CHAPTER 1
INTRODUCTION

In the field of engineering design communication, multi-view orthographic projection techniques have been used by engineers, inventors and designers to produce working drawings for mass production and custom fabrication, at ever enlarging scope since the Industrial Revolution. Such multi-view projection techniques have been greatly improved and formalized into a branch of graphical mathematics called “descriptive geometry,” for which French scientist Gaspard Monge (1746-1818) is generally recognized as the “father” since he published a series of writings on the subject in the 1760s; and since then, the theory and practice of descriptive geometry have become a standard part of engineering curriculum all over the world.

With the introduction of CAD (computer-aided drafting) technology, especially the increased application of three-dimensional parametric solid modeling programs in the recent decades (since the 1990s), engineering design and drafting have been made drastically more efficient and interactive; and for the first time in the history of industrial civilization, engineers and designers can design, modify and test new products in three-dimensional digital space, before any physical prototypes are made. The application of three-dimensional parametric solid modeling technology in computer-aided design and drafting provides modern engineers and designers strong capability of solving descriptive geometry problems in a single virtual three-dimensional digital space, with efficiency and interactivity, in a time-saving mode, instead of solving such problems on flat sheets of paper with time-consuming two-dimensional multi-view projection methods.

Therefore, it can be rationally assumed that, the integration of the most current three-dimensional parametric modeling technology and the traditional subject of engineering descriptive geometry, which is the principle aim of this college textbook project, can make a contribution to the improvement of engineering education in terms of tighter connection with modern technology.

The objectives of this Chapter are:

1. To provide an overview of the science of descriptive geometry, as the foundation of orthographic multi-view projection working drawings, which is used in engineering design;

2. To analyze the evolution of drafting techniques used in the solution of engineering descriptive geometry problems from manual board drafting through 2D CAD to parametric 3D CAD; and

3. To explain the needs to update the science of descriptive geometry to the most currently available CAD, especially 3D parametric CAD technology, through the completion of this college textbook project.

1.1 The Evolution of Descriptive Geometry

1.1.1 Traditional 2D Drafting Technologies and its Application in Descriptive Geometry

In the history of engineering drafting, the methods of multi-view projections called "descriptive geometry" was developed by French scientist Gaspard Monge (1746-1818) in the 1760s; and have been taught in engineering schools as the theoretical foundation for orthographic working drawings, either as a standard topic of typical engineering drafting courses or as separate courses; and the methods have been used for the graphical solutions of engineering calculation problems, such as shortest distance between two pipes in the 3D space, dihedral angles between two surfaces, sheet-metal design and fabrication, etc.

Since the 1760s, more than two centuries have passed; and many textbooks have been published on the subject of descriptive geometry, especially those teaching the solutions of descriptive geometry problems using traditional manual board drafting techniques. Up to the emergence of CAD technology, descriptive geometry-related problems were solved through manual board drafting on vellums and other drafting paper sheets. With the emergence of 2D-based CAD programs such as Autodesk AutoCAD in the late 1970s, attempts have been made to solve descriptive geometry-related problems using 2D tools of related CAD software, and textbooks and articles have been written and published for this purpose.

It is proven by history that the theories and methods of descriptive geometry have made a great contribution to the field of engineering design and drafting; however, using traditional board drafting and even 2D CAD technology to apply these methods to the real-world engineering design problems can be sometimes complicated, time-consuming, and cumbersome; and this is especially true in this age of digital technology, when pre-fabrication testing of new consumer products and complicated engineering systems such as space ships can be conducted virtually in the three-dimensional digital space, before any physical prototypes are built.

1.1.2 3D CAD Modeling Technologies and its Potential Impact in Descriptive Geometry

With the emergence of 3D wireframe modeling technology (NURBS, etc) in the early 1970s, 3D solid modeling technology around the years 1980s, and especially the invention and continuous improvement of parametric 3D modeling programs (such as CATIA, SolidEdge, Autodesk Inventor, etc.) in the recent decades (1990s through 2000s), engineering drafting has entered into a completely new era of revolutionary transformation. Some attempts have been made to incorporate the potential of 3D modeling and parametric 3D modeling technologies into the curriculum of engineering drafting at two-year community colleges and four-year universities; and solutions of descriptive geometry problems have been explored to various extents in industry and at institutions of higher learning. The 3D modeling technology and especially the parametric 3D modeling technology offer great potential to make the solution of descriptive geometry problems more efficient and much less time-consuming, in terms of their ability to solve such problems directly in a 3D environment, on the 3D models of mechanical, architectural and civil engineering designs, bypassing the stage of 2D orthographic projection.

Therefore, the incorporation of parametric 3D modeling technology into the curriculum of engineering drafting and descriptive geometry will bring the teaching of engineering drafting and descriptive geometry courses up-to-date with the most advanced technology currently available in the market; help engineering students to become more efficient future engineers; and increase efficiency in engineering design in general.

1.2 The Need to Update Descriptive Geometry with Three-Dimensional CAD Technology

The followings are justifications for pursuing this project:

1.2.1 The Need for an Extensive Infusion of the Most Current 3D Technology into the Traditional Subject of Descriptive Geometry So As to Better Prepare Engineering Students for Future Professional Practices

According to Ronald E. Barr, Professor of Mechanical Engineering, University of Texas at Austin (2004), “In the last two decades, engineering graphics instruction has been significantly influenced by the advancement of computers and other new technologies. During this short span, the discipline has gone from teaching manual drafting and pencil drawings to the use of 3-D computer modeling and simulation software […] Within the past decade of the 1990’s, the teaching of 3-D solid modeling has become the central theme in most engineering graphics programs. This recent paradigm shift to 3-D has been facilitated by the development and low-cost availability of solid modeling software […] In the Concurrent Engineering paradigm for graphical communication, the student starts with a sketch of an idea. The sketch idea can then be used to build a solid model of the part. The solid model not only serves as a visualization modality, but it also contains the solid geometry data needed for engineering analysis. Typical of these analyses are finite element meshing, stress and thermal studies, mass properties reports, and clearance-interference checking. After analysis, the same geometric database can be used to generate final communications like engineering drawings, marketing brochures, and even rapid physical prototypes that can be held in one's hand." The parametric 3D modeling technology is the most typical example of the "Concurrent Engineering paradigm" mentioned by Professor Ronald E. Barr, as shall be further explained in Chapter 3 of this college textbook.

Due to the fact that 3D modeling technology offers indisputable advantages over traditional 2D drafting technology, such as those discussed by Professor Ronald E. Barr, mastery of 3D modeling and presentation skills is becoming more and more important in the training of future engineers. "The new ABET standards require an outcomes-based approach. Each program is expected to define a set of student outcomes, which are the knowledge, skills, and abilities that must be attained at graduation." These skills include the "ability to communicate effectively in written, oral, and graphical forms." In order to "attain consensus on student outcomes for engineering graphical communication, a survey was conducted at the Midyear Meeting of the Engineering Design Graphics Division of ASEE in Scottsdale, Arizona in November 2003. This survey presented a list of potential graphical communication outcomes derived from a literature search of related journal papers. This resulted in a list of fourteen major graphics outcomes, and included a sub-list of performance criteria that demonstrate the achievement of that outcome," which are listed below:

- Outcome 1: Ability to Sketch Engineering Objects in the Freehand Mode. This outcome includes making sketches in isometric, oblique, perspective, orthographic and auxiliary view modes. It also includes freehand lettering and freehand dimensioning.

- Outcome 2: Ability to Create Geometric Construction with Hand Tools. This outcome includes using hand tools to draw parallel and perpendicular lines, and to construct circles, arcs, tangencies, and irregular curves.

- Outcome 3: Ability to Create 2-D Computer Geometry. This outcome includes setting up grids and units. It also includes creating and editing 2-D computer geometry, and constructing lines, primitives, arcs, and fillets.

- Outcome 4: Ability to Create 3-D Solid Computer Models. This outcome deals with the ability to extrude and revolve 3-D parts. It includes adding and replicating 3-D design features.

- Outcome 5: Ability to Visualize 3-D Solid Computer Models. This is a companion outcome to Outcome 4 and includes setting view direction, panning, and zooming the model, and setting other view controls.

- Outcome 6: Ability to Create 3-D Assemblies of Computer Models. This outcome deals with mating several parts into a computer assembly model.

- Outcome 7: Ability to Analyze 3-D Computer Models. This outcome pertains to analysis of the computer model, including measuring geometry, obtaining mass properties, or creating a mesh to perform a finite element study.

- Outcome 8: Ability to Generate Engineering Drawings from Computer Models. This outcome includes projecting a drawing from a solid model as well as completing the drawing with drafting details.

- Outcome 9: Ability to Create Section Views. This outcome deals with section views in 2-D and 3-D.

- Outcome 10: Ability to Create Dimensions. This outcome includes applying standard vertical, horizontal, radius, diameter, and other dimensions to an engineering drawing.

- Outcome 11: Knowledge of Manufacturing and Rapid Prototyping Methods. This outcome deals with common shop and manufacturing processes that impact drawings, and modern rapid prototyping methods.

- Outcome 12: Ability to Solve Traditional Descriptive Geometry Problems. This outcome covers the classical projective solutions to spatial problems.

- Outcome 13: Ability to Create Presentation Graphics. This outcome includes creating data graphs and charts, generating color raster images, and creating animations and slide show presentations.

- Outcome 14: Ability to Perform Design Projects. This final outcome deals with team work, technical reporting, the design process, and reverse engineering.

The survey results for the proposed fourteen graphical communication outcomes are shown in Table 1 below; and they indicate that 3D modeling abilities are highly valued with a ranking indicator from 3.71 points for “Ability to Analyze 3-D Computer Models” to 4.75 points for “Ability to Create 3-D Solid Computer Models,” while solving descriptive geometry problem using traditional board drafting method is not (2.29 points). These results suggest that the traditional subject of descriptive geometry is in need of an extensive infusion of the state-of-the-art 3D modeling technology so as to keep up with technological and industrial progress.

Table 1. Proposed Graphics Outcome Average Rank

Type of Ability	Rank Point
1. Ability to Sketch Engineering Objects in the Freehand Mode	4.67
2. Ability to Create Geometric Construction with Hand Tools	2.13
3. Ability to Create 2-D Computer Geometry	4.21
4. Ability to Create 3-D Solid Computer Models	4.75
5. Ability to Visualize 3-D Solid Computer Models	4.46
6. Ability to Create 3-D Assemblies of Computer Models	4.29
7. Ability to Analyze 3-D Computer Models	3.71
8. Ability to Generate Engineering Drawings from Computer Models	4.33
9. Ability to Create Section Views	4.13
10. Ability to Create Dimensions	4.38
11. Knowledge of Manufacturing and Rapid Prototyping Methods	3.42
12. Ability to Solve Traditional Descriptive Geometry Problems	2.29
13. Ability to Create Presentation Graphics	3.42
14. Ability to Perform Design Projects	3.96

Note:
Scale of Ranking: 5 = Very Important; 4 = Important; 3 = Somewhat Important; 2 = Not Important; 1 = Not Important at All.

1.2.2 The Need for Teaching and Learning Materials in the Curriculum of Descriptive Geometry Incorporating the Most Current Technology of 3D Parametric Modeling

For the purpose of incorporating parametric 3D modeling technology into engineering drafting and descriptive geometry curriculum, exploration of the technology and development of teaching and learning materials are essential. However, few textbooks have so far been published on using parametric 3D modeling technologies to solve descriptive geometry problems; and none has been found teaching the solution of such problems on a comprehensive and systematic basis. This situation creates a need for the development of teaching and learning materials in the field of solving descriptive geometry related problems using parametric 3D modeling CAD software.

1.2.3 Shortage of Available Textbooks on Solving Descriptive Geometry Problem Using 3D Parametric Modeling Technology

After an investigation of the California State University, University of California, and Los Angeles area library system, as well as current book publishing market, it has been concluded that most of the textbooks written so far on the subject of descriptive geometry teach how to solve related problems using traditional manual drafting methods and/or AutoCAD 2D tools. By including the usage of a variety of 2D and 3D tools of Autodesk AutoCAD and Inventor, the proposed textbook project can make a contribution to updating the subject to the state-of-the-art CAD technology America is currently offering to the world of education; and in addition, the teaching and learning materials on the solution of mechanical engineering related descriptive geometry problems using Autodesk Inventor, a parametric 3D modeling program that is now in increasing use in the field of engineering design, can serve as a template for future development of similar teaching and learning materials using other 3D parametric programs such as SolidEdge, SolidWorks and CATIA. By the same token, engineering professionals well-vested in traditional descriptive geometry problem-solving techniques will have the choice of upgrading their existing knowledge to the currently available 3D parametric modeling technology offered by Autodesk Inventor program. In addition, future graduate students interested in the subject of descriptive geometry can use this graduate project as a template for developing teaching and learning materials on the same subject using other 3D parametric CAD modelers, or additional exercise projects using Autodesk Inventor.

1.3 The Purpose of This Collection of Teaching and Learning Modules

After several years of independent research and studies, this textbook project is hereby proposed to offer teaching and learning materials for engineering students enrolled in engineering drafting or descriptive geometry, as well as sheet-metal design courses.

The textbook project is intended for students of engineering drafting and descriptive geometry, as well as sheet-metal design courses at high school, 2-year community colleges and 4-year universities. The textbook is aimed at studying the capabilities of Autodesk AutoCAD and Inventor programs in the solutions of descriptive geometry problems, and at bringing the subject of descriptive geometry up-to-date with the 3D tools of popular CAD programs.

1.4 Organization and Limitation of the project

1.4.1 Basic Format of the Project

This project will include a thesis part (Chapter 1 through Chapter 5), a textbook part (collection of teaching and learning modules, attached to the thesis as Appendices G and H), and a CD containing relevant instructors' PowerPoint presentations and CAD drawings, as well as students' exercise files. Both thesis part and textbook part will be written in Microsoft Word, and converted to Adobe Acrobat PDF files, and loaded to website for free downloads. The thesis part will be written in standard university thesis format, and the textbook part will be written in convenient teaching material formats.

As the name of the textbook implies, the textbook part of this project will be written in easy-to-understand plain everyday English and accompanied by illustrations, so as to provide average students an opportunity to grasp the essence of the methods of descriptive geometry in a down-to-earth manner. It is a "collection of learning modules" for "dummies." However, advanced students will also have an opportunity to improve their learning of descriptive geometry theory in a more efficient, user-friendly way, and in a learning environment that is more connected to the real-world practice of ever increasing usage of three-dimensional digital virtual space in the solution of engineering design problems.

1.4.2 Organization of the Project

This study basically consists of a thesis (Chapters 1 through 5) and a textbook (Appendices G and H). The thesis part of this project will explore the history of the subject of descriptive geometry and discuss its basic theory. The textbook part consists of two Appendices:

1. Appendix G (Descriptive Geometry with Autodesk AutoCAD, A Collection of Step-by-Step Learning Modules for Engineering Students);

2. Appendix H (Descriptive Geometry with Autodesk Inventor, A Collection of Step-by-Step Learning Modules for Mechanical Engineering Students).

These two appendices will show students how to solve different types of descriptive geometry problems, step-by-step, and give examples on how the techniques can be used in real-world industry practice. The solution to all problems in traditional methods using AutoCAD 2D tools will be explored; and brief discussion of the traditional methods of solving descriptive geometry problems in manual drafting will be made, in Appendix G. In addition, the techniques of solving descriptive geometry problems using Autodesk Inventor will be explored.

1.4.2.1 The Thesis Component

The thesis part of this textbook project will be limited to:

1. A review of the evolution of drafting technologies from traditional manual board drafting, through 2D CAD drafting, to 3D parametric modeling, with an emphasis on its application in industry and engineering education at community colleges in Southern California;

2. An analysis of the capabilities of various CAD programs in terms of solving descriptive geometry-related engineering design problems;

3. A study of the available literature and publications related to descriptive geometry and allied technology, especially sheet-metal design and fabrication.

1.4.2.2 The Textbook Component

The textbook part of this project (Appendices G and H) will be focused on:

1. The study of the methods of solving descriptive geometry problems from the perspective of 2D multi-view orthographic projection using the 2D tools of Autodesk AutoCAD program, in the 2D environment of Autodesk AutoCAD software program;

2. The study of the methods of solving descriptive geometry problems (related to mechanical engineering) from the perspective of 3D modeling using the 2D and 3D tools of Autodesk AutoCAD and Inventor programs, structured as teaching and learning modules, in the 3D environment of both AutoCAD and Inventor software programs.

1.4.3 Limitations of the Project

Due to time constraints, the exploration of the parametric 3D modeling technology in the solution of descriptive geometry problems in this study will be limited to:

1. The field of mechanical engineering;

2. The use of Autodesk Inventor program (in Version 5, with updates for Version 10 Professional). Although there are many 3D parametric modelers currently available in the CAD market, which are generally more capable of solving descriptive geometry-related mechanical engineering design problems (such as SolidEdge, etc), Autodesk Inventor is nevertheless selected for this project due to its reasonable price (under $3,000 for a commercial license and under $200 for an educational license, at the time of this writing); to its fairly strong capabilities in the field, which can offer solutions to most frequently encountered problems; to its continuous improvement that allows it to gradually break into the realm of mid-range 3D CAD modeler; and to its strong market performance (more than 500,000 licenses have been sold all over the world by the time of this writing, according to Autodesk source).

The Inventor-related teaching and learning modules will eventually serve as models for the future development of descriptive geometry learning modules using SolidEdge, SolidWorks and CATIA as well, after the completion of this textbook project.

1.4.4 AutoCAD-Based Textbook Topics and Expected Student Competencies

The textbook part of this study will cover the following topics, which are related to descriptive geometry and its application to engineering drafting:

1. History of evolution of descriptive geometry, its practical application and conventions;

2. Orthographic projection (three principle views, primary, secondary and tertiary auxiliary views);

3. Pictorial views in 2D and 3D (axonometric, oblique, and perspective);

4. Characteristics of geometric elements: point, line, plane and solids;

5. Spatial relations among geometric elements: intersection of planes, piercing point, visibility, bearing, slope and grade, shortest distance, dihedral angle, true-length and true-shape, edge view and point view, perpendicularity and parallelism, plane tangencies;

6. Conics (ellipse, parabola and hyperbola);

7. Vector force analysis and other graphical math drafting techniques;

8. Sheet-metal pattern development (parallel-line, radial-line, transition and triangulation, and intersection);

Most of the above-mentioned topics will be explored with step-by-step instructions using Autodesk AutoCAD and Inventor programs. Comprehensive coverage of most aspects of mechanical engineering-related descriptive geometry projection techniques will be provided in a step-by-step format using the 2D tools and settings of AutoCAD. This will give students an opportunity to study the subject in a systemic way, building a solid theoretical foundation. In addition, as much as possible, 3D tools and settings in AutoCAD will be explored to give students an opportunity to learn a more efficient way to solve descriptive geometry problems in 3D digital space.

1.4.5 Inclusion of Autodesk Inventor 3D Parametric Modeling Technology in the Project

The Autodesk Inventor descriptive geometry teaching and learning modules of this project that teach the skills of solving engineering descriptive geometry problems with the Sheet-Metal 3D modeling environment in Autodesk Inventor, including determination of shortest distances and dihedral angles; creation of 3D folded models and 2D flat patterns for sheet metal parts in the categories of parallel line and radial line, transition pieces (through triangulation using Derived Parts as well as 3D wire-frame models), approximate development of spheres, intersection of sheet-metal parts with different geometric space, creation of polyhedrons, and creation of 2D working drawings for sheet metal patterns. Examples will be provided on the application of descriptive geometry in the real-world scenario with some special learning modules.

The capabilities of Autodesk Inventor program in solving descriptive geometry problems will be explored to give students an opportunity to learn a more efficient way to solve descriptive geometry problems in 3D digital space, in a way that is more integrated with current industry trend toward 3D modeling in engineering presentation, simulation and computation.

1.5 Definition and Abbreviations of Terms

Some basic descriptive geometry and sheet-metal trade, as well as CAD technology-related technical terms and their abbreviations used throughout this textbook project can be defined as follows (Giesecke, 1991, et al):

1. Auxiliary view: An orthographic view that is not projected onto any of the principle plane (frontal, horizontal or profile), but onto an auxiliary view plane that is parallel to an inclined or oblique surface or plane.

2. CAD-based 2D multi-view drafting: Creation of separate orthographic projection view to represent parts or assemblies, using 2D drafting tools of a CAD program, such as AutoCAD.

3. Cartesian Coordinate System: The system of locating any point in the three-dimensional space in terms of its values of measurements along three mutually perpendicular axes (the horizontal x-axis, the vertical y-axis, and the receding z-axis), all measured from a center point called "the origin" having the coordinate values of (0, 0, 0). In the Cartesian Coordinate System, points above, on the right of and moving towards the viewer from the origin are designated as "positive;" while points below, on the left of and moving away from the viewer from the origin are designated as "negative." The Cartesian Coordinate System is the foundation of orthographic projection techniques used in engineering drafting, and of 3D visualization and CAD modeling in modern engineering design.

4. Cone: A solid of revolution with a top point called the vertex and a circular or elliptical base profile created on a plane that is perpendicular to the axis of revolution, and an element line that form any angle except 90° with the axis of revolution; abbreviated as CN.

5. Cylinder: A solid formed by extruding a closed base profile (generally a circle or an ellipse) along a straight line path; abbreviated as CY.

6. Descriptive geometry: The methods of graphical representation of 3D objects and the solution of spatial relationships of points, lines, and planes in 3D space by means of projections onto 2D multi-view drawings (six standard orthographic principal views: front, right side, left side, top, bottom, and rear or back; plus orthographic primary, secondary and tertiary auxiliary views for the determination of the true shape of an inclined or oblique surface); and in addition, three basic solution views: the true length of a line, abbreviated as TL; the point view of a line; abbreviated as PV; and the true shape of a surface, abbreviated as TS.

7. Dihedral angle: The angle formed by two flat surfaces or the intersection of two planes in the three-dimensional space.

8. Double-curved surface: A surface formed by the revolution (curved once) of a curved profile (curved twice) around a central axis, such as the surfaces of sphere, ellipsoid, vase or flower pot, etc.

9. Edge view: A view where a surface or plane appears and is drawn as an edge (a line); abbreviated as EV.

10. Element: A straight line used to form surface (flat, single-curved, double-curved, and warped); abbreviated as EL.

11. Flat pattern: The surface of a three-dimensional solid (such as a cone and a cylinder) or, to be more specific with regard to sheet-metal trade, the surface of the sheet-metal part wrapping the space of a three-dimensional solid, laid flat on a two-dimensional plane. Also called "development."

12. Frontal plane: The plane where the front view of an object is projected onto, in orthographic multi-view drawings (abbreviated as F or FP).

13. Generatrix: A straight line used in the formation of a surface or a plane; abbreviated as GX.

14. Hem: A type of seams used to eliminate the raw edge and to stiffen the sheet-metal material, usually made by bending the edge.

15. Horizontal plane: The plane where the top view or bottom of an object is projected onto, in orthographic multi-view drawings (abbreviated as H or HP).

16. Inclined line: Also called "angled line;" a straight line that lie on any of the principle planes (horizontal, frontal or profile) or any plane that is parallel to any of these principle planes, but is not parallel to any of the three axis (x, y and z) of the Cartesian Coordinate System.

17. Inclined surface: A surface that does not lie on any of the principle planes (horizontal, frontal or profile) or any plane that is parallel to any of these principle planes, but is perpendicular to one of the three principle planes and form angles other than 90° with two other principle planes.

18. Inclined plane: Any plane, which is not parallel to any of the three principle planes, but is perpendicular to one of them, and form any angles except 90° with two others.

19. Intersection: The edge where two surfaces or planes meet; commonly abbreviated as IN.

20. Isometric view: The visual representation of a three-dimensional object in a single view that looks "three-dimensional." In isometric views, the angles between the projection of the x-axis, y-axis, and z-axis are all the same, or 120° apart, and any lines parallel to any of these three axes are drawn at true length. Isometric projection is used for representing engineering design to clients in presentation drawings.

21. Line: A straight one-dimensional geometric entity established by two points, having no thickness but the potential of extending infinitely in both directions. A line is sometimes called a straight line or a right line. The dimension or size for a line is its length.

22. Line of sight: The imaginary line that is parallel to the direction of the sight of the viewer, abbreviated as LOS.

23. Loft: A solid feature created by blending the shapes (sketch profiles) of two or more sections on different work planes or planar faces. In sheet-metal design, the three-dimensional space enclosed by the transition piece between a circular tube and a rectangular tube is a typical example of a lofted solid.

24. Normal: The condition where a view, a surface or a plane is perpendicular to the line of sight; abbreviated as NL.

25. Oblique line: Any line that does not lie on any of the principle planes (horizontal, frontal or profile) or on any plane that is parallel to any of these principle planes.

26. Oblique plane: Any plane that is not parallel to any of the principle planes (horizontal, frontal or profile).

27. Orthographic projection: The representation of a three-dimensional object in two-dimensional views, using multiple views of the object (in most cases, the top, front and right-side views in the United States), from points of view rotated about the object's center through increments of 90°. Orthographic multi-view projection is used in working drawings intended for machinists to fabricate the parts and for construction team to build the project. Abbreviated as OP.

28. Parallel-line development: The development of the lateral surface of a solid formed by parallel line elements, namely, cylinders and prisms.

29. Parametric 3D modeling: The latest 3D CAD modeling technology using the editing of dimensional parameters of the sketch profiles and solid features as a convenient way to change and improve design.

30. Plane: A geometric entity having two dimensions, generated by a line called the "generatrix" of the surface, or two intersecting lines, or a line and a point. For practical purposes in descriptive geometry, a plane can be considered as a flat surface extending into infinity in all directions but generally intersected by other planes or surfaces of a three-dimensional solid object. Abbreviated as PLN in some textbooks.

31. Point: A zero-dimensional geometric entity, which can be specified in the three-dimensional space using the Cartesian coordinates. Point is a strictly theoretical concept and has no dimension (or size). Abbreviated as PT.

32. Point view: A view where a line is parallel to the line of sight; appears and is drawn as a point, also called "end view;" and is abbreviated as PV.

33. Polyhedron: A solid bounded by multiple plane or flat surfaces.

34. Profile plane: The plane where the left or right side view is projected onto, in orthographic multi-view drawings; abbreviated as P or PP.

35. Projection: The method of representing points, lines, and surfaces in the 3D object on a 2D drawing view by extending these geometric entities to the view along imaginary straight line path that are parallel to the line of sight; abbreviated as PR.

36. Radial-line development: The development of the lateral surface of a solid formed by radial line elements radiating from a common point called the "vertex," namely, right circular cones and pyramids.

37. Seam: Extra material added at the edge of a sheet-metal part on one side or both sides, or as separate pieces, for the purpose of connecting both sides

of sheet-metal parts, by riveting, welding, soldering and other methods, so as to fix the flat sheet-metal cutout piece into a finished folded part.

38. Single-curved surface: A surface formed by the revolution (curved once) of a strait line element or profile around a central axis, such as the lateral surfaces of cylinder and cone.

39. Skew lines: two or more lines that appear to be parallel in one view but are actually not parallel because they do not lie on the same plane.

40. Sheet-metal: The industrial arts of creating folded up tubes, connectors, enclosures, fasteners and other devices with flat sheets of metal materials (Aluminum, steel, etc), for HVAC (heating, ventilating, and air-conditioning), industrial products enclosures or packaging (computer cases, etc.), and bodies of transportation vehicles (bus and airplanes, etc.).

41. Solid of extrusion: A solid created by extending a two-dimensional shape (sketch profile) into the third dimension. A prism is an example of solid of extrusion.

42. Solid of revolution: A solid created by revolving a plane figure (a sketch profile) about an axis (called “the axis of revolution”) located in the plane of the figure, such as a sphere, etc.

43. Surface: A geometric entity having two dimensions, generated by a line called the “generatrix” of the surface, or two intersecting lines, or a line and a point. Surfaces can be either flat, single-curved (such as the lateral surface of a cone or a cylinder, double-curved (such as the surface of a sphere), or warped (surface of a sports car’s body). Abbreviated as SF. The dimension or size for a surface is its area.

44. Traditional board drafting: The methods of representing architectural, engineering or product design with mechanical instruments (pencils, erasers, drawing boards, etc), on paper sheets or translucent vellums, in manually created drawings.

45. Triangulation development: The method of dividing a surface into a number of triangles and of transferring them to the development. Triangulation is used to develop surfaces of three-dimensional solids that are not in the categories of parallel-line or radial-line developments; and its application includes the development of the conical parts of circular tube-to rectangular tube transition piece, of the surface of elliptical cone, oblique cone, etc.

46. True length: The true size of a line drawn on a view that is perpendicular to the line of sight, abbreviated as TL.

47. True shape: The true size of a surface drawn on a view that is perpendicular to the line of sight, abbreviated as TS.

48. Wireframe 3D modeling: Three-dimensional CAD (computed-aided drafting) technology using networks of wire-frame or connecting lines created in three-dimensional digital space, with surfaces attached to the line-works.

The above definitions of terms are based on information provided throughout related publications as listed in the Reference section of this thesis, from the Internet, as well as from personal experience practicing and teaching engineering drafting.

CHAPTER 2
REVIEW OF THE LITERATURE

The theory and practice of descriptive geometry, as established by Gaspard Monge, have evolved over the past more than two centuries; and many books and articles have been published in the field. This textbook project is a natural and logical extension to the contributions and achievements of numerous others in the field.

The objectives of this Chapter are to present an overview of

1. The methods of descriptive geometry;

2. The evolution of the tools in applying the methods of descriptive geometry for the solution of engineering design problems, and

3. The currently available textbooks on the subject, particularly those collected by the libraries of California State University System, used at community colleges in Southern California, or available in publishing market.

2.1 Historical Overview: The Methods of Descriptive Geometry

2.1.1 The Origin of the Science of Descriptive Geometry

Modern descriptive geometry is an integration of mathematics (plane geometry), engineering drafting (orthographic projection) as legacies of industrial and technical civilization, and high-speed digital computation (CAD or computer-aided drafting software programs) as a revolutionary invention of the electronic age since the introduction of computers after World War II.

According to the 4th Edition of Engineering Graphics by Frederick E. Giesecke et al (New York: Macmillan Publishing Company, 1987, ISBN 0-02-342760-4, p. 587), descriptive geometry can be defined as "The science of graphical representation and the solution of spatial relationships of points, lines, and planes by means of projections." In plain English, descriptive geometry is dealing with the relationships among points, lines, and planes in a 3D space; and it uses the techniques of "projection" to represent 3D objects and solve related problems of geometric calculations on a 2D drawing, using a "graphical" or pictorial method.

Although Gaspard Monge is generally recognized as the father of descriptive geometry for his writings on the subject, the origin of descriptive geometry, in a broader sense, can be traced back to the ancient time of Roman Empire; Marcus

Vitruvius, an appointed superintendent of military design for the Roman army at the time of Augustus, once wrote a book on architecture, where he explored the concepts of horizontal and vertical planes of construction of public buildings, which is the first record of the concepts of orthographic projection.

In 1525, a German artist and scientist named Albrecht Dürer publish in Nuremberg a book titled Geometry and Perspective, in which he explored the mathematic principles of descriptive geometry and three-view drafting techniques.

Gaspard Monge, a French scientist, discovered the graphical or geometrical solutions to the creation of elevation and plan drawings, while designing the fortifications used by French Army; and his methods were kept secret by the French Army until he lectured at the École Polytechnique in 1795; and his book on descriptive geometry was published in 1801. Since then, the science of descriptive geometry has gradually become the foundation of orthographic projection views used in engineering design and has been adopted as an important topic in engineering drafting courses. Details on the successful career of Gaspard Monge and the origin of descriptive geometry can be found in Appendix A (The Career of Gaspard Monge and The Origin of Descriptive Geometry).

2.1.2 The Inclusion of Descriptive Geometry in Engineering Curriculum

In 1816, Claude Crozet introduced descriptive geometry into the curriculum of the United States Military Academy at West Point. In 1821 Crozet published his *Treatise on Descriptive Geometry*, the first important English work on descriptive geometry published in this country (Giesecke, Frederick E. et al. 1987, p. 587). Since then, engineering colleges started to teach descriptive geometry either as a separate course or as part of regular engineering drafting course.

2.1.3 The Evolution of the Technology Used In the Solution of Descriptive Geometry Problems

The technology used in the solution of descriptive geometry-related engineering design problems has evolved from traditional board drafting to 2D CAD drafting and 3D CAD modeling, as explained below:

1. Traditional board drafting technology: traditionally, solutions to descriptive geometry problems, like regular engineering design representations, are achieved by manual drafting using pencils, ink-pens, templates, French curves, flexible curves, eraser, eraser shield, ruler, scales, drafting boards, protractor, compass, and other mechanical drafting instruments, as well as blue-print maker, etc; and it was a rather time-consuming endeavor.

2. 2D CAD drafting and 3D CAD modeling technology: Since the birth of AutoCAD and other CAD programs, solutions to these problems can be achieved through 2D CAD drafting and/or 3D CAD modeling. Most of community colleges in Southern California nowadays use 2D tools of AutoCAD to teach descriptive geometry projection theory. Some schools, such as Pasadena City College, one of the best community colleges in Southern California and perhaps in the nation also incorporate 3D CAD programs, such as SolidEdge, in the teaching of descriptive geometry course. However, the textbooks dealing with the topics of descriptive geometry currently available cover traditional board drafting and AutoCAD 2D tools only. This textbook is intended to upgrade the science of descriptive geometry to the most current 3D capabilities of popular CAD programs. Details on the evolution of these techniques will be explored in Chapter 3.

2.2 Textbooks and Internet Resources on Descriptive Geometry and Related Subjects: An Evaluative Overview

Many textbooks have been published on the subject of descriptive geometry and sheet-metal design and fabrication, one of its most related fields of application. Most of these books are based on traditional manual drafting technology. They can be found through university and local public library systems, as well as local or online bookstores. For a list of descriptive geometry-related text books found in the John F. Kennedy Library at California State University Los Angeles, as well as in other libraries within the California State University system, refer to Appendix B.

2.2.1 Textbooks on Engineering Descriptive Geometry Theory and Practices

Textbooks under this category include the following types:

2.2.1.1 Original Textbooks Written in French by Gaspard Monge, the Inventor of Descriptive Geometry Methods, and Found in the CSU Library System

1. *Géometry descriptive (Descriptive Geometry)*: published in 1820 by Ve Courcier in Paris.

2. *Géometry descriptive leçons données aux écoles normales, l'an 3 de la république (Descriptive Geometry Lessons Delivered to Teacher's Schools in the 3rd Year of The Republic)*: published in 1798 by Baudouin in Paris.

The above-listed books are collections of Gaspard Monge's lecture notes on the subject of descriptive geometry compiled during his professorship at various institutions of higher learning in France.

2.2.1.2 Textbooks on Descriptive Geometry with Traditional Manual Drafting Methods

1. *Descriptive geometry, 9th Ed* (ISBN No. 0-02-391341-X) and associated *Worksheet* workbooks (ISBN No. 0-02-391342-8, and ISBN No. 0-02-391344-4): written by E. G. Paré, R. O. Loving, and I. L. Hill (1997), and published by Prentice Hall (New Jersey), this textbook is totally dedicated to the subject of descriptive geometry; and it is one of the most popular teaching traditional board drafting skills for descriptive geometry courses. In Southern California, it has been used at Santa Ana College, Glendale Community College and others.

2. *Applied Descriptive Geometry, 2nd Edition*: written by Kathryn Holliday-Darr, published by Delmar Publishers (1998) and used at Pasadena City College and Santa Ana College. This textbook is written in an easy-to-read, step-by-step, student-friendly manner (ISBN No. 0-8273-7912-5).

3. *Geometry For Engineers*: written by James H. Earle, published by Addison-Wesley Publishing Company (1984), and used at Los Angeles Valley College. This textbook provides a comprehensive coverage of most of descriptive geometry course content (ISBN No. 0-201-11315-5).

4. *Technical Graphics Communication, 3rd Edition*: written by Gary R. Bertoline and Eric N. Wiebe, and published by McGraw-Hill (2003), this book is one of the most popular engineering drafting textbooks that include a substantial coverage of descriptive geometry topics. It is currently used at Pasadena City College and California State University Los Angeles; it teaches traditional board drafting techniques.

5. *Engineering Graphics* written by Frederick E. Giesecke, Alva Mitchell, Henry Cecil Spencer, Ivan Leroy Hill, Robert Olin Loving and John Thomas Dygdon, and published by Macmillan Publishing Company (1987). It teaches traditional board drafting techniques (ISBN No. 0-07-365598-8).

2.2.1.3 Textbooks on Descriptive Geometry with AutoCAD 2D Drafting Methods

1. *Descriptive Geometry, An Integrated Approach Using AutoCAD*: written by Kevin and Deborah Standiford and published in 2001 by Delmar Thomson Learning. This book covers some basic topics in descriptive geometry and includes a short lesson on solving concurrent coplanar and

coplanar vector problems using AutoLISP and DCL programming languages (ISBN No. 0-7668-1123-9).

2. *Engineering Graphics with AutoCAD 2006*: written by James D. Bethune, published by Prentice Hall (2005) and used at Santa Ana College, California (ISBN No. 0-13-171391-6).

Both of these two books provide only a partial coverage of descriptive geometry topics, mainly spatial relationships among points, lines and planes, shortest distance, dihedral angles, as well as parallel-line and radial-line development of solids, and intersection of solids.

2.2.1.4 Internet Resources on Descriptive Geometry

In addition to hard-copy publications, the Internet provides a great resource of information for the science of engineering descriptive geometry. A Google search with “descriptive geometry” as search item on Saturday, February 25th, 2006 yielded 1,020,000 entries. Two outstanding entries are worth mentioning:

1. The website of Vikipedia The Free Encyclopedia (http://en.wikipedia.org/wiki/Descriptive_geometry); this website provide a comprehensive overview of all topics of descriptive geometry, including orthographic projection and orthogonal projection, axonometric projection (isometric, dimetric, and trimetric), oblique projection, and perspective projection.

2. The website of MathWorld Wolfram (http://mathworld.wolfram.com/ProjectiveGeometry.html), which provides a wealth of information on descriptive geometry from the perspective of mathematics, including definitions of terms (lines, points, and planes, etc). This website also contains a wealth of information on all topics of mathematics, and is a great resource for engineering students.

2.2.2 Textbooks and Internet Resources on Sheet-Metal Flat Pattern Layout, Fabrication and Trade Practices

Sheet-metal flat pattern layout is one of the major topics of the traditional engineering descriptive geometry curriculum; it is generally classified as “intersection and development,” which constitute about 50% or more of all topics of the entire descriptive geometry curriculum. The topics of descriptive geometry in generic engineering drafting textbooks usually deals with flat pattern development in a “theoretical” way; in other words, it teaches how to draw the 2D flat patterns using the orthographic projection theory and practices, without going into the details of sheet-metal layout and fabrication, such as the issues of bend allowance, corner relieves, seams, etc. Many textbooks and trade manuals on sheet-metal layout and fabrication have been published; and they provide additional information on descriptive geometry in a more practical and real-world-oriented manner.

2.2.2.1 Textbooks on Sheet-Metal Trade

Many books have been published on sheet-metal fabrication technology. At John F. Kennedy Memorial Library at California State University, Los Angeles alone, about 40 books dealing with technical aspects of sheet-metal trade, including fabrication techniques and cost estimation and other topics, have been found through on-line search in the Library's book collection database. Most of these books have been published before 1990's. These books usually provide substantial to comprehensive coverage of traditional board drafting of sheet-metal patterns as well as technical data (such as stretches, shrinkages, or bend allowances) related to sheet-metal fabrications. They also provide valuable information on the history and practice of sheet-metal trade, including valuable technical data tables. A list of these books is attached in Appendix D. Among these books, the following are worth mentioning and evaluating:

1. *Sheet Metal Technology*: written by Richard S. Budzik, and published by Howard W. Sams & Co., Inc (Indianapolis, Kansas City, New York), in 1971. The author of this book is an instructor of sheet metal technology at Prosser Vocational High School, Chicago, Illinois, and a practitioner of the trade. The book gives a comprehensive coverage of topics related to sheet metal trade, including job opportunities, workshop safety, materials, hand tools and equipment, measuring, snipping, pattern notching or cutting, punching and drilling holes, bending brake, seam-making, riveting, soldering, metal finishing, assembling, application of sheet metal projects in HVAC (heating, ventilating and air-conditioning) industry, precision sheet metal mass production, sheet metal blue print reading, etc. The book also includes 16 basic sheet metal projects for students. The book is 319 pages thick and is well illustrated (CSULA JFKL Call Number: TS250B875. Library of Congress Catalog Card Number: 74-97565).

2. *Sheet Metal Shop Practice, 3rd Edition*: written by Leroy F. Bruce and Leo A. Meyer, and published by American Technical Society (Chicago), in 1965. The authors of this book are both instructors of sheet metal technology (Leroy F. Bruce at Vocational School of Rochester in New York; and Leo A. Meyer at Bakersfield College in California). This book gives a fairly comprehensive account on how sheet metal parts were designed and fabricated before the 1960's, including manual drafting layout for sheet metal patterns using simple tools and shortcut methods. The book is 296 pages thick and is well illustrated (CSULA JFKL Call Number: TS250B86.1965. Library of Congress Catalog Card Number: 65-12621).

3. *Sheet Metal Work An Introduction to the Craft in Keeping with Modern Trade Practice*: written by Stewart G. Wissell, published by Rigby Limited Adelaide (Sidney, Melbourne, Brisbane, Perth, Australia), in 1965. This book gives a detailed account on different types of sheet metal materials and their usage in industry. The book is 207 pages thick and is well illustrated (CSULA JFKL Call Number: TS250W58. Library of Congress Catalog Card Number: 65-23893).

4. *Sheet Metal Work Part 2*: written by R. G. Blackburn and J. Cassidy (both Lecturer of the Mechanical Engineering Department at Mathew Boulton Technical College, Birmingham, Great Britain), and published by Edward Arnold (Publishers) Limited (London, Great Britain), in 1958. This book devotes a large portion to sheet-metal related mathematic calculations, such as volume of solids and surface areas of sheet metal parts. The book is 219 pages thick and is well illustrated (CSULA JFKL Call Number: TS250B55 pt.2).

5. *Air Conditioning Metal Layout*: written by Joseph J. Kaberlein (Instructor of Sheet metal Apprentices at Washburne Trade School, Chicago, Illunois), and published by The Bruce Publishing Company, Milwaukee, in 1954. This book provides a comprehensive coverage of sheet-metal parts' layout for HVAC (Heat, Ventilating and Air Conditioning) industry. The book is 207 pages thick and is well illustrated (CSULA JFKL Call Number: TS250K3.1954).

6. *Triangulation Short-Cut Layouts*: written also by Joseph J. Kaberlein and published by The Bruce Publishing Company, Milwaukee, in 1948. This book provides a comprehensive coverage of sheet-metal transition pieces' layout by triangulation. The book is 290 pages thick and is well illustrated (CSULA JFKL Call Number: TS250K333).

7. *Sheet Metal Pattern Layouts*, written by Edwin P. Anderson, and published by Theodore Audel & Co., A Division of Howard W. Sams & Co., Inc., New York, in 1948. This book con be considered as an "encyclopedia of sheet metal layouts" and it provides a comprehensive coverage of sheet-metal parts' layout problems, for HVAC (Heat, Ventilating and Air Conditioning) industry, as well as for architectural and boat construction applications (sheet metal boat patterns, roofing, skylight, louvers. The book is 1102 pages thick and is well illustrated (CSULA JFKL Call Number: TS250A56.1965. Cat. No. AUD-29).

2.2.2.2 Internet Resources on Sheet-Metal Trade

In addition to hard-copy publications, the Internet provides a great resource of information for sheet-metal design and fabrication. A Google search with "sheet-metal design and fabrication" as search item on Saturday, February 25th, 2006 yielded 1,020,000 entries. Two outstanding entries are worth mentioning:

1. The website of SolidWorks Express (http://www.solidworks.com/swexpress/pages/nov05/TT_Sheetmetal_Tips.html); this is a technical service website maintained by SolidWorks CAD developer; and it provides a wealth of information on general sheet-metal design and fabrication practices.

2. The website of AboutConstruction (http://www.aboutconstruction.org/Sheet-Metals.php?keyword=sheet-metal-design&engine=google&contextual=no), which provides some basic information on sheet-metal fabrication process, such as rolling, stretching, bending, drawing and flanging.

2.2.3 Literature on Platonic and Archimedean Solids and Other Polyhedrons

The geometry of Platonic, Archimedean solids and other polyhedrons, as well as sheet metal parts wrapping these solids' 3D space is a natural extension to the subject of engineering descriptive geometry. Information on Platonic, Archimedean solids and other polyhedrons are widely available from library and Internet resources.

2.2.3.1 Textbook on Platonic and Archimedean Solids and Other Polyhedrons

There are a lot of books which give a comprehensive overview of Platonic and Archimedean solids, and other polyhedrons, with their 3D view, 2D pattern as well as relevant geometric data, such as dihedral angles, central angles, circum-radius edge length, mid-radius, and in-radius, and formulas for calculation. They include:

1. *Platonic and Archimedean Solids*: written by Daud Sutton, and published by Walker & Company (New York). This book is 58 pages thick and is well illustrated (ISBN No. 0-8027-1386-6).

2. *Polyhedra A Visual Approach*: written by Anthony Pugh, and published in 1976 by University of California Press (Berkeley, Los Angeles, London). This book is 118 pages thick and is well illustrated (CSULA JFKL Call Number: QA491P83. ISBN No. 0-520-02926-7).

3. *Polyhedra Primer*: written by Peter and Susan Pearce, and published in 1978 by Van Nostrand Reinhold Company (New York, Cincinnati,

Toronto, London, Melburne). Thisook is 134 pages thick and is well illustrated (CSULA JFKL Call Number: QA491P4. ISBN No. 0-442-26496-8).

4. *Descartes on Polyhedra, A Study of the De Solidorum Elementis*: written by P. J. Federico, and published in 1982 by Springer-Verlag (New York, Heidelberg, and Berlin). This book is 145 pages thick and is well illustrated (CSULA JFKL Call Number: QA491D473F43.1982. ISBN No. 0-387-90760-2).

5. *Polyhedron Models*: written by Magnus J. Wenninger, and published in 1971 by Cambridge University Press (London). This book is 208 pages thick and is well illustrated (CSULA JFKL Call Number: QA491W39. ISBN No. 521-06917-3).

2.2.3.2 Internet Resources on Platonic and Archimedean Solids and Other Polyhedrons

In addition, the Internet provides a great resource for polyhedral geometry. A Google search with "polyhedron" as search item on Thursday, November 3rd, 2005 yielded 1,380,000 entries. Two outstanding entries are worth mentioning:

1. The website of MathWorld (http://mathworld.wolfram.com/Polyhedron.html. This website is a virtual on-line math classroom for people to learn all topics of mathematics; and in the Polyhedron section, it gives a comprehensive presentation of different types of polyhedrons, including tetrahedron (4-faced), pentahedron (5-faced), hexahedron (6-faced), heptahedron (7-faced), octahedron (8-faced), nonahedron (9-faced), decahedron (10-faced), undecahedron (11-faced), dodecahedron (12-faced), tetradecahedron (14-faced), icosahedron (20-faced), icositetrahedron (24-faced), triacontahedron (30-faced), icosidodecahedron (32-faced), hexecontahedron (60-faced), enneacontahedron (90-faced). Related technical information, including dihedral angles, formula for surface areas, orthographic and isometric views, polyhedron vertices, circumradius, midradius, and inradius, are given as well.

2. The website of Wikipedia, The Free Encyclopedia (http://en.wikipedia.org/wiki/Polyhedron). This website also provides valuable information on polyhedral geometry. This is a multilingual on-line encyclopedia published in English, French, Chinese, Russian, Japanese, Italian, Korean, Spanish, Dutch, Portuguese, Romanian, Polish, and Swedish.

2.3 Conclusion

In conclusion, in terms of textbooks dealing with the subject of descriptive geometry, which are currently available in the publishing market, the implementation of CAD technology is generally restricted to AutoCAD 2D drafting tools and settings. Since 3D parametric modeling technology represent the future for computer-assisted engineering design drafting, there is a need to update the traditional subject of descriptive geometry to the currently available 3D parametric modeling technology; and such update shall help students of engineering succeed in their future career, in terms of more efficient way of design visualization and presentation. Therefore, this textbook project will definitely contribute to the general upgrade of the subject of descriptive geometry to the most current CAD technology.

CHAPTER 3
CAD TECHNOLOGY & APPLICATIONS IN ENGINEERING DRAFTING PRACTICES AND DESCRIPTIVE GEOMETRY PROBLEM SOLUTIONS

The objective of this Chapter is to present an analytical comparison of features of popular CAD in terms of their application in the solutions of problems related to engineering descriptive geometry, including those related to the practical design problems in the sheet-metal trades. The selection of CAD programs used in this study was based on the analysis of the evolution of CAD technology, their capabilities in solving mechanical engineering-related descriptive geometry problems, their applications in industry and in educational curriculum, as it shall be presented in this chapter and in Chapter 4.

3.1 Two Major Categories of CAD/CAM Programs (Design-Centric and Process-Centric), and Their Application in Descriptive Geometry Problem Solution

Computer-Aided Design (CAD) programs are now widely used in industry and taught at high schools, two-year community colleges and four-year universities all over the world. They can be used to digitally design and simulate mechanical, civil engineering and architectural design projects before physical working prototypes are built; and when such projects are represented as 3D solid models, they can be digitally analyzed in terms of surface areas, volumes, distances between two points in a 3D space, angles between two planes or faces, and length of an open or closed contour lines. This provides an opportunity to solve descriptive geometry problem at a few click of the mouse once a 3D solid model has been created.

According to lectures delivered by Dr. Virgil A. Seaman (Technology 502-Modern industry, Summer 2004, California State University Los Angeles), there are two major categories of CAD programs, i.e., the “design-centric” and the “process-centric.”

3.1.1 The “Design-Centric” CAD Programs: Solutions for Engineering Design

The “design-centric” CAD programs have tools and features related to 2D and 3D design and drafting; and to various extent, they have the capability of solving descriptive geometry-related problems in 3D environment. They are usually low-end or mid-range packages. Examples include: AutoCAD, Mechanical Desktop, Inventor, SolidWorks, and SolidEdge for mechanical engineering design, Architectural Desktop and Revit for Architectural Design; AutoDesk MAP 3D for Geographic Information System (GIS); Land Desktop and Civil Design Suit for civil engineering. Among these programs, AutoCAD, and SolidWorks are the most used in mechanical design, while Architectural Desktop is powerful and getting popular now in the field of architecture. Prices for these design-centric software range from $2,000 to $6,000 approximately. They are used by small to medium-sized companies, and by individual engineers and designers. AutoCAD MAP 3D, Architectural Desktop and Revit can solve related descriptive geometry problems in 3D environment, including the mathematical calculations of cut and fill volumes in civil engineering design. Architectural Desktop is a great 3D modeler for building design; Revit is a parametric 3D modeler for architectural design. Both can be used to model 3D terrain as well.

3.1.2 The "Process-Centric" CAD Programs: "Total Solutions" for Engineering Design, Testing/Simulation, Manufacturing and Management

The "process-centric" CAD programs are usually high-end programs that include all features of design-centric software with more powerful options plus specialty tools for particular industries, and features for production process planning, simulation and verification, cost estimation, management and other "processes," which might include, or be integrated with such macro-management features or programs as computer-aided process planning (CAPP) systems used in the calculation of equipment depreciation costs, operating costs and personnel costs and then overall manufacturing cost. Examples include ProEngineer and ProSheetmetal, CATIA, I-Deas and Unigraphics. These programs can perform the entire modern manufacturing process. Due to high purchasing and maintenance cost (from $10,000 and up per license purchase, $1,000 and up for maintenance per license per year), process-centric programs and associated hardware are usually used in large and financially resourceful corporations and institutions, especially aerospace and automobile manufacturers, such as Boeing, Lockheed Martin, NASA and the United States Department of Defense.

3.2 The Evolution of Computer -Assisted Drafting (CAD) Technology and its Impact on Engineering Drafting Practice

The standards for CAD are evolving from traditional standard based on AutoCAD to new standards based on parametric 3D modeling. This evolution offers great potential for the improvement of engineering drafting and descriptive geometry curriculum as well as engineering design practice in industry.

3.2.1 The Evolution of CAD Standards and its Impact on the Science of Descriptive Geometry in Engineering Design Applications

CAD technology has experienced significant changes in the last three decades, mainly, from 2D drafting, through wireframe and solid 3D modeling, to parametric 3D modeling, as shall be explained below:

1. 2D drafting technology: Before the 1970s, graphical CAD systems were 2-D drafting systems, or semi-automatic digital drawing boards offering more precision and faster speed in drafting, which required users to draw the basic 2D geometry, but allowed them to save time through the use of automated techniques for generating drafting symbols, for copying other recurring combinations of geometric elements, and for generating assembly drawings from previously created part drawings. In the beginning of CAD programs as pioneered by Autodesk AutoCAD, CAD programs were based on 2D drawing geometry, and products were represented with separate 2D orthographic (top, front, right, auxiliary) and isometric views. With the birth of 2D CAD programs such as AutoCAD, descriptive geometry problems can be solved in a more precise manner since CAD drafting increases precision in 2D drawings; and it increases efficiency in drafting by decreasing the time it takes to complete a drawing, as compared to traditional manual drafting. However, 3D objects are still represented in 2D projection alone, and it still takes a lot of time solving a descriptive geometry problem since several view are usually needed to solve a problems, as will be explained in Chapter Four.

2. 3D wireframe and solid modeling technology: 3D wireframe models were introduced in the early 1970s and are based on meshes or edges of the models placed in a 3D space and covered with 3D surfaces; and the 3D surface models so created usually have no volume or mass. The wire-frame surfaces so created can be either based on regular geometric shapes such as cones, cubes, prisms, spheres, ellipsoids; or irregular, complex or "warped" shapes called NURBS (non-uniform rational B-splines), which are pioneered in the 1960s mainly by the aircraft industry. "One immediate advantage of the wire-frame representation is that the computer can automatically generate drawings of the object from any point of view, using any projection chosen by the viewer" (US Government, 2000). Technology to create solid model with both surfaces and physical data such as volume, mass and moments of inertia of the object was later added. However, both wire-frame and solid models so created are all based on 2D geometry and once created, editing is a difficult and time-consuming task because the 2D geometry is usually "consumed" by or converted into the 3D models; and the software programs do not store the original 2D geometry data used to generate the 3D geometry. Therefore, any attempt for editing has to be made on the finished existing 3D models.

Most major CAD systems today have both surface and solid modeling capability, and both techniques are well integrated; in other words, a 3D model can contain both solid and surface features.

3. Parametric 3D solid modeling technology with sheet-metal design capabilities: With the introduction of parametric 3D CAD programs since 1990s, especially Inventor, SolidEdge, SolidWorks, CATIA and others with strong sheet-metal development capabilities, virtually all descriptive geometry-related problems can be solved at a few clicks of the mouse once the 3D models are completed, with no need for drawing 2D projected view. Unlike "regular" 3D CAD program such as AutoCAD, parametric CAD programs record the history of the creation of both the 2D profile sketches and the 3D features that make up the 3D part; this allow the designers to always return to either the original 2D sketches or the 3D features, so as to implement changes to the 3D parts by simply changing the dimension parameters. This makes editing the 3D models easier, more efficient and more interactive. One of the major components of this project is to explore the 3D capabilities of Autodesk Inventor parametric CAD program in the solution of descriptive geometry problems.

3.2.2 Significant Impact of the 3D Modeling Technology on Engineering Drafting and Design

With the birth of 3D modeler such as AutoCAD, tedious and time-consuming procedures of 3D CAD modeling programs (such as AutoCAD), and especially of parametric 3D CAD modeling programs (such as Autodesk Inventor, SolidEdge, etc), engineering drafting and design have experienced a revolutionary breakthrough. It is no longer necessary to spend tremendous amount of time to draft orthographic projection multi-views with 2D tools; instead, engineers and designers can just make a quick rough sketch to record their design ideas; then, use the 3D tools to create the 3D models of the components or assemblies; and finally, use the multi-view creation tools and dimension/notation tools in the 2D working drawing environment to automatically generate the orthographic as well as isometric views and to add dimensions and notations. With the parametric 3D CAD modelers, any changes made to the 3D parts or assemblies will automatically update in the pre-existing 2D working drawings. All of these substantially increase the speed of engineering design and product development. For further details on current CAD technology, please refer to Appendix C (The Application of CAD/CAM & Simulation/Analysis Programs in Industry & Educational Institutions).

3.3 Capabilities of Major CAD Programs For Solving Descriptive Geometry Problems

The strength of various CAD programs and their application in the solution of descriptive geometry problems will be explained as follows.

3.3.1 Low-End to Mid-Range CAD Programs: the Autodesk Family (AutoCAD, Mechanical Desktop, Inventor, 3D StudioMAX and 3D VIZ

Autodesk, the owner of AutoCAD, Mechanical Desktop, Architectural Desktop, Revit, and Inventor, was funded and started to ship AutoCAD® software in 1982 and went public in 1985. Autodesk family products are the most used in industry, with the largest clientele in the world CAD market (over five million customers, including two million manufacturing customers, and 300,000 Mechanical Desktop licenses, plus over 500,000 Inventor licenses sold worldwide). Autodesk family of diverse software offers solutions for professionals in building design, geographic information systems, mechanical engineering, consumer product design and presentation, manufacturing, digital media, and wireless data services; and they provide tools for solution of descriptive geometry problems, as illustrated in Table 2 below. Although they do not offer the most high-end tools, their tool sets are nevertheless more than adequate for most of engineering design situations for small to medium-sized companies, as well as design firms. Autodesk's pricing policy is reasonable and affordable (usually around or under $3,000 for any field of engineering design). It is also supported by the greatest amount of educational materials (textbooks, coursewares, etc.) in the field of CAD.

3.3.1.1 The Autodesk Family CAD Products

The Table 2 below explains Autodesk family programs that include 2D drafting and 3D modeling tools for the solutions of descriptive geometry problems:

Table 2. Autodesk Family Programs and Descriptive Geometry

Name, Application & Pricing	Descriptive Geometry Problem Solution Capabilities
Mechanical Desktop: This is a parametric CAD program based on AutoCAD's 2D interface. Price: around $2,000-$3,000 for commercial license; $150 for educational license.	• The incorporated AutoCAD 2D tools can be used to solve all descriptive geometry problems; • The 3D tools can be used to solve all mechanical design-related descriptive geometry problems, except sheet-metal pattern development problems and some others.

Table 2 (Continued).

Name, Application & Pricing	Descriptive Geometry Problem Solution Capabilities
AutoCAD: AutoCAD program has strong 2D drafting capabilities but limited 3D modeling ability. AutoCAD is the most suitable CAD program for teaching and learning traditional orthographic projection as well as isometric and oblique drafting techniques. Price: around $2,000-$3,000 for commercial license; $150 for educational license.	• The 2D tools can be used to solve all descriptive geometry problems; • The 3D tools can be used to solve most of descriptive geometry problems, except sheet-metal pattern development problems and some others (some third party plug-ins for solving sheet-metal pattern development problems shall be explored later in this Chapter). AutoCAD will be used throughout this textbook for learning traditional descriptive geometry drafting techniques. In addition, 3D tools and settings in AutoCAD will be explored for the solution of descriptive geometry problems.
Architectural Desktop: This is a powerful parametric CAD program based on AutoCAD's 2D interface and designed for architectural applications. Price: around $2,000-$3,000 for commercial license; $150 for educational license.	• The incorporated AutoCAD 2D tools can be used to solve all descriptive geometry problems; • The 3D tools can be used to solve all architectural design-related descriptive geometry problems.
AutoCAD MAP 3D: This is a Map drafting program based on AutoCAD's 2D interface and designed for GIS (Geographic Information System) applications.	• The incorporated AutoCAD 2D tools can be used to solve all descriptive geometry problems; • The 3D tools can be used to solve GIS-related descriptive geometry problems.
Land Desktop and Civil Design Suit: These programs are designed for civil engineering applications. Price: around $2,000-$3,000 for commercial license; $150 for educational license.	• The incorporated AutoCAD 2D tools can be used to solve all descriptive geometry problems; • The 3D tools can be used to solve civil engineering-related descriptive geometry problems.
Autodesk® VIZ (formerly 3D Studio VIZ®, www.discreet.com): A 3D modeling, rendering, and animation software for photo-realistic design visualization and motion-picture quality animation. The combination of a light version of Discreet's 3ds MAX and some features of AutoCAD such as layers. Designed for architectural and engineering presentation. Price: around $2,000-$3,000 for commercial license; $150 for educational license.	• Ability to generate polyhedrons of various type; • 3D modeling of complicated features such as springs, helix, NURBS, mesh surfacing, etc., which are not readily available in regular AutoCAD 3D environment; • Ability to connect or import directly to DWG source files created in AutoCAD or in the industry-specific applications based on AutoCAD, Autodesk Inventor programs for further development. Creation of polyhedrons and export to AutoCAD and other popular CAD format will be explored.

Table 2 (Continued).

Name, Application & Pricing	Descriptive Geometry Problem Solution Capabilities
Inventor 10 Professional: This popular program is Autodesk's flagship 3D parametric CAD program. It used Parasolid kernel technology developed by Unigraphics; and can do about 75% what mid-range 3D parametric CAD programs such as SolidWorks can do, for half of the price (around $2,000 for a commercial license; $150 for educational license).	• The 3D tools can be used to solve all mechanical design-related descriptive geometry problems that AutoCAD is capable to solve; • Sheet-metal (3D) Template can be used create folded-up sheet-metal parts with face, flange, punches and other industry-standard features and their derived flat pattern drawings. It can generate regular radial-line and parallel line development of patterns for cones, cylinders, pyramids, and prisms; Inventor will be the parametric CAD program used in this textbook project, for the solution of mechanical design-related descriptive geometry problems.

A few years ago, Autodesk Inventor could be classified as a low-end parametric modeler; however, recent versions, especially the Inventor 10 Professional (2005 Version) has scored great improvement of interface and strengthening of modeling capabilities that it can now be considered as a fairly strong mid-range program, if all third-party plug-ins are included. In terms of solving descriptive geometry problems in 3D modeling environment, as shown by the learning Modules in the Appendix H, Inventor is very capable as a parametric CAD program by itself. If third-party sheet-metal design plug-ins are included, then Inventor can be used to solve all mechanical engineering related problems in 3D environment very efficiently. Therefore, solving descriptive geometry problems with Inventor 3D parametric modeling technology has been chosen as the focus of this textbook project (Figure 1).

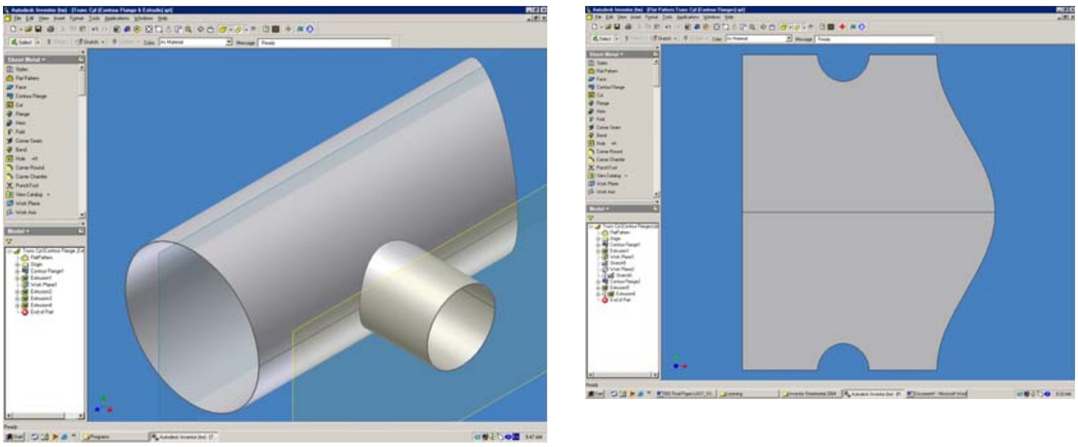


Figure 1. Sheet-metal folded model (left) and developed flat pattern (right) created in Inventor (Edward Locke, 2003)

3.3.1.2 Autodesk's Acquisition of Alias: an Entry into the High-End 3D Modeling Market (in Consumer Product Design, Automobile Styling and Other Fields)

Recent development in AutoCAD shows that company's great potential of growth in the high-end CAD and 3D modeling market. On January 10, 2006, Autodesk completed the acquisition of Alias for US $197 million (Autodesk, 2006). The acquisition allows the linkage between Autodesk solid financial and marketing strength and Alas' world-leading high-end 3D modeling technologies (especially those applicable to automobile styling and industrial product design), thereby providing users with an integrated approach that simplifies the design-to-manufacturing process.

Alias is a leading developer of high-end 3D graphics technology with 22 years of history; founded as Alias Research in 1983, it merged with Wavefront Technologies merged under SGI in 1995, and changed its name to Alias in July 2003; the company became an independent company privately owned by Accel-KKR and Ontario Teachers' Pension Plan in June 2004, Alias, before its acquisition by Autodesk in 2006.

Alias is used by many high-profile corporations and design studios in the fields of automobile styling, industrial product design, manufacturing and entertainment. According to Autodesk website, Alias' automotive and design customers include BMW, Boeing, General Motors, Mattel, Honda, Renault, Kodak, Mattel, Renault and Trek Bicycle and Rollerblade. Alias' manufacturing customers include Belshaw Bros., Hummer, Osgood, Parker Hannifin, Tegron and Wipaire. Alias' media and entertainment customers include major film studios and game developers, such as Industrial Light & Magic, DreamWorks SKG, Weta Digital, Sony Pictures Imageworks, Electronic Arts, Midway Games, Nintendo, Digital Domain, Epic Games, Prime Focus, Ubisoft and Weta Digital Ltd and SEGA. Many of these customers use both Autodesk and Alias products, providing an opportunity for the combined company to deliver a more comprehensive suite of solutions.

According to Alias' website at http://www.alias.com/glb/eng/community/customer_story_details.jsp?itemId=11000019, Alias' principal 3D modeling products include the following:

1. <u>StudioTools™:</u> used in automobile styling and industrial product design, with an integrated suite of tools for shape definition, visualization and refinement - from concept sketches through to engineering; supports a native data exchange with CATIA V4 and V5 via its DirectConnect products. It includes: 1. <u>Design Studio®</u> for ideation and concept design using sketches, illustrations, photorealistic rendering, animations, and digital 3D models; 2. <u>Studio™</u> for the entire design process from ideation through to design refinement and resolution; 3. <u>AutoStudio™</u> as the

industry-standard software for transportation design and styling; and 4. SurfaceStudio™ for surface modeling and refinement.

2. Maya® Family: an Academy Award winning high-end 3D modeling and animation effects, and rendering software for digital movies, video and games industry;

3. Alias® SketchBook® Pro: for sketching, annotating, and presenting visual ideas anywhere on a Tablet PC or Wacom Tablet;

4. Alias® ImageStudio™ 3: for the creation of professional quality rendered images from 3D models, capable of opening native SolidWorks or Pro/ ENGINEER models files, and of importing models from CAD software via industry standard IGES or STEP formats, for rendering purposes;

5. Alias® PortfolioWall®: a 2D and 3D data organization, collaboration, and review software, supporting a variety of 2D image and movie formats, including RGB, PIX, JPEF, GIF, TIF, BMP, PIC, TGA, EPS, Photoshop PSD, IFF, AVI, QuickTime® MOV, MPG and Flash;

6. Mental Ray® Standalone: a rendering software for digital films and games, working on multiprocessor workstations and networked computers for large volume data processing;

7. Alias® MotionBuilder® 7: a productivity suite for 3D character animation for high-volume animation projects for game, film, broadcast and multimedia production;

8. Alias® FBX®: a free platform-independent 3D content exchange utility, which allows 3D data to flow between tools, teams and locations, and different formats, with support for all major 3D data elements, as well as 2D, audio, and video media elements;

9. Alias® Human IK® Middleware: "a licensed development library that allows game developers to integrate an intelligent (full body or by body part) character IK system that can be used within the runtime game engine in order to process biped and quadruped character animations" (Alias, 2006) with Biped/Quadruped template that allows for any character to be defined in a unified way, independent of bone structure (from 18 to 178 bones including fingers, toes, multiple bones spine, etc.).

With the acquisition of Alias technologies, Autodesk is now in full control of one of the world's most advanced 3D modeling tool set; and it can be realistically expected that the existing Autodesk products, such as AutoCAD, Inventor, 3D VIZ, may benefit from the integration of Autodesk and Alias technologies in the foreseeable future.

3.3.2 Mid-Range 3D Parametric CAD Programs: SolidEdge and SolidWorks

SolidEdge, a program made by Unigraphics (www.ugs.com), is the most powerful mid-range 3D parametric CAD software. Its powerful 3D tools can be used to solve all mechanical design-related descriptive geometry problems. Its sheet-metal environment is powerful enough to create folded-up sheet-metal parts with face, flange, punches and other industry-standard features and their derived flat pattern drawings. It can generate both regular radial-line and parallel line development of patterns for cones, cylinders, pyramids, and prisms, as well as transition pieces for circular-to-rectangular pipes. In Southern California, at Pasadena City College, SolidEdge is used to teach descriptive geometry together with AutoCAD. SolidEdge will be one of the principle parametric CAD programs used for the solution of mechanical design-related descriptive geometry problems.

SolidWorks Corporation (www.solidworks.com, info@solidworks.com, 1-800-693-9000), founded in 1993, and headquartered at 300 Baker Avenue, Concord, MA 01742, was acquired by Dassault Systèmes S.A. since 1997; and it develops and markets software for mechanical design, analysis, and product data management, and introduced the first powerful 3D CAD software available for a native Windows® environment. It is a mid-range 3D parametric solid modeler based on Parasolid kernel owned by Unigraphics. SolidWorks® is, after AutoCAD and Inventor, the most popular 3D parametric modeling tool; and the second most powerful mid-range solid modeling CAD program after SolidEdge. SolidWorks will be one of the principle parametric CAD programs used for the solution of mechanical design-related descriptive geometry problems.

3.3.3 High-End 3D Parametric CAD Programs: CATIA, Unigraphics and ProEngineer/ProSheet-Metal

CATIA, an acronym for Computer Aided Technical Industrial Application developed by French company Dassault Systemes (http://plm.3ds.com/10.0.html), is a high-end integrated and comprehensive “total solution” for parametric 3D engineering design and drafting, parts and assembly analysis and simulation, which offers much more tools and options than any mid-range packages such as SolidEdge and SolidWorks. It is still a pricey software that only large and medium-to-large corporations can afford (around $10,000 per seat for basic design package, commercial version). The total package with full functionalities for a particular industrial corporation might cost between $20,000 and $30,000 and much more per seat, depending on applications. The student academic license that includes basic design tools is $150 per seat. CATIA offers the best tool sets for surface modeling and aerodynamic design, including many special tools for automatic creation of standard parts and fixtures, such as mold tooling using pre-designed components from standard catalogs, and therefore, is the preferred software for aerospace industry and used in Lockeheed Martin, Boeing, NASA and other space and defense corporations. Its strong automotive and styling design capabilities also make it an ideal choice for automobile and consumer product manufacturing companies. It offers great tools for solution of descriptive geometry problems and even mathematical graphing problems. Its diverse tools sets are organized into "workbenches." For sheet-metal pattern development, it offers three workbenches: Sheet-Metal design, Aerospace Sheet-metal Design, and Sheet-metal Production.

Unigraphic and ProEngineer/ProSheet-metal are also powerful 3D parametric CAD programs that offer full solutions to all mechanical-design-related descriptive geometry problems imaginable.

The Table 3 below gives an overview on the capabilities of various CAD programs in solving descriptive geometry-related problems.

Table 3. CAD Programs and Descriptive Geometry Problem Solution Capabilities

	Categories of Descriptive Geometry Problem							
	Orthographics and Pictorials				**Descriptive Geometry Computations**			
CAD Program	**Ortho-graphic Views**	**Iso-metrics**	**Obliques**	**Pers-pectives**	**True Shape, Length, Angles**	**Sheet-metal Pattern**	**Gra-phical Math**	**Poly-hedron**
AutoCAD 2D	x	x	x	N/A*	x	x	x	
AutoCAD 3D	x	x		x	x			
3DS MAX and 3D VIZ	N/A**	x	N/A**	x	N/A**	N/A**	N/A**	x
Inventor	x	x		x	x	Strong		
SolidEdge	x	x		x	x	Very Strong		
SolidWorks	x	x		x	x	Fairly Strong		
CATIA, Pro-Sheetmetal, Unigraphics	x	x		x	x	Very Strong	x	

* It is not productive to draw perspectives in AutoCAD with 2D tools. It is more convenient to create a 3D model and generate a perspective view instead. The same principle applies to isometric view although AutoCAD 2D is good for teaching and learning isometric projection theories.
** 3DS MAX (formerly 3D Studio MAX) and 3D VIZ are designed for creation of 3D animated presentations, not for engineering design per se, although 3D VIZ includes many tools and settings (such as Layers) similar to those available in AutoCAD. However, they are very strong in generating polyhedron geometry, which can be imported into AutoCAD and other CAD programs.

3.4 Professional Sheet-Metal Design and Fabrication Software Programs

Close to 50% of topics in the subject of engineering descriptive geometry deal with sheet-metal 2D flat pattern layout. Most of the low-end to mid-range CAD programs can only solve very basic sheet-metal design problems, with or without third-party plug-ins (such as in the case of AutoCAD, Mechanical Desktop, Inventor, SolidWork). High-end CAD programs can solve more sheet-metal design problems. In addition to "regular" CAD programs, there are mid-range to high-end professional sheet-metal design and fabrication programs (either as stand-alone programs or as plug-ins for popular CAD packages such as AutoCAD, Inventor, Mechanical Desktop, SolidWorks and SolidEdge), which are all encompassing in scope. There are a dozen of such programs. Some of these programs, made by Swedish and German, British and American companies respectively, are worth mentioning.

3.4.1 Sheet-Metal Design Software and Plug-ins

Table 4A provides some basic information on the above-mentioned sheet-metal design and fabrication stand-alone software programs and plug-ins, as well as their applications in major CAD programs, such as Autodesk AutoCAD, Mechanical Desktop, Inventor, SolidWorks, and SolidEdge.

Table 4A. Sheet-Metal Design and Fabrication Software and Their Application in 3D CAD Programs

Name of Software	Software Maker	Stand-alone Program	Plug-Ins for Major CAD Programs				
			AutoCAD	**Mechanical Desktop**	**Inventor**	**Solid-Works**	**Solid-Edge**
AutoPOL	FCC	Yes	Yes	Yes			
Sheetmetal	SPI GmbH		Yes		Yes	Yes	
SS-Design SS-Unfold SS-Nest	Striker Systems	Yes	Yes		Yes	Yes	Yes

3.4.2 Contact Information of Sheet-Metal Design Software and Plug-in Makers

Table 4B. Sheet-Metal Design and Fabrication Software Maker Contact Information

Company & Address	Products
FCC Software AB Sankt Olofsgatan 14, 52143 Falköping, Sweden http://www.autopol.com/ mail@autopol.com	AutoPOL for Windows, AutoPOL 8DT, AutoPOL 7, Bend Simulator for Windows
SPI GmbH Kurt-Fischer-Str.30a, 22926 Ahrensburg, Germany http://www.spi.de/index_e.htm cb@spi.de	SPI Sheetmetal Inventor for Autodesk Inventor (V10), SPI Ducting Inventor, SPI Sheetmetal Desktop SPI SheetmetalWorks for SolidWorks, SPI Sheetmetal for AutoCAD 2002/2004/2005,

Table 4B (Continued).

Company & Address	Products
Striker Systems P.O. Box 41, White House, TN 37188 http://www.striker-systems.com/ 800-950-7862 sales@striker-systems.com	SS-Design, SS-Unfold, SS-Punch, SS-Profile, SS-Nest, PARTShare

3.5 3D Modeling of Plutonic Solids, Other Polyhedrons & Polyhedral Stars

Many general 3D modeler, mathematics software and special polyhedron 3D modelers can generate 3D models of polyhedrons as well as 2D flat patterns.

3.5.1 Generic 3D Modelers

3D StudioMAX and 3D VIZ 3D modeling programs, developed by Discreet, now a subsidiary of Autodesk, possess great capabilities of creating surface models of polyhedrons and polyhedral stars. The 3D models created in these two programs can be exported as AutoCAD .dwg format files for further design operations.

3.5.2 Mathematics Software Programs

Mathematica (http://www.wolfram.com) and MathCAD (http://www.mathcad.com/products/mathcad13/), two popular math computation programs, can also create 3D models of polyhedrons and polyhedral stars.

3.5.3 Special 3D Polyhedron Modelers

Small Stella and Great Stella polyhedron 3D modelers: Software 3D, an Australian software firm (Home Page: http://www.software3d.com/Stella.html. Alternative link to home page: http://web.aanet.com.au/robertw/Stella.html. E-mail for additional information: RobertW@kagi.com) has developed two polyhedron-creation software programs, which let the users create and view polyhedra on the screen with photo-realistic rendering, apply images on the surfaces of the 3D polyhedrons (Figure 2), then print out the nets (flat patterns) required to build the folded 3D models out of paper:

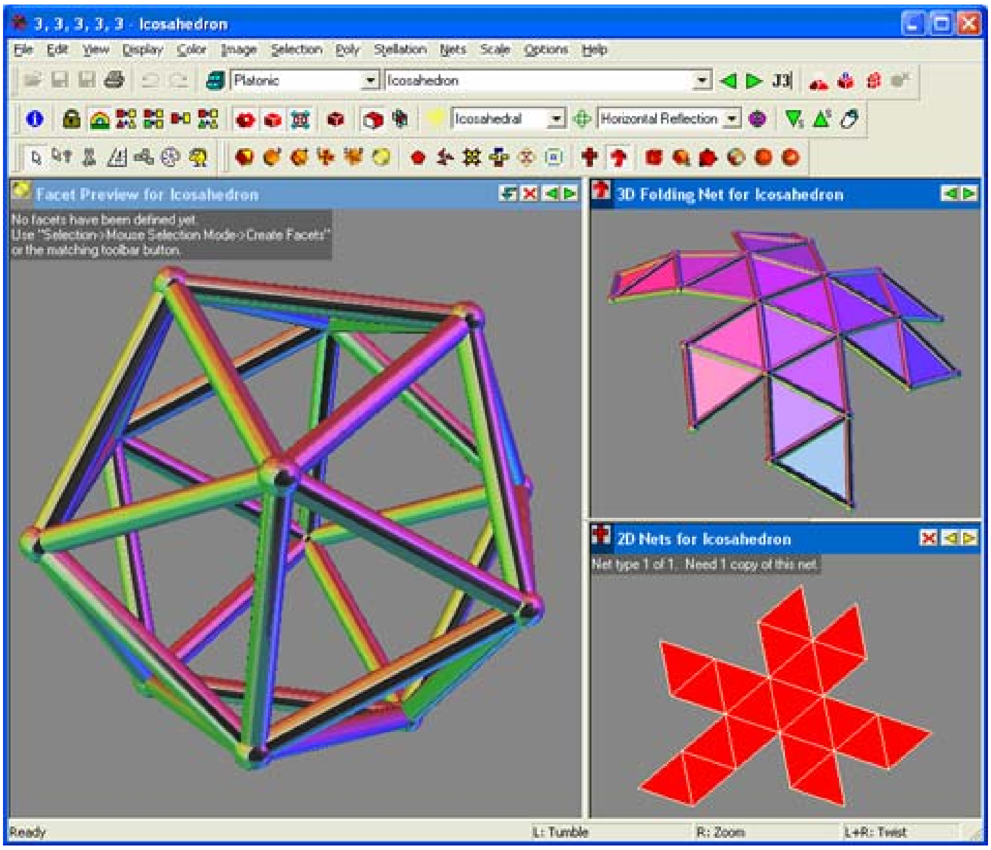


Figure 2. Polyhedron frames with Show Edges and Show Vertices on (left), 3D net (top right), and flat net pattern (bottom right) (Source: Locke, 2006).

1. Small Stella: this program has a fixed list of built-in models and can print out nets for over 300 polyhedrons. Built-in models include: Platonic solids, Archimedean solids, Kepler-Poinsot solids, convex prisms and antiprisms, Johnson solids (non-uniform regular-faced convex polyhedra), "Near misses" (models that are almost Johnson solids), Stewart toroids (regular-faced polyhedra with holes), and Stewart's G3, Z4, X and K4 models, five popular compounds (5 cubes, 5 octahedra, 2/5/10 tetrahedra. See Figure 19), a collection of geodesic domes (including geodesic spheres and geodesic hemispheres), and duals of the above polyhedra. In addition to 3D models and 2D flat patterns, Small Stella can also provide geometric indicators (such as edge, symmetry axis, reflection plane) on the 3D polyhedral models (Figure 3). Small Stella can be upgrade to Great Stella with additional features. Price (for latest version 3): US $30 for Single User License; US $90 for Primary or Secondary School (years 1 through 12) License; and US $150 for University License.

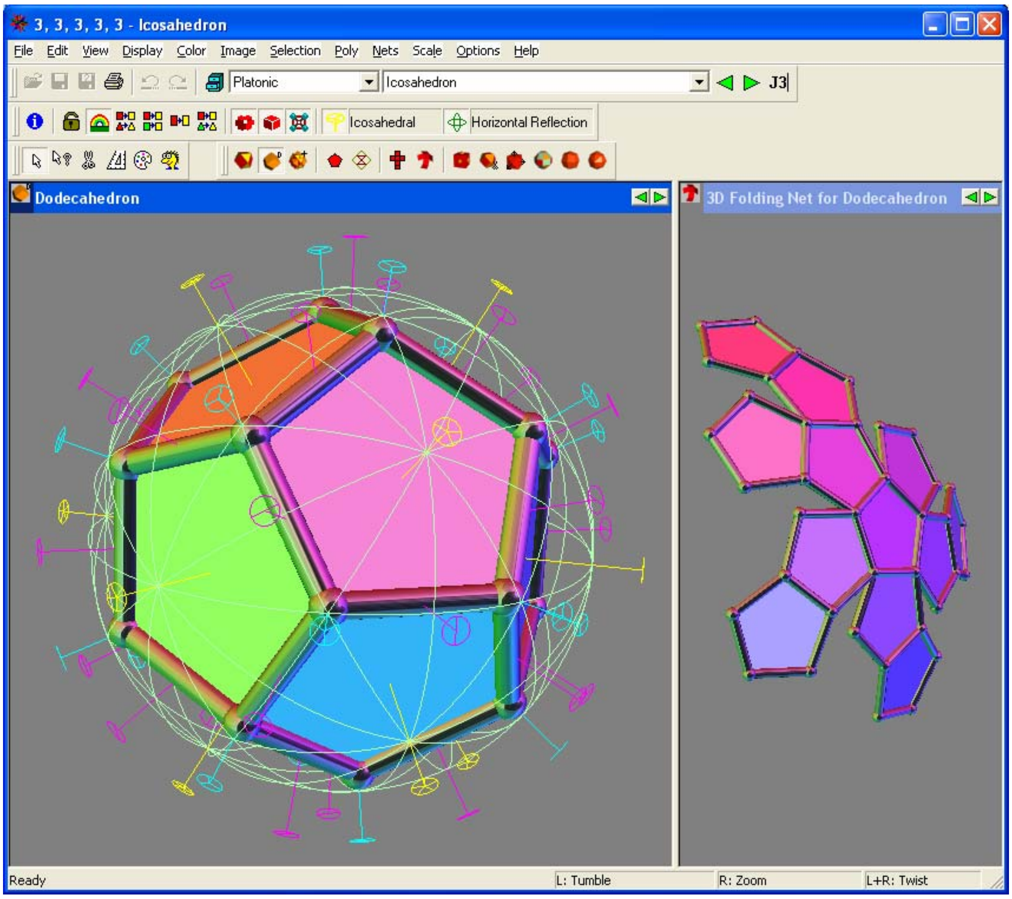


Figure 3. A dodecahedron with Show Symmetry Axis and Show Reflection Planes, Show Edges and Show Vertices all on, and Rainbow Color Mode selected (left panel); and 3D net model (right panel) (Source: Locke, 2006).

2. <u>Great Stella:</u> “the ultimate tool for creating, visualizing, and printing nets for polyhedra” and “a more advanced program, with many more built-in models, and tools for building literally trillions of new ones” (Aanet, 2006). It includes all features from Small Stella, plus the capability to create the following: all uniform polyhedra, any regular-faced prisms and antiprisms, any regular-faced pyramid, cupola, cuploid or cupolaic-blend, a library of over 400 other models including most of Brückner’s 1906 polyhedra, and a category for compounds (including 2, 4, 5, 6, 8, 10, 20 and 40 tetrahedra, 2, 3, 4, 5, 6, 8 and 20 cubes/octahedral, 2, 5 and 8 dodecahedra/icosahedra; 2 and 5 small stellated dodecahedra/great dodecahedra/great stellated dodecahedra/great icosahedra; 3, 4 and 5 cuboctahedra; 2 and 5 icosidodecahedra; 4, 5 and 20 tetrahemihexahedra and others, plus duals of any model; and in addition to all of the above, compounds of polyhedra with their duals, convex hull of any models, stellations of any polyhedral models, stellation from an arbitrary set of planes, facetings of any model may be faceted to create new polyhedra,

augmentation, excavation and drilling of Polyhedra using any other polyhedron, zonohedron, Stewart toroids, geodesic spheres, as well as symmetry group of any model, and many others. Polyhedra created in this program may be exported to DXF, POV-Ray (a free ray-tracer), VRML, Wavefront OBJ, or OFF format. It can import any closed 3D model in OFF format. Price (for latest version 3): US $75 for Single User License; US $225 for Primary or Secondary School (years 1 through 12) License; and US $375 for University License.

CHAPTER 4
CAD TECHNOLOGY AND ITS APPLICATION IN ENGINEERING DRAFTING AND DESCRIPTIVE GEOMETRY CURRICULUM

The objective of this Chapter is to present an analysis of the application of CAD programs in the solutions of engineering descriptive geometry problems, in engineering drafting courses offered at community college and university levels, especially in Southern California.

4.1 The Application of CAD Technology in Descriptive Geometry Curriculum and Engineering Design Practice

Before the birth of 3D modeling technology, all engineering drafting started with 2D tools; and therefore, the efficiency in engineering drafting depended on the efficiency of using the 2D drafting tools of 2D CAD such as AutoCAD. In addition, the orthographic projection methods learned in typical engineering drafting courses were heavily used in daily drafting operations. With the development of the 3D modeling technology, especially the birth of parametric 3D modeling technology, the conditions of engineering drafting as well as the relationship between orthographic projection methods taught in engineering drafting curriculum and real-world industry practice in engineering drafting/design have substantially changed, as explained in the following paragraphs.

4.1.1 For Learning the Theory of Orthographic Projection in 2D Drafting

Among all major CAD programs currently taught in schools and used in industry, AutoCAD is the only one that is originally developed as a 2D drafting program; and it has the best 2D drafting tools for the creation of 2D geometric entities such as lines, splines, circles, ellipses, etc, with the strongest capabilities. Therefore, for the learning of descriptive geometry and orthographic projection theory, the 2D drafting tools of AutoCAD are still the most suitable; therefore, AutoCAD 2D drafting tools will be used throughout this project for learning foundations techniques used in descriptive geometry and orthographic projection problem-solving. However, creation of 2D orthographic multi-views with 2D drafting tools is no longer the most efficient way in engineering drafting and design.

The 2D tools of AutoCAD can be used to solve all descriptive geometry problems with multi-view orthographic projection methods, as shown in Figure 4 through Figure 17 below and in the subsequent pages, which come from the learning modules in the Appendices G and H.

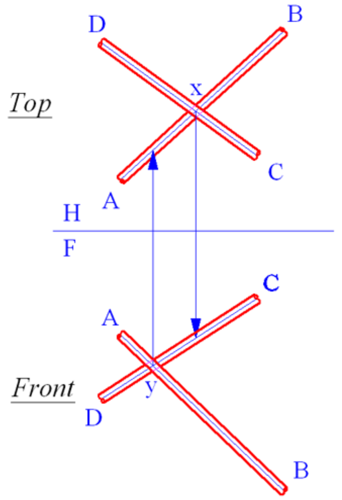


Figure 4. Determination of visibility of lines.

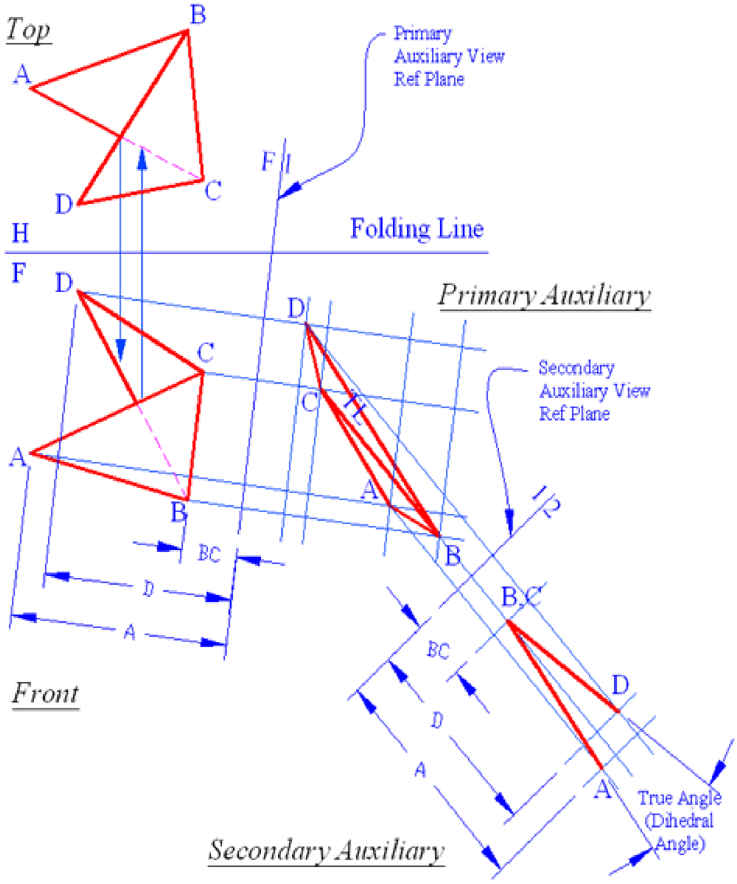


Figure 5. Dihedral angle.

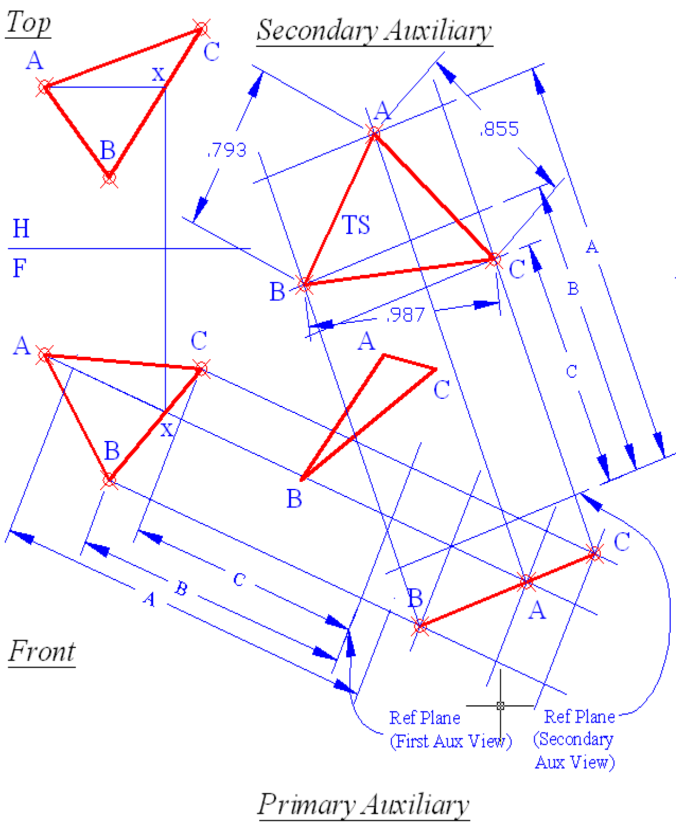


Figure 6. True shape of a plane (primary and secondary auxiliary views).

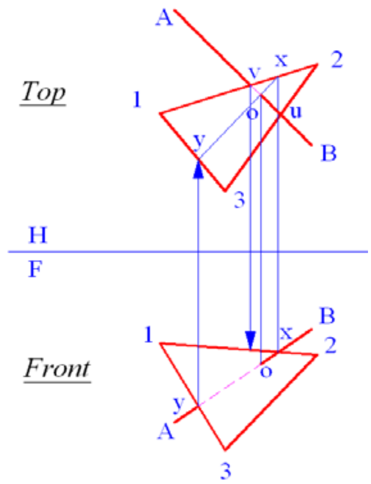


Figure 7. Piercing point.

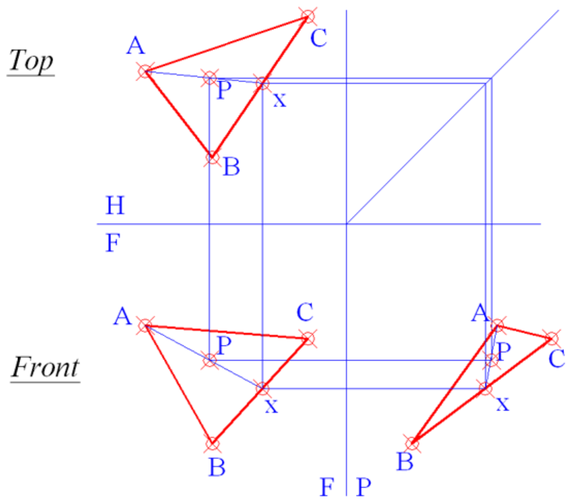


Figure 8. Locating a point on a plane.

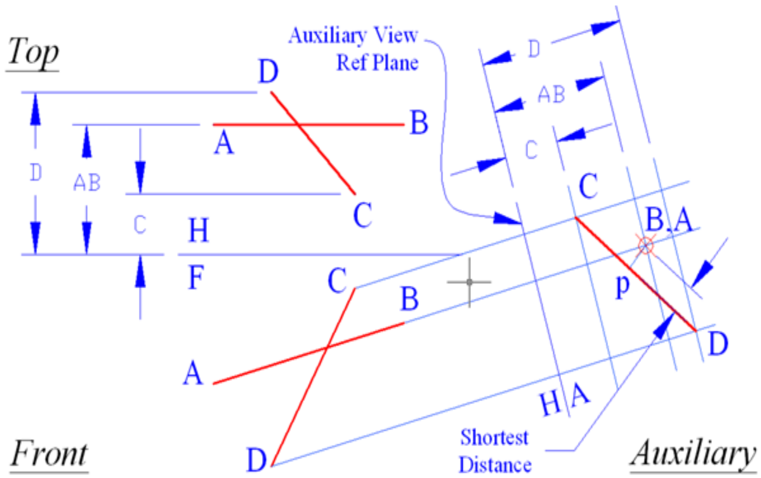


Figure 9. Shortest distance.

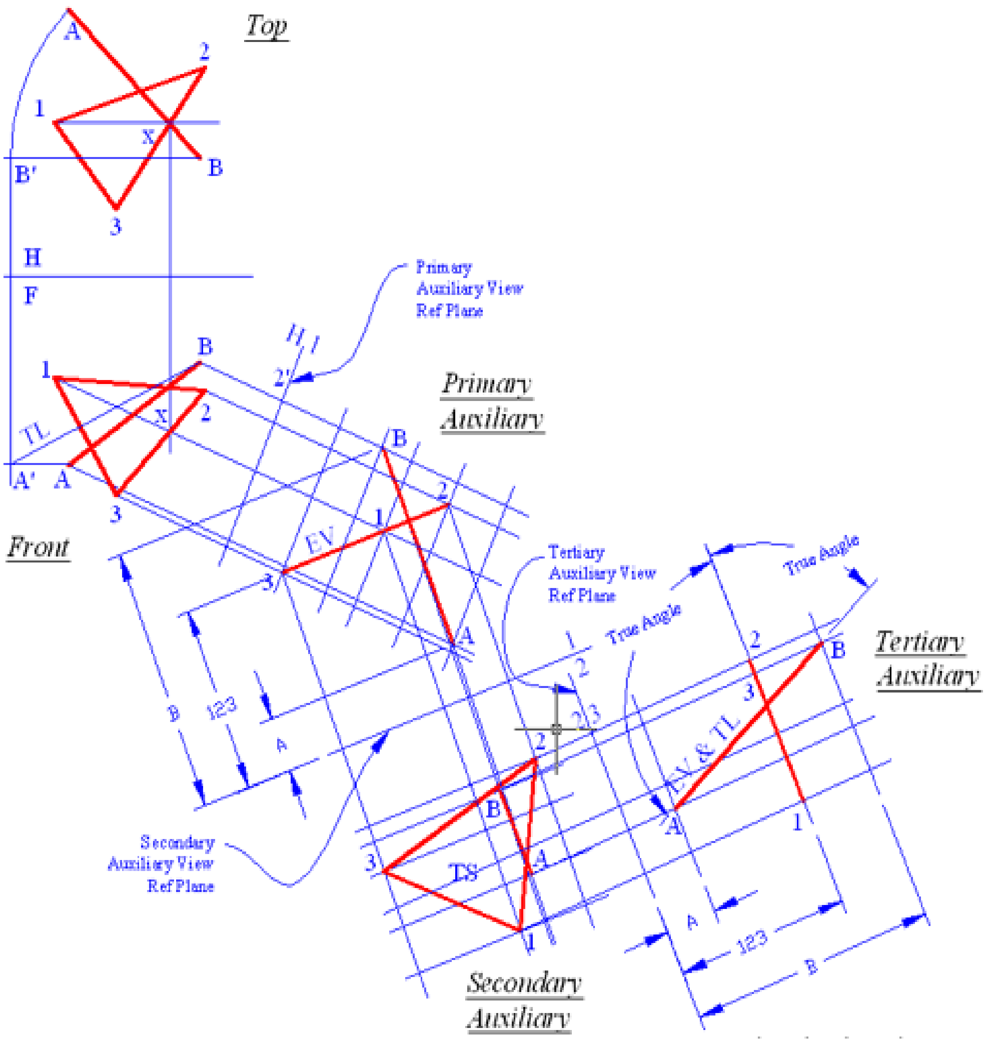


Figure 10. Angle between a line and a plane.

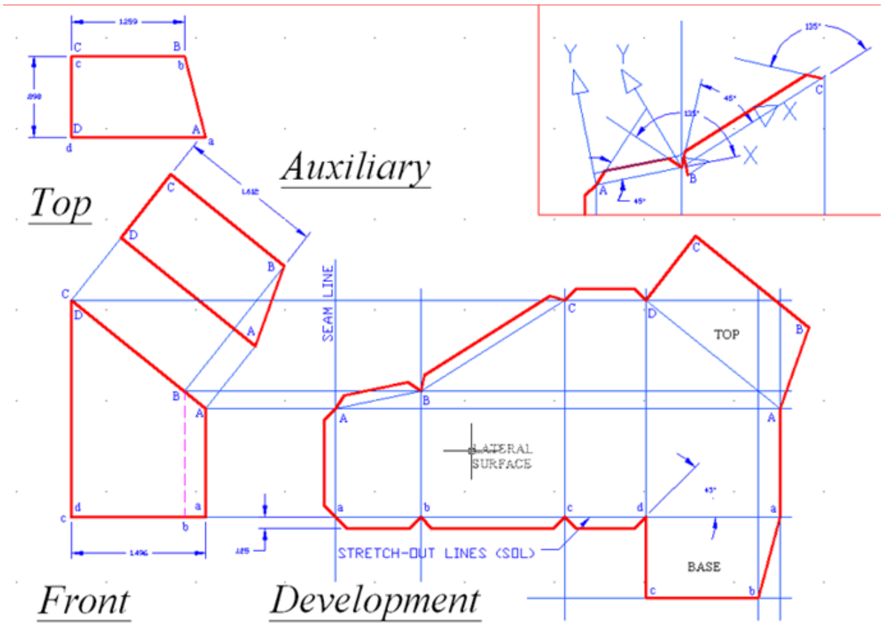


Figure 11. Parallel-line development.

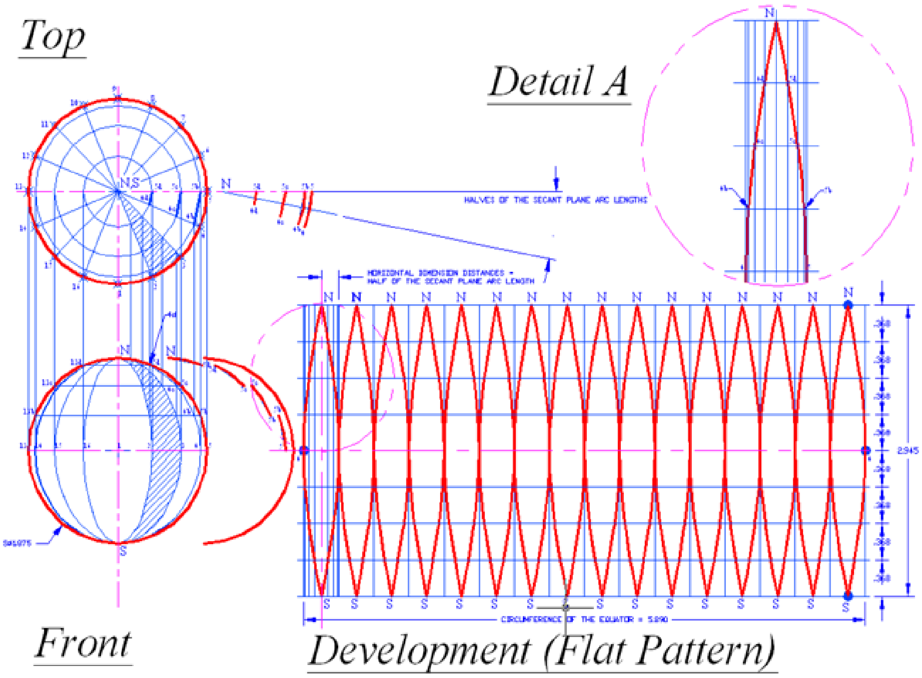


Figure 12. Approximate development of sphere
(Gore or poly-cylindrical method).

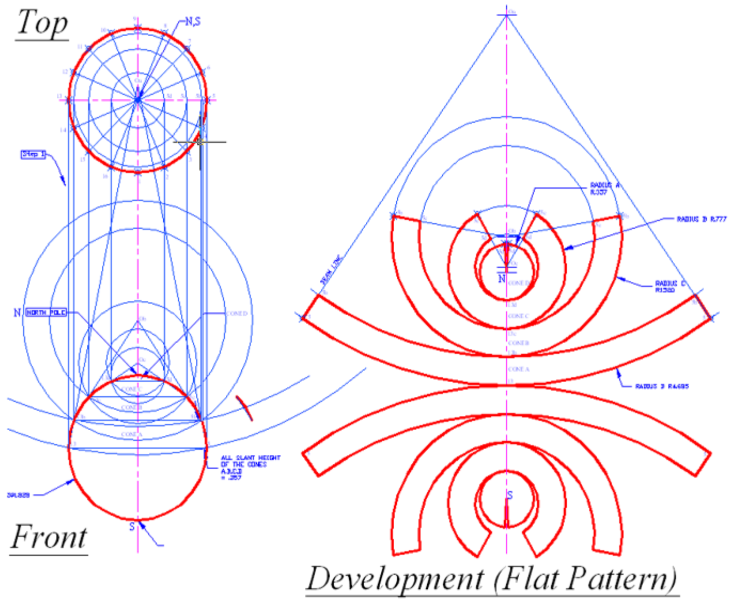


Figure 13. Approximate development of sphere (poly-conic method).

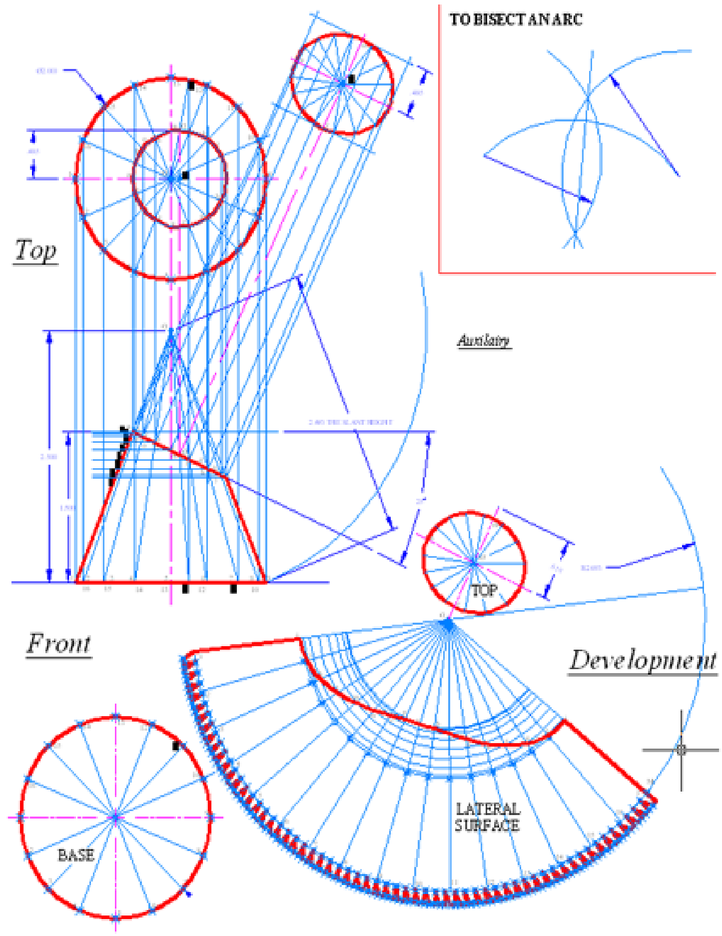


Figure 14. Radial-line development of a cone.

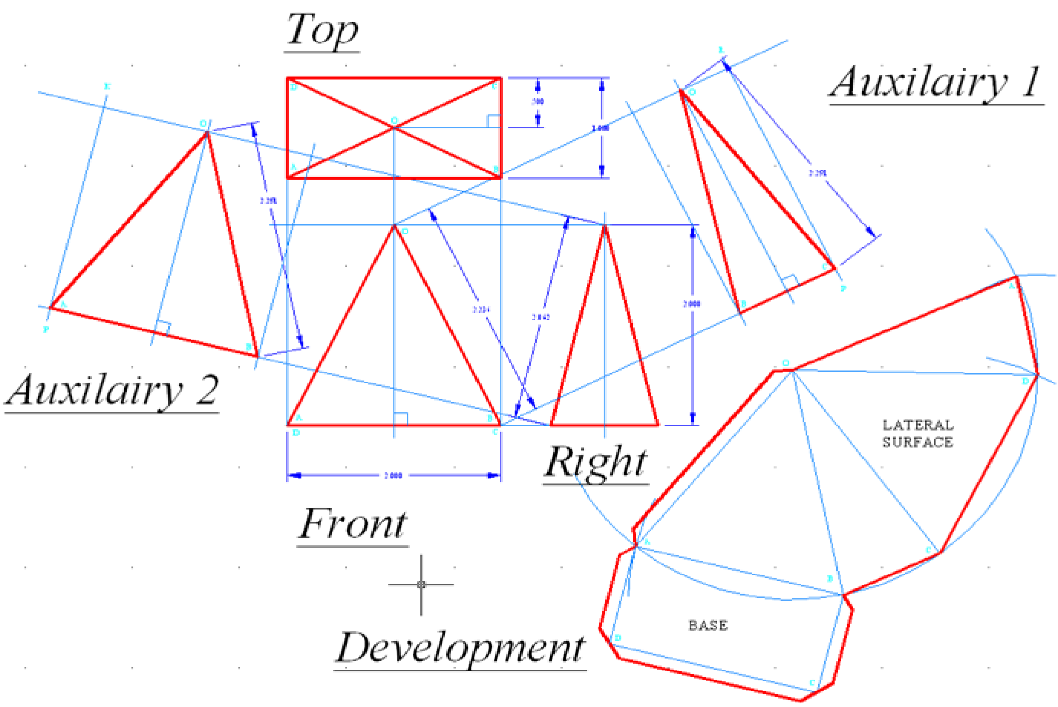


Figure 15. Radial-line development of a pyramid.

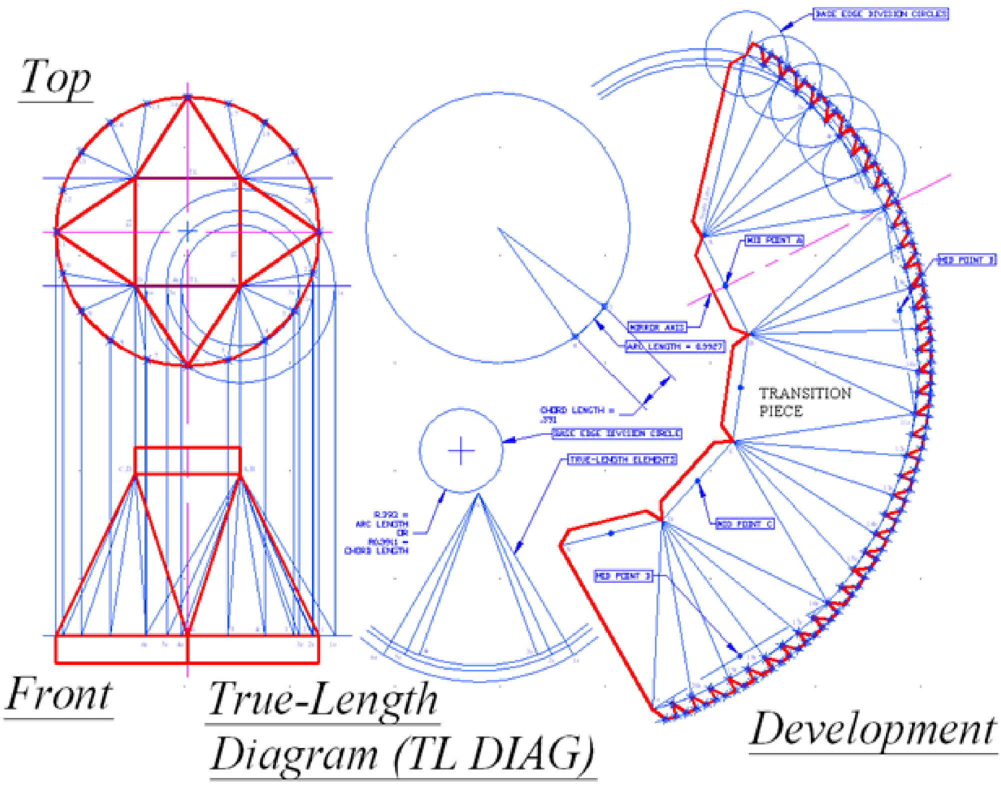


Figure 16. Triangulation development of the lateral transition piece between square and circular tubes.

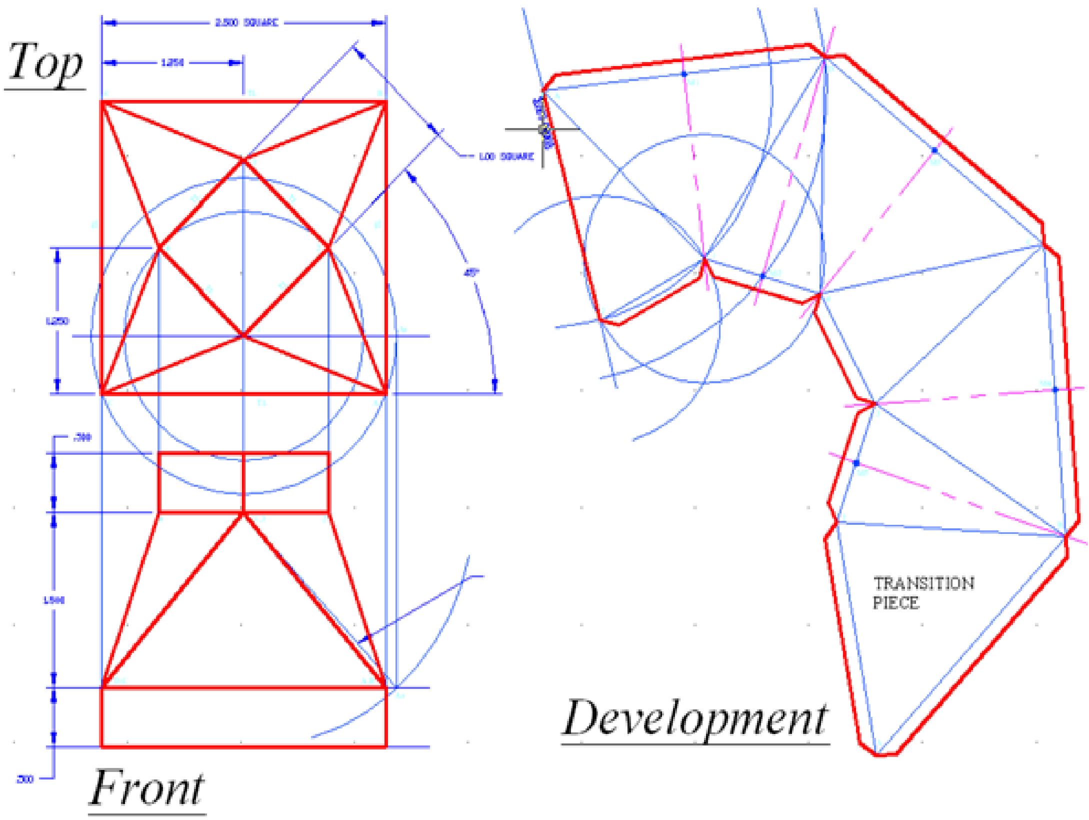


Figure 17. Triangulation development of the lateral transition piece between a two square tubes.

4.1.2 For Learning the More Efficient Methods of Solving Descriptive Geometry Problems in 3D Modeling Environment

Due to the fact that 3D solid modeling tools in AutoCAD and in parametric 3D solid modelers such as Inventor, SolidEdge, SolidWorks, etc., are much more efficient in solving descriptive geometry problems, this textbook will cover the usage of 3D tools in AutoCAD and in Inventor. However, it is not the mission of this textbook to teach these two popular CAD programs per se; instead, this textbook will offer a short tutorial on relevant tools used for the solution of descriptive geometry problems, and offer recommendations for suitable textbooks that are dedicated to teaching generic skills with these two CAD programs. In other words, this textbook is dedicated to tools and settings that are important for the solutions of descriptive geometry problems, which are normally not covered in regular CAD textbook.

Autodesk Inventor's parametric 3D modeling tools can be used to solve most of the mechanical engineering-related descriptive geometry problems (Figure 18 through Figure 31).

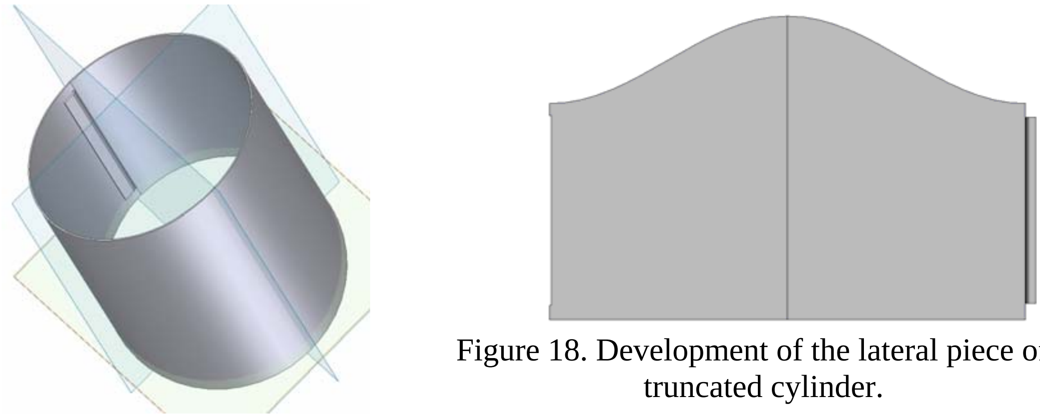


Figure 18. Development of the lateral piece of a truncated cylinder.

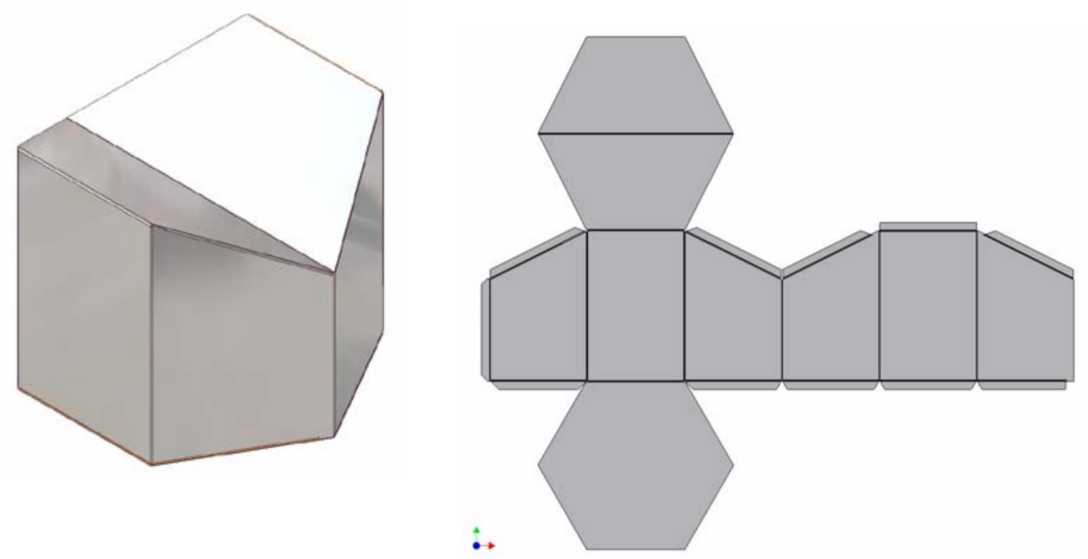


Figure 19. Development of a truncated prism.

Figure 20. Development of an interested cone

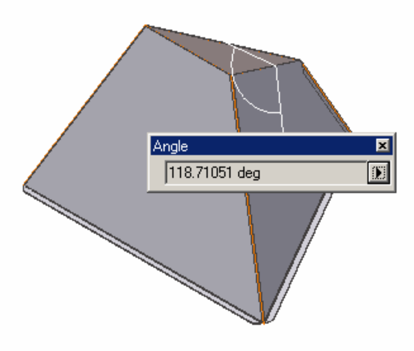


Figure 21. Measuring the dihedral angle.

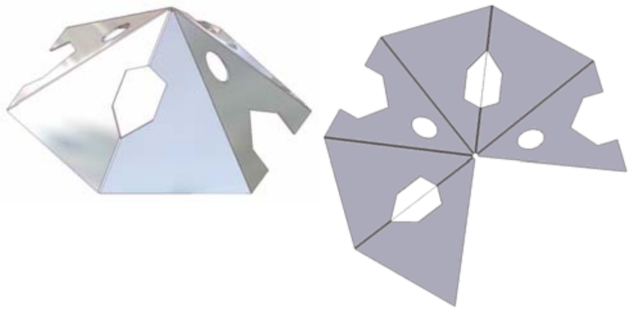


Figure 22. Development of an intersected pyramid

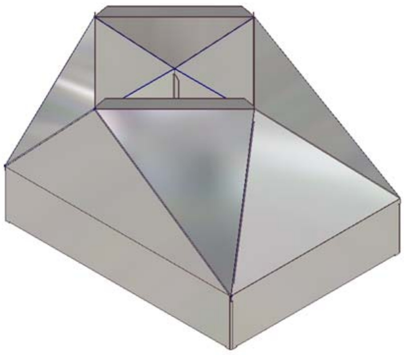
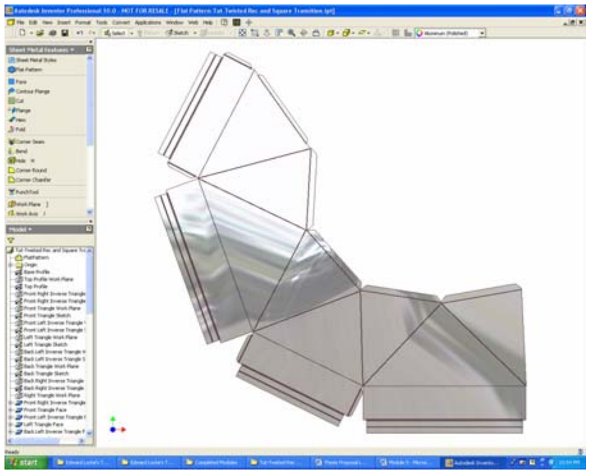
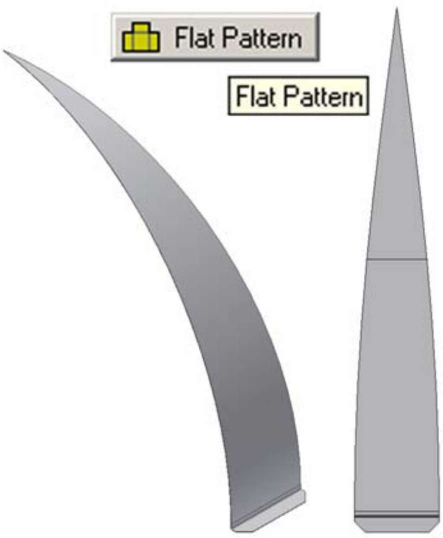


Figure 23. Triangulation development of a transition piece between two square tubes.





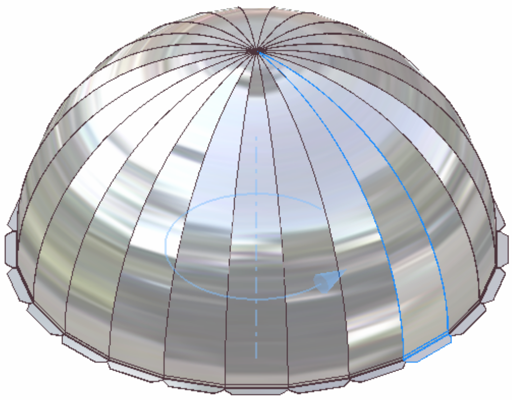
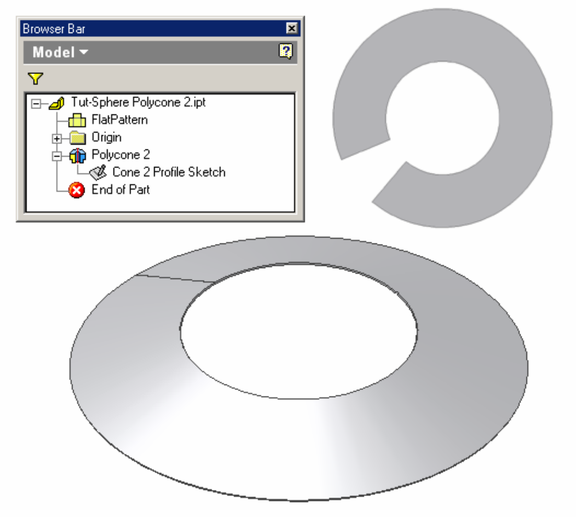


Figure 24. Approximate development of a hemisphere by poly-cylindrical (Gore) method.



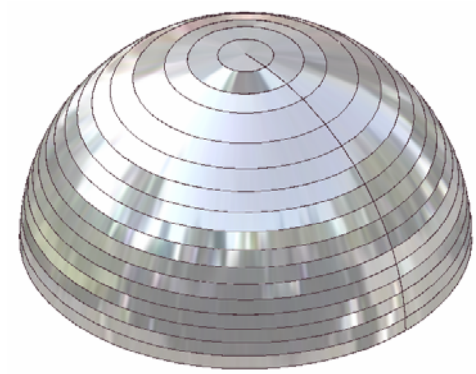


Figure 25. Approximate development of a hemisphere by poly-conical (zone) method

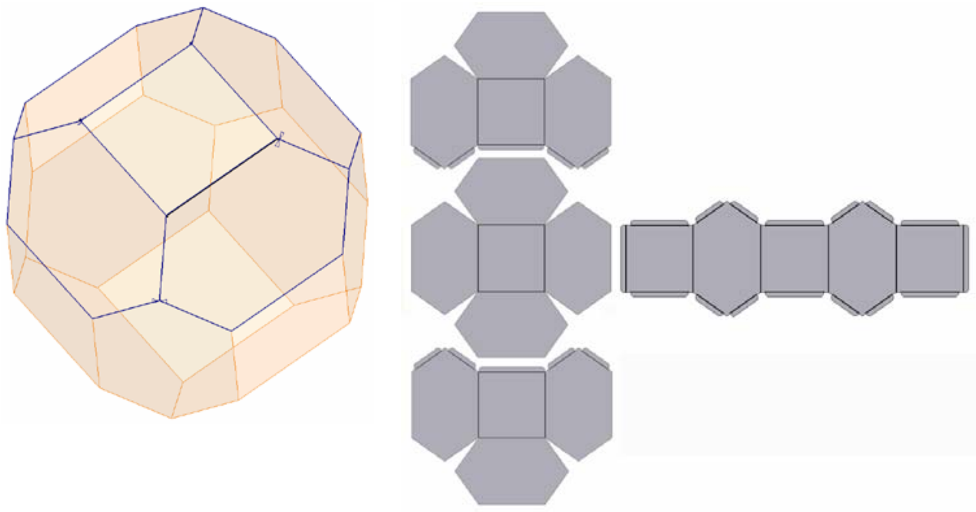
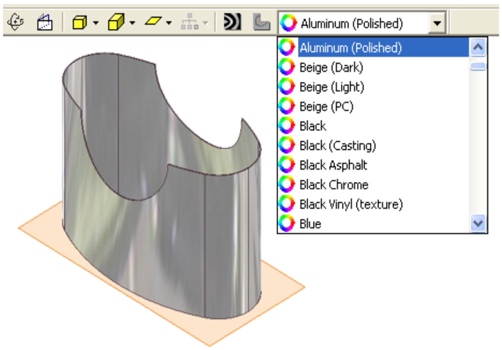


Figure 26. Development of a polyhedral surface.



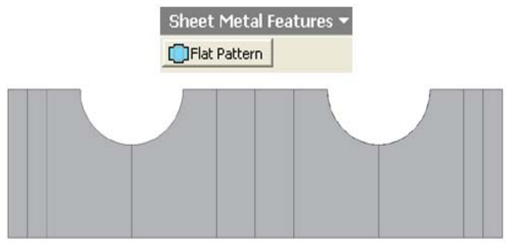


Figure 27. Development of an elliptical cylinder.

Figure 28. Intersection of cylinder and sphere.

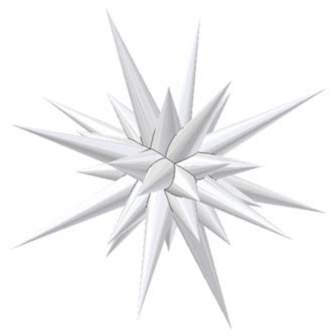


Figure 29. 3D model of a star.

Figure 30. A Y-Branch.

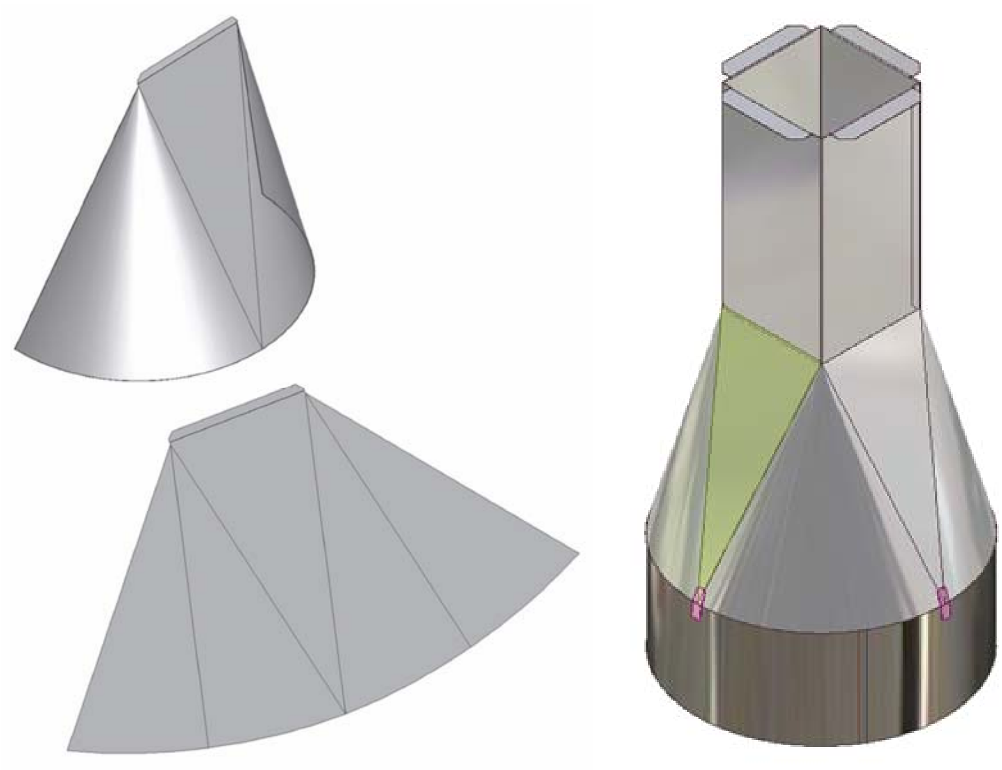


Figure 31. Transition piece between square and circular tubes.

4.2 CAD and Descriptive Geometry Education at Community Colleges in Southern California

At community colleges in Southern California, generally speaking, the subject of descriptive geometry is taught either as a 3-unit full-semester course, or as part of a basic engineering drafting course (usually as a 3-unit full-semester course).

4.2.1 Stand-Alone Descriptive Geometry Courses

In terms of the structure of curriculum coverage, when the subject of descriptive geometry is taught as an independent course, it normally includes a comprehensive coverage of all topics, including 3D spatial relations among points, lines, planes, shortest distances, point views, true-length, true-shape, bearing, slope, parallelism and perpendicularity, dihedral angles, orthographic projection and auxiliary views, revolution, intersection and development, and mining and civil engineering applications, and others.

4.2.2 Descriptive Geometry as Part of Engineering Drafting Courses

Many two-year community colleges, including Santa Ana College, Glendale Community College, Pasadena City College, teach descriptive geometry as a separate course, while others incorporate it as a part of the regular engineering drafting curriculum.

When the subject of descriptive geometry is taught as a part of a basic engineering drafting course, the main focus is usually placed on 3D spatial relations among points, lines, planes, as a foundation for orthographic projection and auxiliary views, and on intersection and development of sheet-metal patterns. The Table 5 below provides basic data on how descriptive geometry is taught at some community colleges in Southern California, according to respective 2003-2005 college catalogs as a well as on-campus visits:

Table 5. Descriptive Geometry Education at Community Colleges in Southern California

College Name	Teaching of Descriptive Geometry		CAD Software Used at CAD Labs
	As An Independent Course	As Part of A Basic Engineering Drafting Course	
Santa Ana College	Engineering 228-Descriptive Geometry (3)	Engineering 125-Engineeing Graphics (3) Engineering 122-Engineering Drawing (3)	AutoCAD, Inventor
Pasadena City College	Drafting 2-Introduction to Mechanical Design (Formerly: Descriptive Geometry) (3)	Drafting 8A-Engineering Drafting Technology (3)	AutoCAD, SolidEdge, Unigraphics, SolidWorks
Cerritos College	Engineering 123-Descriptive Geometry	Engineering 112-Engineering Graphics Engineering Design Technology 133-Sheet Metal Layout and Applications	AutoCAD, Inventor, Mechanical Desktop

Table 5 (Continued).

College Name	Teaching of Descriptive Geometry		CAD Software Used at CAD Labs
	As An Independent Course	As Part of A Basic Engineering Drafting Course	
Glendale Community College	Engineering 103-Descriptive Geometry (3)	Engineering 101-Engineering Drawing (3)	AutoCAD, SolidWorks
East Los Angeles College	General Engineering 112-Descriptive Geometry (3)	General Engineering 110-Engineeering Graphics (2)	AutoCAD
Los Angeles Valley College	General Engineering 112-Descriptive Geometry (3)		AutoCAD, 3D Studio MAX
Rio Hondo College		Drafting 131-Engineering and Manufacturing Applications of Technical Drawing (4) Drafting 122-Engineering Design Graphics (4)	AutoCAD, SolidWorks

In terms of techniques of teaching and learning, most of the above courses utilize traditional board drafting, as well as AutoCAD 2D tools, and 3D CAD tools with Inventor and SolidEdge. For example, at Santa Ana College, Engineering 125 and122 both include two weeks of instruction dedicated to traditional board drafting techniques such as lettering and basic geometric construction. At Pasadena City College, which so far offers a descriptive geometry course with the best balance of 2D and 3D teaching modules, AutoCAD 2D tools are used to learn basic projection theory while SolidEdge 3D tools are used to teach how to solve descriptive geometry problems in a real-world setting.

CHAPTER 5
CONCLUSIONS & RECOMMENDATIONS

As explained in Chapter 4 and demonstrated by the teaching and learning Modules contained in the Appendix G, Autodesk AutoCAD can be used to solve all types of engineering descriptive geometry problems with 2D tools in the traditional 2D orthographic projection methods; and it can be used to solve some of such problems with 3D tools in the new 3D modeling methods explored in this graduate project.

In addition, as shown by the teaching and learning modules contained in the Appendix H, Autodesk Inventor can be used to solve some mechanical engineering related descriptive geometry problems with 3D tools in the new 3D modeling methods; and with third party plug-ins (as explored throughout Chapter 4), it can be used to solve all types of such problems.

This graduate project is completed and it can serve as a template for future study, either by the author of this study, or by other graduate students.

This chapter will:

1. Explain the application of the result of this study, which is the completion of a textbook teaching the solutions of mechanical engineering-related descriptive geometry problems using Autodesk AutoCAD and Inventor programs; and

2. Make recommendations for further studies on the same subject.

5.1 Recommendation for Post-Study Classroom Testing

5.1.1 Classroom Testing at Santa Ana College

After the completion of this study, some or all of the AutoCAD and Inventor-related descriptive geometry teaching and learning Modules can be used in the Engineering 122-Engineering Drawing (3-units), Engineering 125-Engineering Graphics (3-units), and Engineering 228-Descriptive Geometry (3-units) courses at Santa Ana College, Orange County, California, for teaching and learning the basics of descriptive geometry in 3D digital space. Student survey could be conducted at the end of each semester so as to collect valuable feedbacks for the improvement of the textbook. For survey forms, please refer to Appendix E (Part A: List of Local Community Colleges and University Engineering and Drafting Departments in California for Potential Post-Study Survey & Survey Forms).

5.1.2 Classroom testing at other local community colleges and universities in Southern California

Digital files of the completed Modules as well as associated CAD files would be hosted at the website of Dr. Chivey C. Wu, Professor of Mechanical Engineering and member of the Thesis Committee, at the College of Engineering, Computer Science & Technology, California State University, Los Angeles (Website address: http://instructional1.calstatela.edu/cwu/DesGeom), for free downloads as instructional materials, by faculty and students of engineering departments al local community colleges in Southern California (Los Angeles and Orange Counties). Instructors at these institutions of learning could be requested to test the Modules as teaching and learning materials and to conduct similar student surveys so as to collect feedbacks on the teaching and learning Modules, which could be used as valuable reference for the improvement of the textbook project.

5.2 Measurement of Expected Student Competencies

By using the text of this thesis, and the Appendix G (Descriptive Geometry with Autodesk AutoCAD, A Collection of Step-by-Step Learning Modules for Engineering Students) and Appendix H (Descriptive Geometry with Autodesk Inventor, A Collection of Step-by-Step Learning Modules for Mechanical Engineering Students), engineering students at community colleges and universities are expected to:

1. Understand the evolution of the methodology of engineering design and drafting, as well as descriptive geometry problem solving over the years; and the need to better prepare for future engineering careers by learning the most current parametric 3D modeling technology;

2. Understand how the methods of orthographic projection are applied, in the solution of descriptive geometry problems applied to all field of engineering, using the traditional manual board drafting tools, materials and techniques;

3. Learn the traditional methods of orthographic projection in the solution of descriptive geometry problems applied to all field of engineering, using the 2D tools of Autodesk AutoCAD program;

4. Learn the new methods of solving descriptive geometry problems in the three-dimensional digital space, on the 3D models, bypassing the stage of manually creating orthographic projection views, which can be applied to the field of mechanical engineering, using the 2D tools from the Sketch Panel and 3D tools from the Part Features and the Sheet metal Features tool panels, in the 3D environment (with the Standard [in].ipt, Sheet Metal

[in].ipt, Standard [in].iam, and ANSI [in].idw templates), in Autodesk Inventor;

5. Understand how third party plug-ins can be used to solve special types of descriptive geometry related problems (sheet-metal design and fabrication) in Autodesk Inventor.

5.3 Recommendation for the Development of Further Materials Based on Industry & Academic Surveys

Surveys on the uses of CAD software and of textbooks in descriptive geometry and engineering courses, as well as on the desirability of additional teaching and learning modules on the application of the 3D parametric modeling technology in the solution of engineering descriptive geometry, could be conducted through email. Feedback could be tabulated and analyzed, so as to provide valuable information on the application of CAD technology in the sheet-metal trade, which could be considered as one of the most important beneficiary of the update of the science of descriptive geometry to the most current 3D parametric modeling technology, in Southern California; and to set priority or sequence on the development of additional teaching and learning materials using 3D parametric CAD modelers other than Autodesk Inventor (using SolidEdge, SolidWorks, CATIA, and others).

Similarly, for the field of architectural design and civil engineering, similar surveys could be conducted; and feedbacks could be tabulated and analyzed, so as to provide valuable information on the application of CAD technology in these fields, which could also be considered as among the most important beneficiary of the update of the science of descriptive geometry to the most current 3D parametric modeling technology, in Southern California; and to set priority or sequence on the development of teaching and learning materials using related 3D CAD programs (Autodesk Architectural Desktop, Revit, Civil Design Suit, Land Desktop, MAP 3D; ArcView, and others).

5.3.1 Academic Surveys

It is hereby recommended to conduct academic surveys with faculty and administrators of engineering and technology departments of 2-year community colleges and 4-year public universities in the State of California, which are listed in www.assist.org, a website that assists students in two-year community colleges to determine transferability of courses through articulation agreements between two-year community colleges and four-year universities. For the survey form, please refer to Appendix E (Part A: List of Local Community Colleges and University

Engineering and Drafting Departments in California for Potential Post-Study Survey & Survey Forms) for details.

5.3.2 Business Surveys

It is hereby recommended to conduct business surveys on the uses of CAD software through email with sheet-metal fabricators in Southern California. For a list of fabricators and the survey form, please refer to Appendix E (Part B: List of Local Sheet-metal Fabricators in Southern California for Potential Post-Study Survey & Survey Form).

Similarly, it is hereby recommended to develop a list of appropriate local government agencies in charge of civil works, architectural design firms, and construction companies in Southern California; and to conduct business surveys on the uses of CAD software.

5.4 Conclusion

This project is completed; the Appendix G and Appendix H can be offered to engineering departments/schools at local community colleges and universities as teaching and learning materials for the subject of descriptive geometry. In addition, recommendations for further study have been presented in the Chapter 5, the last Chapter of this thesis.

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