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Solid Modeling and Applications

Rapid Prototyping, CAD and CAE Theory

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Dugan Um
Texas A&M University
Corpus Christi, TX, USA

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Preface

As the rapid introduction of new designs to the market becomes the key success factor in modern industry, demands arise for lessons in solid modeling and applications. Conventional drawing tables are replaced by CAD and CAE technology, while manual machines are upgraded with more flexible and numerically controlled systems on the shop floors. This book addresses scope of lessons primarily for design engineers involved in the disciplines from product design, analysis, and validation. Theoretical backgrounds introduced in this book will help students understand operational knowledge of CAD, CAE, and Rapid Prototyping technology, so that engineers can operate or develop design tools in a more efficient manner. Theoretical outlines as well as mathematical examples introduced in the book will help students understand the concept of each theory up to the level of practical use in real-world applications. The general audiences are mechanical or manufacturing engineers with little or no coding experience for applications of theory, but with limited spreadsheet experiences. The book is designed to enable students to understand and apply theories to practical applications. Therefore, the focus of theories and illustrations in each chapter are prepared to help maximize learning experiences from understanding to practical applications.

Corpus Christi, TX, USA Dugan Um

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Chapter 1
Introduction to CAD

The Big Picture

Discussion Map

You need to understand terminology and design mechanism with Computer Aided Design.

Discover

Understand basic concept of CAD and benefits of CAD.
Understand terminologies used for modeling technology and CAD.
Understand why designers prefer using CAD compared to manual drawing.
Understand design as a process.
Understand components of CAD system.

CAD is an acronym used for Computer Aided Design, while CAE is for Computer Aided Engineering. CAD is often used for drawing aspects, while CAE is used for analysis aspects. Thanks to advanced analysis software embedded in the most of CAD packages, they are often used together as CAD/CAE. Modern design engineers are likely to use a type of CAD system such as ACAD, Pro-E, Solidworks, or TurboCAD, etc. Although many pros and cons exist in each CAD system, all of the design tools are made with fundamentally similar concept in mind: Help designers facilitate to bring their ideas into reality. It is true to say that it takes time to get used to a CAD system. However, once a designer obtains knowledge and knows how to handle a CAD package, it is more or less the same as a plot understanding aerodynamic principles of a plane. In addition, understanding design as a process is another important aspect to an effective designer. Although design requires trial and error, in general, a good understanding of design as a process will help minimize trial and error cycles and will make a final product more efficient from

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manufacturing stand point. In this chapter, our study will be focused on design fundamentals, CAD, CAE, and design processes.

1.1 Computer Aided Design

Design is an art. The most important ingredient in art is creativity. The idea of a new design is in our mind, but it has to be brought out for presentation. Traditionally, it is done by manual drawings using tools such as drafting tables, technical tools, templates, etc. Now in twenty-first century, advanced technologies including computers, man–machine interface devices, and sophisticated software made it all changed to a new paradigm, called Computer Aided Design. Thanks to the advancements in CAD technology, design is expanding its scope to CAE, by which a complex analysis such as stress, thermal, fluid, or dynamic analysis are all possible in a package such as Multi-Sim, ANSIS, or Abacus. In this section, we introduce CAD to discuss about its usefulness, applications, as well as benefits over the manual hand drawings, followed by examples generated by a modern CAD package. Definitions and terminologies introduced in this section will be used further in the later chapters. Therefore, a good understanding of the overall concept of CAD will be beneficial for understanding the rest of the chapters in this book.

Definition: CAD is defined as creation and manipulation of pictures (design prototypes) on a computer to assist engineers in design.

In order to facilitate creation and manipulation of 2D or 3D pictures, CAD provides various geometric models such as patterns, symbols, and diagrams, which are all fundamental elements for CAD. Primarily, geometric models are used for representation of products to realize abstracted ideas in designer's mind and to use for evaluation purposes. In a modern design process, modeling by CAD, in general, is followed by analysis by CAE for design validation. Depending on the purpose of design validation, the same design can be represented in different geometric models. For instance, in Fig. 1.1, the basic design of the connecting rod is represented in two different geometric models. The representation on the left is a simplified kinematic model for statics or dynamics analysis, while the representation on the right is a model for FEM (Finite Element Method) for stress/strain analysis.

By using such models, a designer can not only represent ideas, but also can communicate with other designers to share ideas and exchange details about the product. Since the geometric models allow communication between designers, geometric models are often called language of designer. Even if designers create

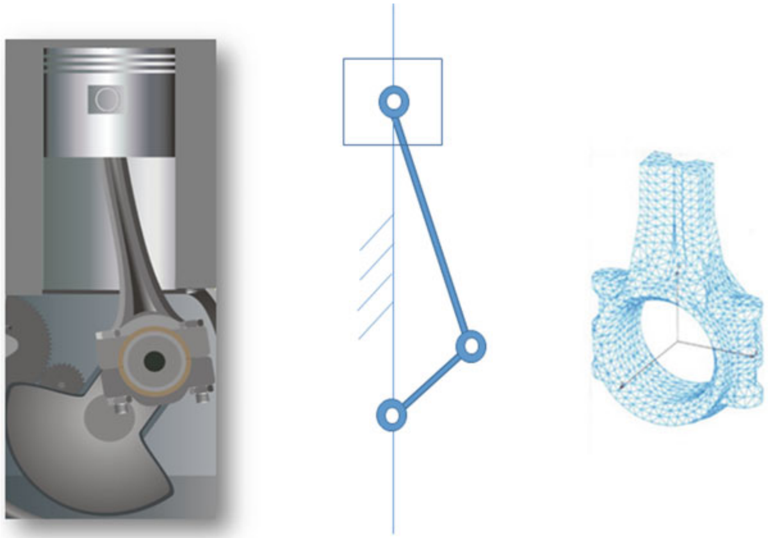


Fig. 1.1 Geometric models change depending on the purpose of analysis

designs with different CAD packages, it can be interpreted easily between designers since the geometric models are all standardized in engineering discipline. Therefore, geometric models are great tools to share design ideas between participants in a design process.

Important Lesson (Two Main Goals of Geometric Models)

- Geometric models of design
  - Patterns, symbols, diagrams
  - Language of designer
- Importance of modeling
  1. Representation
     - Realization of an abstracted ideas
     - Evaluation
  2. Communication
     - Share ideas and designs between participants in a design process

Next question that may come to our mind is that “why CAD?” then. Although designers can achieve two main goals with hand-drawn pictures and diagrams, CAD facilitates many aspects of design process. First of all, CAD can increase the productivity of the designer throughout the entire design process. It helps conceptualize the ideas and bring it to reality. In addition, thanks to CAE, it will reduce the time for analysis. Second, CAD can improve the quality of the design with more complete analysis ability. Thanks to expedite and elaborate design tools that CAD can provide, designers can test more alternatives to find the optimum solution to help customers' needs. Third, the quality of documentation is improved with better graphics quality, more standardization, and fewer drafting errors. Recent CAD packages mostly provide error checking capability of the final drawing for overlapping, tolerance verification, and grammar and symbolic usages. Forth, the majority of modern CAD packages also provide the ability of creating a manufacturing database directly from the design. Manufacturing data such as BOM (Bill of Material), geometric specifications, dimension of components, and even material specifications can be directly created for futuristic use in manufacturing process. Finally, CAD offers various functions to facilitate the entire drafting process with geometric modeling database, engineering analysis, and design review capabilities, and even automated drafting functions in some advanced CAD packages.

All the aforementioned functions that CAD can provide are the answers to the question of "why CAD?". In Table 1.1, the conventional method of manual drafting is compared to CAD. As is shown in the table, the conventional method still serves engineers for many products. Most of the basic principles of manual drafting have been adopted in modern CAD packages. However, there are numerous benefits that CAD can offer. For instance, in Fig. 1.2, there are six different methods of drawing a circle in CAD as opposed to only one method of drawing a circle in manual drafting with a compass. For instance, a circle can be defined by a center with a

Table 1.1 Conventional method vs. CAD

Conventional method	CAD
Served engineer for many products from screw to building	Provide rich variety of techniques for the definition of geometry
Mongian projection can be used for a drawing as complex as an aircraft	Identical representation is used (compatible with conventional method)
Diagrams may be used to represent virtually any system	Shorten the design process significantly (concurrent engineering)
Skill is required in the construction and interpretation	Minimum skill is required for operation, but analytic skills are required
Possible to have conflicting or erroneous models	Automatic error checking in each model is possible
Hard to deal with complexity of today's products	Suitable to deal with complexity of today's products
Hard to generate further representations for assessment, manufacturing information	Easy to generate further representation
Drawings are easily misread because of ambiguity or error in the drawing or simple human error in the interpretation	High accuracy in representation and less error in interpretation
Size of the representation is constrained by the physical size of the drawing paper	No limitation in representation by size

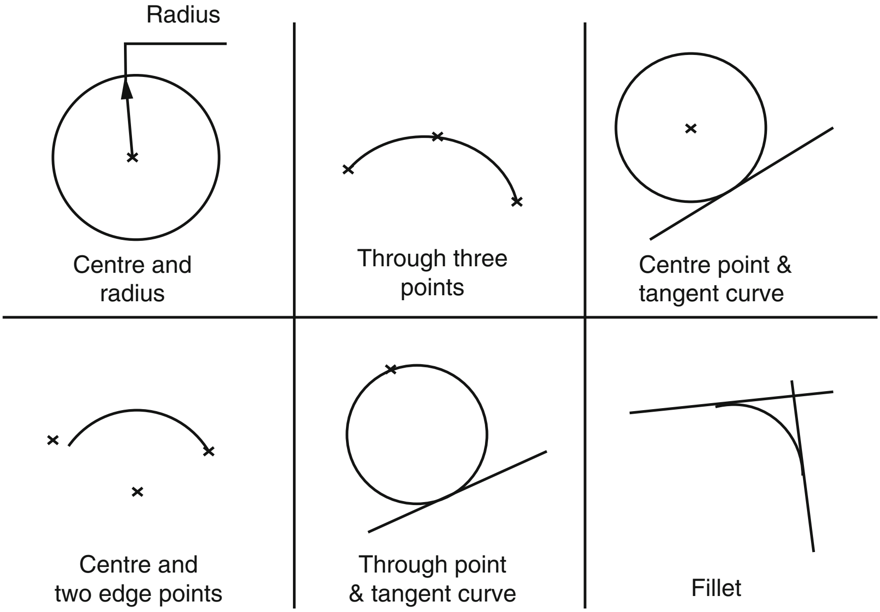


Fig. 1.2 Rich variety of techniques for the definition of geometry

radius, through three points, center with tangential line, center and two edge points, through a point and tangential line, or two filet lines. CAD also provides means to accomplish concurrent engineering where all relevant disciplines for design and manufacturing are simultaneously involved from the earliest stage of product design so that a new product can be introduced rapidly for a higher percentage share of the market, thus yielding higher profits for the company.

Important Lesson (Why CAD?)

1. To increase the productivity of the designer
2. To improve the quality of the design
3. To improve design documentation
4. To create a manufacturing database
5. Various CAD functions

In summary, the aim of CAD is to apply computers to both modeling and communication of designs. Two levels of usage of CAD have been identified so far. At the basic level, CAD assists drawings, diagrams, and the generation of list of parts in a design. In a more advanced level, CAD provides new techniques that give the designer enhanced facilities in system engineering with the function of CAE. Rapid prototyping is often used for design validation as well as functional verification.

Important Lesson (Two Levels of Usage of CAD)

1. Basic level
   - Automate or assist drawings, diagrams, and the generation of lists of parts
2. Advanced level
   - Provide enhanced facilities in system engineering

1.2 Design Process

In modern design approach, design is no longer a simple drafting, but it involves other activities such as analysis, documentation, and manufacturing data generation, etc. Therefore, design is a process with multiple stages with iterations for validation of works done in each stage. Proper design process will save time with careful thinking at the early stage. Using a proper model and validation at early stage will not only save time, but also will save material and manufacturing cost. A simple, but an exemplary design process for a small scale project is outlined below.

Define

The problem has to be defined clearly and completely. The objective of the design has to also be stated. Since time, material, and skill sets are all limited for any design team, the most important aspect of the solution for a given project has to be addressed and shared in a design team.

Ideate

Once the problem is defined and the design objective is well understood, all the participants need to be involved in a brainstorming session to come up with a solution. Importance of this state is to discuss as many alternatives as possible. Examine each alternative for possible scenarios to make sure that an optimal solution can be selected.

Design

Before building parts of the design, design validation has to be done. Geometric models or kinematic models can be used to realize the solution proposed at the ideation stage. Multiple alternatives can be examined in this stage as combined activities with the Ideation stage. A CAD package can be an efficient tool for design validation for static as well as mobile parts. The manufacturing aspect of each part can be discussed as well. Tolerance check can be done by virtual assembly in the design creation.

Manufacture

Manufacturing of the designed parts is the final stage. A proper manufacturing process has to be selected for each part. Careful selection of tools and manufacturing methods is the key to minimize the trial and error cycle in this stage.

In summary, four common steps can be sequentially walked through for a small scale project.

Define

Ideate

Design

Manufacture

The design process introduced above is suitable for a small scale project such as a capstone project at high school or at engineering college, a project for robotics competitions, or a small scale indusial project as well. Industrial design for a large scale manufacturing, in general, requires similar but a more detailed process. Two standard approaches are popular and prevailing in industry: Pahl and Beitz's proposal and Ohsuga's approach.

1.2.1 Pahl and Beitz's Approach

Pahl and Beitz proposed a sequential design process that allows revisiting each stage if needed so that feedback and modification can take place as many times as possible before finalizing the design (see Fig. 1.3). The uniqueness of the Pahl and Beitz's approach is of its sequential manner in design process so that each stage can produce specific outcomes until the final design is produced. The overall process is organized in a way that each stage has an input and an output. Each design stage can be done by an individual, or by a team. Teamwork generally results in better solution since more alternatives can be examined.

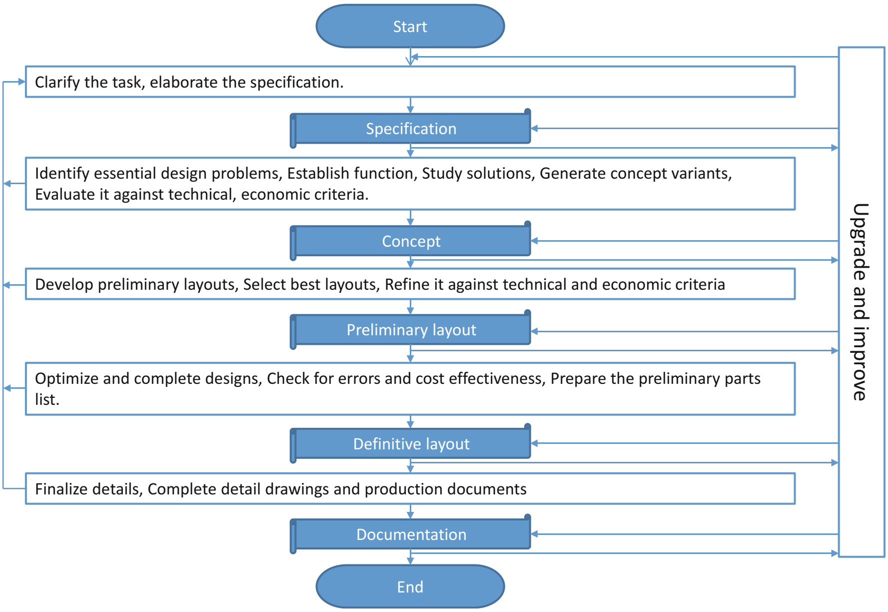


Fig. 1.3 Pahl and Beitz's approach

Specification

The first stage accepts the task as an input and clarifies the task and elaborates the specification. The output of the first stage is the specification. If an upgrade or an improvement is required on the specification, then the process can be reverted to revisit the first stage.

Concept

The second stage, taking the specification as an input, identifies the essential problems, establishes function structures, searches for solution principles, combines and firms up into concept variants, and evaluates against technical and economic criteria. The output from the second stage is the conceptual design or simply the concept. A tangible geometric design is yet to be consolidated at further design stages.

Preliminary Layouts

Once the concept is confirmed, then preliminary layouts and detail geometry have to be developed at the third stage. If several alternative layouts are developed, then the best preliminary layout has to be chosen. Finally, the best alternative has to be refined and evaluated against technical and economic criteria. Other alternatives can be chosen if the selected layout does not meet the technical or economic criteria. In addition, if no layout can be selected, then the process can be reverted back to the first or second stage to revise the specification or concept.

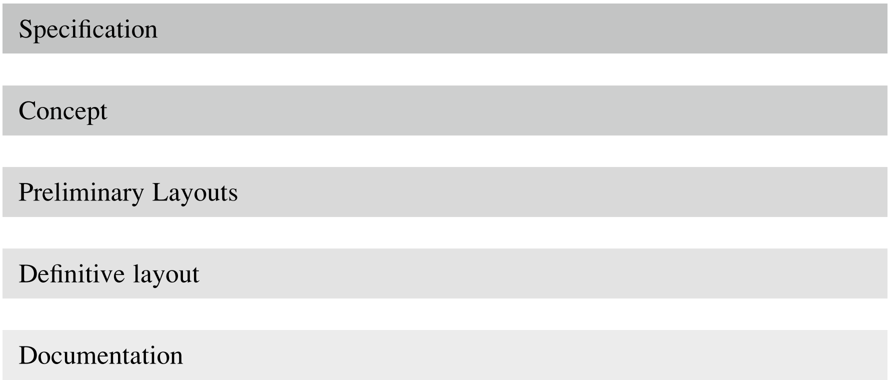
Definitive layout

The preliminary layout now has to be converted into a definitive layout at the fourth stage. First, the preliminary design has to be optimized and completed with details of precise geometry. It also has to be checked for errors and for cost-effectiveness. Automatic error checking functions, if available, can be utilized. Finally, the preliminary parts list and documents have to be prepared for the definitive layout.

Documentation

At the fifth stage, the final documentation will be revealed by finalizing the details. First, the detail drawings and production documents have to be completed at this stage. Finally, all the documents have to be checked again thoroughly to minimize the probability of failures in manufacturing. Again, if it turns out that the final documents cannot serve the needs in manufacturing or customers' demand, the process can be reverted back to previous stages. However, the number of backtracking should be minimized at all costs at this stage.

In summary, Pahl and Beitz's approach is a sequential process to arrive at the final documentation.



1.2.2 *Ohsuga's Approach*

While a sequential progress of design process is natural in engineering sense, another view has been evolved by Ohsuga. Instead of viewing the design process as a streamline of sequential progression, he proposed an iteration of several

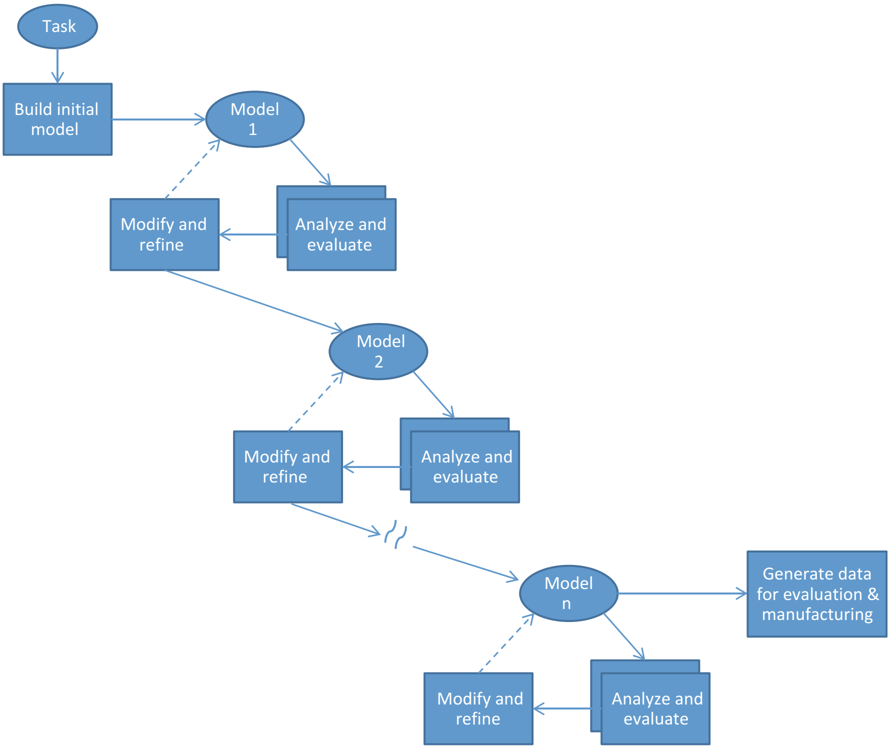


Fig. 1.4 Ohsuga's approach for design process

confined design steps until a satisfactory draft is obtained. As shown in Fig. 1.4, similar design loops that include two steps are represented in series: first, analysis and evaluation, and second, modification and refinement.

Once a preliminary model is built by the requirements, the model will be updated in all of the iterations until the final model is obtained. The uniqueness of Ohsuga's approach is that the design team can take as many iteration loops as possible until the final model is satisfactory. This is a typical trial and error approach to solve a problem if there is no immediate known solution. A solid and reliable inner step will improve the model gradually until no further improvement seems necessary. Once the final model is obtained, then the information for manufacturing data and testing data will be generated. While the Pahl and Beitz's approach is suitable for a sizable project for thorough step-by-step progression, the Ohsuga's approach may suit well for a smaller scale project since the design team can arrive at a final design in a faster pace with minimum number of iterations. Therefore, it is time-efficient, but it is more prone to errors.

We discussed two general design approaches. There are numerous design processes tailored to the needs of each entity. For example, NASA developed a circular design process where it has unique steps defined in each loop, but multiple iterations will be executed until no further improvement is necessary. PBS design squad developed a unique approach for a design process for educational purpose of children. A cyclic design process is embedded in the overall sequential process to optimize students' thought process in their approach. In short, various combination or alternative design processes can be created to serve for specific needs in a small entity or for more general needs in a large entity with a room for tailoring certain areas for adaptation.

1.3 Applications of Design Models

In the previous section, we discussed about the geometric models, aims of CAD, and design as a process. As a result of the design process, we obtain design documents primarily for manufacturing. The importance of a geometric model is not only to generate design documentation for manufacturing, but also to transform models into other forms for evaluations during the design process (see Fig. 1.5). The design model is transformed to various models for design evaluation with the environment data, load case/duty data, as well as materials data.

As discussed in Sect. 1.1, the design model can be transformed into different models for the evaluation purposes. There are several common models for design evaluations: kinematic models, dynamic models, stress models, and thermal models (see Fig. 1.6). Each evaluation requires a different type of model for careful analysis in each area. A design engineer needs to be able to produce a specific model suitable for each design evaluation process. The evaluation of design is often called CAE,

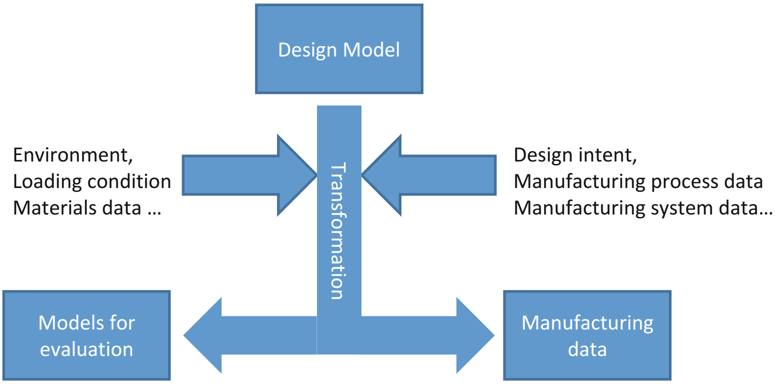


Fig. 1.5 Application of design models

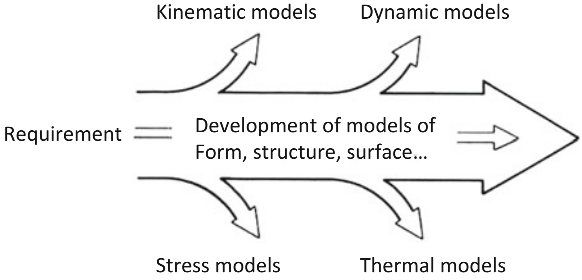


Fig. 1.6 The use of models in design

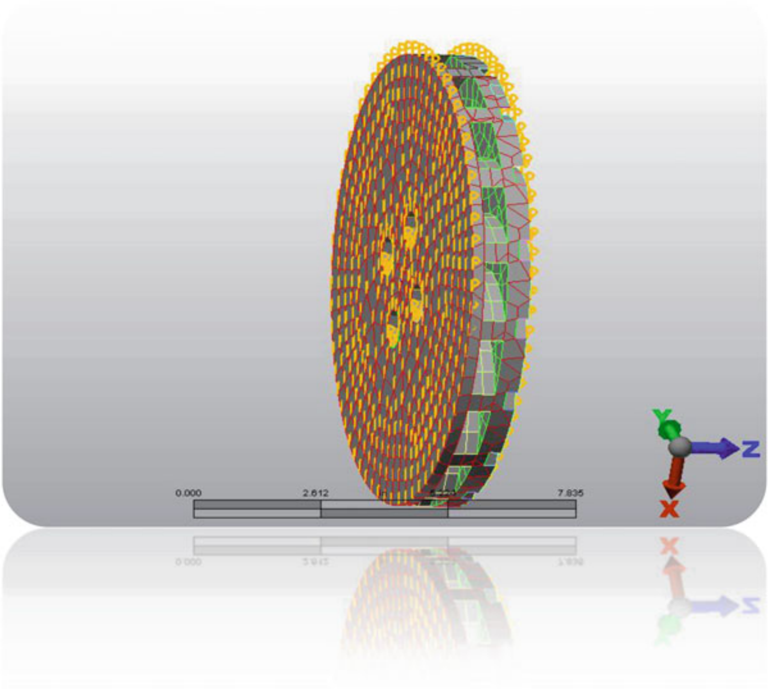
which requires not only knowledge in engineering, but also skill for system operation. Conventionally, the CAE is performed separately from the design stage with the help of a skillful analysis professional. Thanks to the advances made in CAE technology, however, both are now merged into an integrated system for faster design cycle and more alternative evaluation, thus early introduction to the market with higher satisfaction of customers is feasible. In order to transform the design model for manufacturing, the manufacturing data such as design intent, manufacturing process data, and manufacturing system data have to be complemented.

1.4 Examples by CAD/CAE

In this section, several CAD/CAE examples are introduced. The package used for these examples is Auto CAD inventor and Auto CAD Mechanical Engineering Simulator. Students may peruse this section to obtain indirect experiences of CAD/CAE exercises.

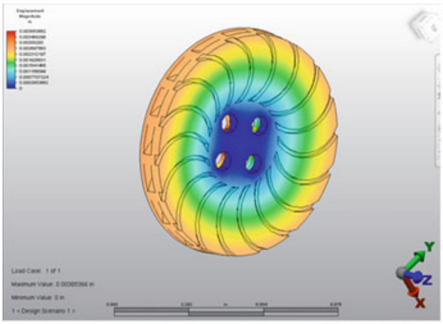
1.4.1 Disc Rotor

In this example, two different types of materials are compared in order to determine the best material for the specific type of a rotor disk. Upon observations, the material chosen for this application by comparing the displacement and stress analysis results is Ceramic Grade 447 Cordierite because of its endurance to stress. The load placed on each of the materials during analysis was 800 PSI applied to both sides of the part with the holes being constrained as fully fixed.

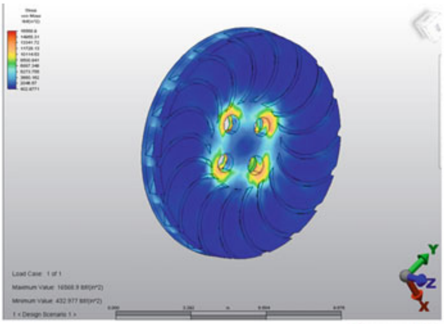


Meshed Ceramic Disc model for CAE

Color-coded analysis results of the chosen material are shown in the figures below. The CAE package can evaluate stress and strain level at each part of the product and visualize the level of stress and strain in color concentration.



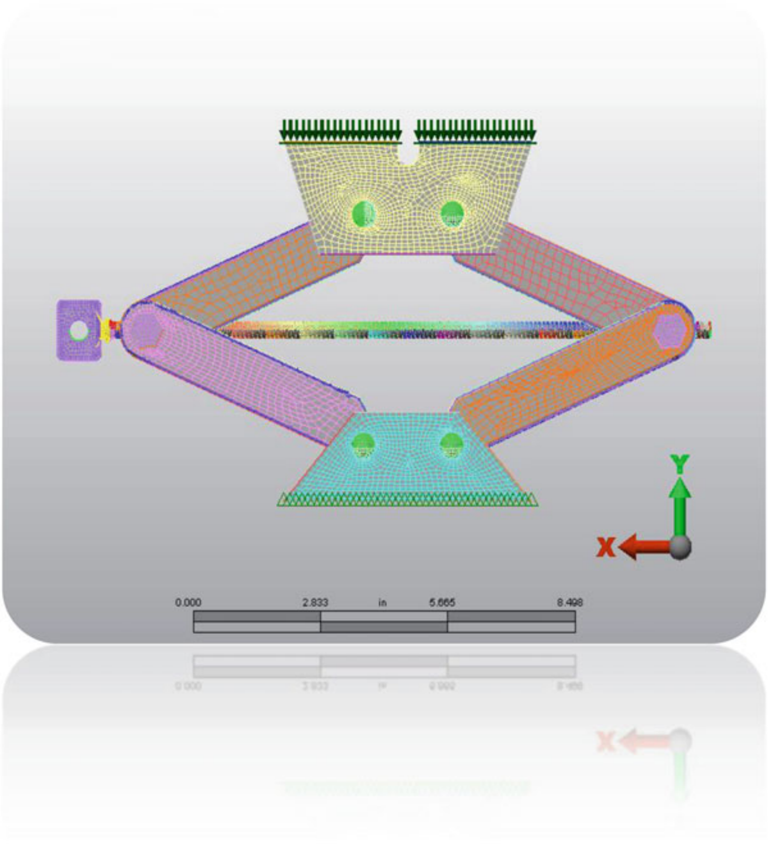
Strain analysis



Stress analysis

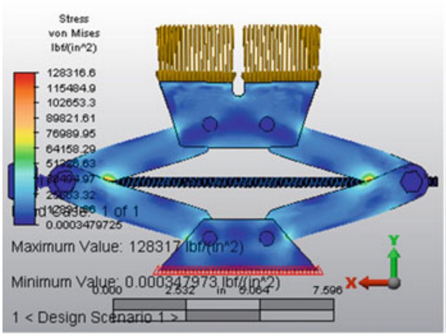
1.4.2 Scissor Jack

The purpose of this work is to compare the strengths of a car jack built using ASTM A36 Steel to one built using Grey Cast ASTM 48-A Grade 50 Iron, in order to compare the values of stress, strain, and displacement. A force of 2000 lbs was used to simulate the weight of an average-sized car. As a result of the analysis, the car jack made by steel demonstrated less deformation compared to the one made by iron.

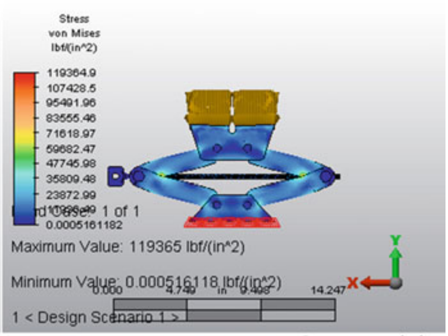


Car Jack FEM model

While iron is cheaper than steel, if we take the safety factor into consideration for design stress, the maximum stress found by simulation may fail the iron car jack. In this study, therefore, steel is chosen to make the car jack for safety and longer life span. Color-coded analysis results are shown in the figures below.



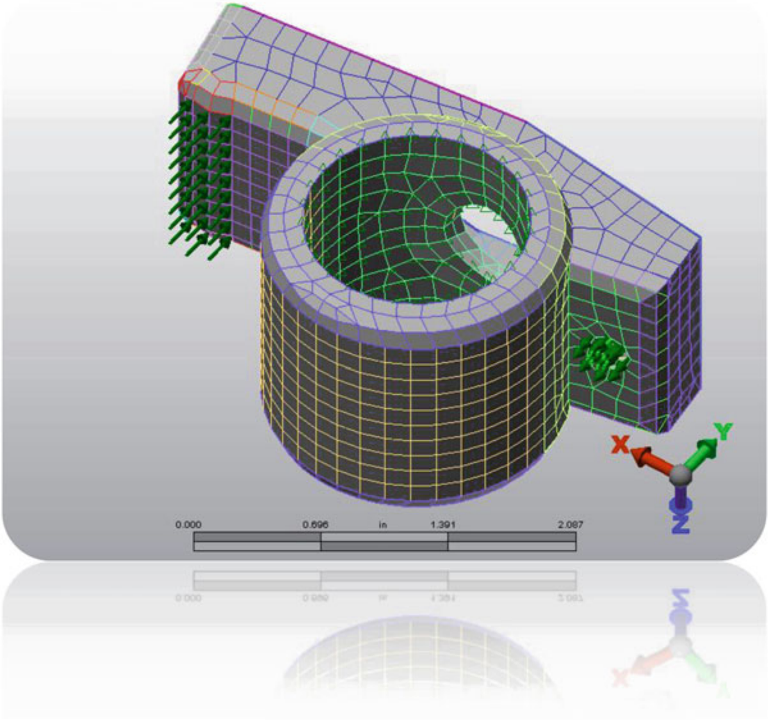
Steel: stress analysis



Iron: stress analysis

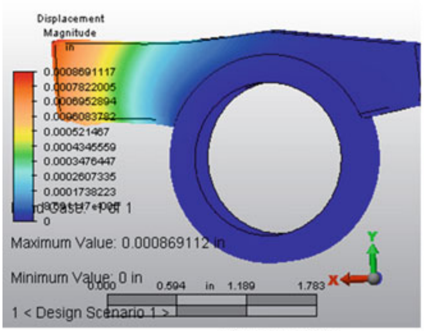
1.4.3 Automotive Rocker Arm

The purpose of this project was to discover the most economic material that would be strong enough for an automotive rocker arm. The objective is to use the strongest and lightest materials capable of withstanding the given loads.

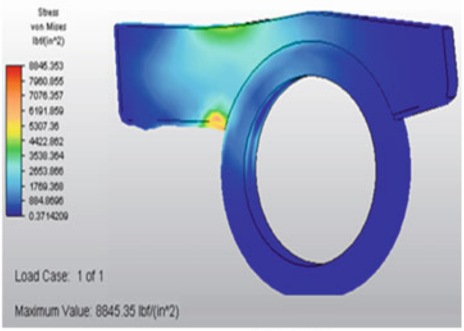


Automotive rocker arm FEM model

The strength of a vehicle's valve train is critical not only for longevity of the motor, but also as a factor in performance. Among various materials tested by CAE simulation, it is found that Toughened Alumina (Al2o3-zro) is chosen among all of alternatives because it is less expensive, easier to machine, stiffer, and lighter than the next best material. Color-coded analysis results are shown in the figures below.



Displacement analysis



Stress analysis

Sample Exercise

Form a discussion group and brainstorm to discuss as to which design process would be more suitable for the following products. Try to come up with your own design process that would better serve the product manufacturing

1. Chopstick design
2. Power transmission shaft design for a vehicle
3. New vehicle deign

Chapter 2
Graphical Representation for Mechanical Design

The Big Picture
Discussion Map
To understand geometric modeling techniques and their applications

Discover
How do we represent our product?
What types of models are available for representation?
What are the advantages and disadvantages of each model?

The desire of representing ideas of a novel design is human nature. Humans communicate with each other through various means to share ideas. As engineering becomes an important discipline, difficulty arises as to how to represent an idea of a product and how to share it with other engineers. To that end, engineers invented a drawing table and drawing tools to express their ideas. However, engineers are also challenged to invent geometric models to share ideas in mutually agreeable forms. Geometric models developed in engineering discipline enable engineers to make a significant progress in sharing ideas. The main objective in creating geometric models is to facilitate representation and interpretation of the product ideas. However, representation and interpretation of the drawings made in a two-dimensional paper often result in errors due to the lack of standard formats. Especially, in order to express a three-dimensional shape in a two-dimensional drawing paper, more caution is needed. In order to standardize the drawing procedure, various ideas of descriptive geometry have been proposed. Descriptive geometry is the branch of geometry that allows the representation of three-dimensional objects in two dimensions, by using a specific set of procedures. The resulting techniques are important for engineering, architecture, design, and in art as well [1]. The theoretical basis for descriptive geometry is provided by planar geometric projections. Gaspard Monge is usually considered as the “father of descriptive geometry.” He first developed his

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techniques to solve geometric problems in 1765 while working as a draftsman for military fortifications, and later published his findings [2].

2.1 Mongian Projection

Monge's protocols or Mongian projection rules allow an imaginary object to be drawn in such a way that it appears to be a 3-D model. All geometric aspects of the imaginary object are accounted for in true size-to-scale and shape and can be imaged as seen from any position in space. All images are represented on a two-dimensional surface. Descriptive geometry uses the image-creating technique of imaginary, parallel projectors emanating from an imaginary object and intersecting an imaginary plane of projection at right angles. The cumulative points of intersections create the desired image. Below is the summary of the Monge's basic protocols.

- Project two images of an object into mutually perpendicular, arbitrary directions. Each image view accommodates three dimensions of space, two dimensions displayed as full-scale, mutually perpendicular axes and one as an invisible (point view) axis receding into the image space (depth). Each of the two adjacent image views shares a full-scale view of one of the three dimensions of space.
- Either of these images may serve as the beginning point for a third projected view. The third view may begin a fourth projection, and on ad infinitum. These sequential projections each represent a circuitous, 90° turn in space in order to view the object from a different direction.
- Each new projection utilizes a dimension in full scale that appears as a point-view dimension in the previous view. To achieve the full-scale view of this dimension and accommodate it within the new view requires one to ignore the previous view and proceed to the second previous view in which this dimension appears in full-scale.
- Each new view may be created by projecting into any of an infinite number of directions, perpendicular to the previous direction of projection. (Envision the many directions of the spokes of a wagon wheel each perpendicular to the direction of the axle.) The result is one of stepping circuitously about an object in 90° turns and viewing the object from each step. Each new view is added as an additional view to an orthographic projection layout display and appears in an "unfolding of the glass box model."

Mongian Projection

- 3D forms are represented in 2D by mapping points on the object into multiple mutually perpendicular planes of projection
- Parallel projection normal to the planes of projection
- First angle and third angle representations are most popular

Aside from the orthographic, six standard principal views (front, right side, left side, top, bottom, rear), descriptive geometry strives to yield four basic solution views: the true length of a line (i.e., full size, not foreshortened), the point view (end view) of a line, the true shape of a plane (i.e., full size to scale, or not foreshortened), and the edge view of a plane. These often serve to determine the direction of projection for the subsequent view. By the 90° circuitous stepping process, projecting in any direction from the point view of a line yields its true length view, projecting in a direction parallel to a true length line view yields its point view, projecting the point view of any line on a plane yields the plane's edge view, and projecting in a direction perpendicular to the edge view of a plane will yield the true shape (to scale) view. These various views may be called upon to help solve engineering problems posed by solid-geometry principles. Details of Monge's protocol are in ANSI Y14 (American National Standards Institute) or BS 8888 (British standard). Below is the list of ANSI Y14 that contains description of each title associated with it (Table 2.1).

2.2 ANSI Y14

Below is the list of some important aspects of ANSI 14 relevant to engineering drawing principle.

Table 2.1 ANSI Y14 example list

Y14.100	Engineering drawing practices
Y14.24	Types and applications of engineering drawings
Y14.3	Multiview and sectional view drawings
Y14.31	Undimensioned drawings
Y14.36M	Surface texture symbols
Y14.38	Abbreviations and acronyms for use on drawings and related documents
Y14.4M	Pictorial drawing
Y14.41	Digital product definition data practices
Y14.42	Digital approval systems
Y14.5	Dimensioning and tolerancing
Y14.5.1M	Mathematical definition of dimensioning and tolerancing principles
Y14.6	Screw thread representation

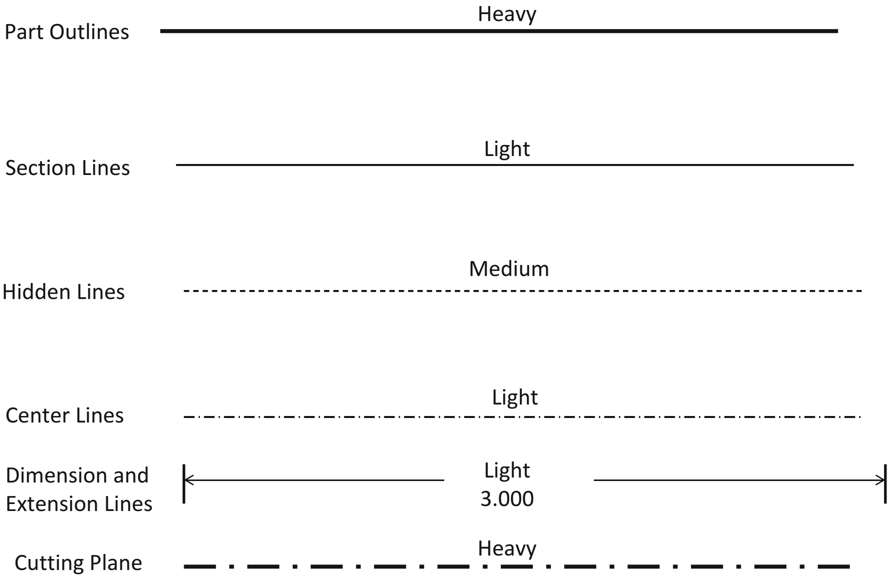

Fig. 2.1 Line style for engineering drawing

- Different line-styles have different meanings on a drawing (see Fig. 2.1).
- The internal form of shapes is described by imagining part of the object removed to show internal details in a sectional view.
- Two principal conventions (first, third angle projection) exist to specify how views should be related to each other on a drawing.
- Projection into a single plane that is not aligned with any of the main faces of an object is known as pictorial projection.
- Dimensions, tolerance, surface conditions are identified using a symbolic representation.
- Repetitive drawing of complex shapes is represented by symbolic notation.

2.2.1 Line Style

Y14 defines meanings of various line styles (see Fig. 2.1). Examples of line styles are in Fig. 2.2.

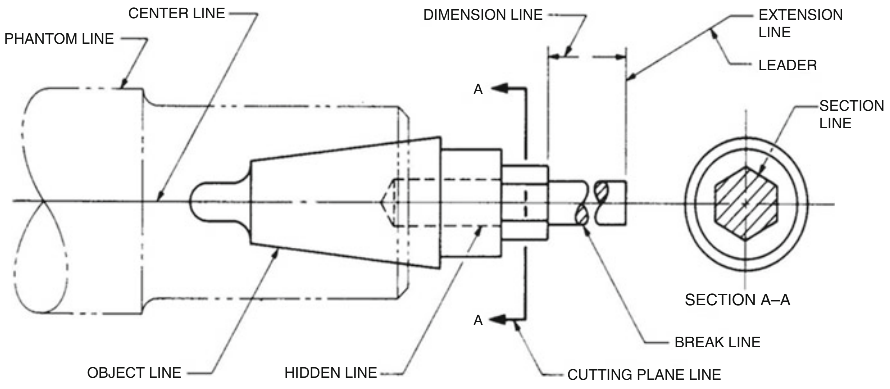

Fig. 2.2 Family of lines

2.2.2 *Sectional View*

Sectional view is a useful drawing to understand the internal structure of a part. They are used when other view would fail to clearly show the internal details. Sectional views are created by placing an imaginary cutting-plane through the part to expose the interior. There are three different types of sectional view: conventional, half, and full sectional views. The half sectional view is the most popular since it reveals the internal view in conjunction with the exterior view.

2.2.3 *Orthographic Projection*

Orthographic Projection is a way of drawing a 3D object from different directions. Usually a front, side, and plane views are drawn so that a person looking at the drawing can see all the important sides. Two principal conventions exist to specify how views should be related to each other on a drawing: First Angle and Third Angle. They differ only in the position of the plan, front and side views. In both projections, an object is placed in a box where a parallel project will take place on each side of the box. In first-angle projection, each view is pushed through the object onto the plane furthest from it. For instance, the top view will be pushed through the object and it forms on the bottom plane. In third-angle projection, each view is pulled onto the plane closest to it. Therefore, the top view is on the top of the parallel projection of the orthographic views (Figs. 2.3, 2.4, and 2.5).

First angle orthographic projection is more popular in Europe, while the third angle orthographic projection is popular in USA. Another example is shown in Fig. 2.6.

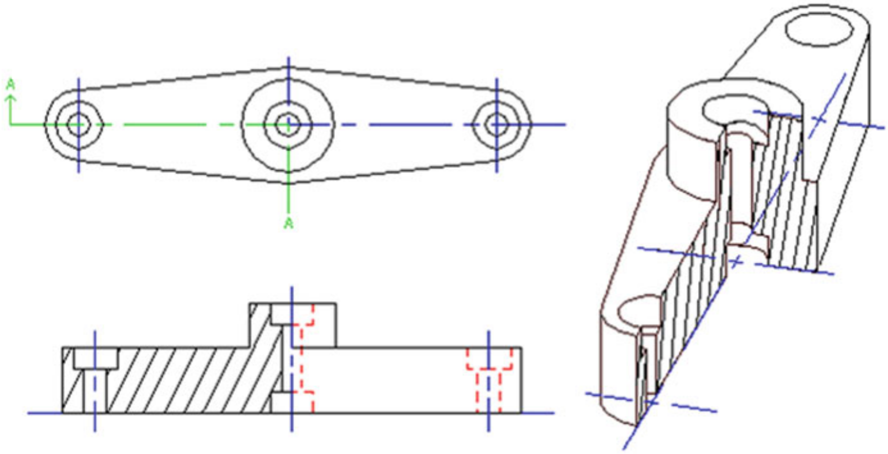

Fig. 2.3 Sectional view (half sectional view)

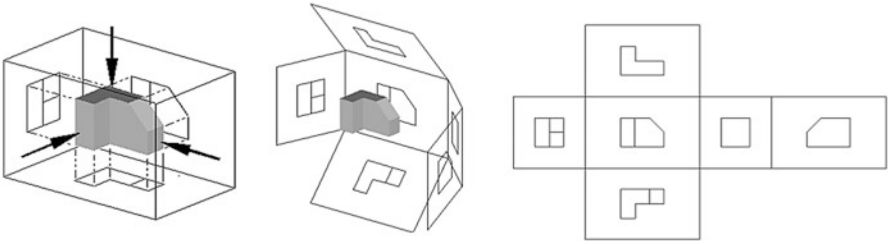

Fig. 2.4 First angle projection

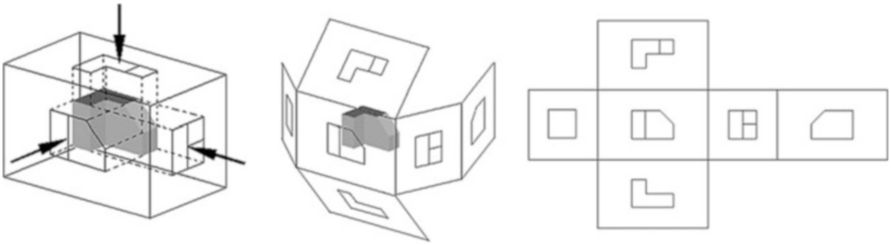

Fig. 2.5 Third angle projection