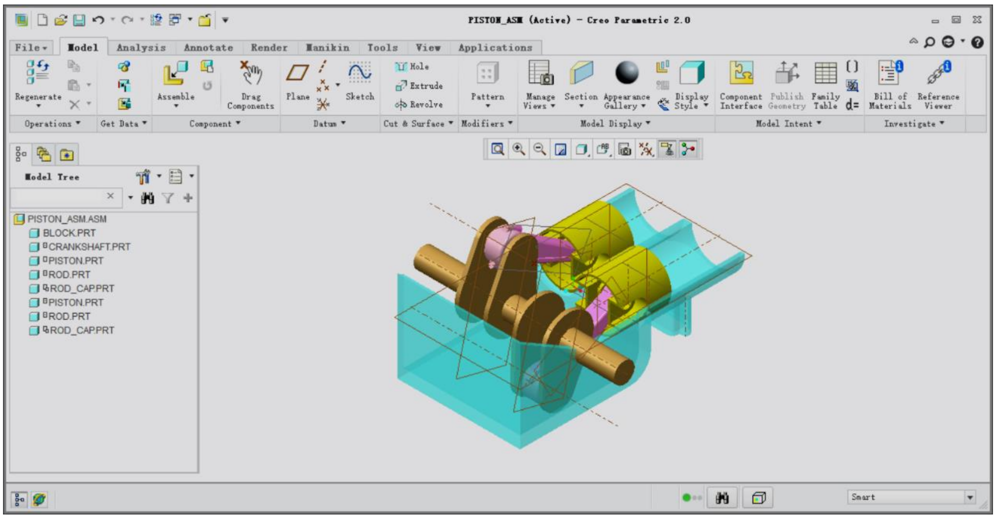


Fig.1.24 Typical screen from Creo software

All CAD software generates familiar geometric terminology for creating drawings. But even though the geometry is common and the procedures for construction are similar, every CAD software program will vary in operational procedures typically involving the basic hierarchy of command structure. Despite their differences, all CAD software has similar capabilities. Once a member of an engineering team has learned to use one software, it is easily adapt to another package. Additionally, all CAD packages have similar basic functions that can be grouped into several categories, some of which are the following:

- File management such as opening and saving files.
- Object or entity creation.
- Object edit or entity modification such as scaling.
- Control of the display and work environment.
- Analysis for volume and mass.
- Definition and generation of output for printers or plotters.

1.3.3 CAD and technical drawing

The CAD system on the computer has replaced many traditional drafting tools, drafting tables, and drafting files in most engineering designs. Today, CAD software is another tool used by many designers and drafters. The basic concepts of drawing and measuring lines and circles is the same for traditional and CAD drawing. By understanding the basic principles of drawing, one can create and modify any type of drawing. CAD software makes drawing easier and raises engineering productivity. However, it does not replace the basic knowledge that enables a skilled designer or drafter to manipulate either a pencil or CAD software.

Therefore, understand the latest engineering drawing standards, learn the method of manual drawing and computer drawing, cultivate the ability of reading and understanding engineering drawings correctly, is the basic task of the subject of engineering graphics.