APPENDICES

APPENDIX A

The Career of Gaspard Monge and the Origin of Descriptive Geometry

Figure 1: French postal stamp honoring Gaspard Monge

Gaspard Monge's Life

Gaspard Monge (1746-1818) is remembered as a great French scientist who initiated the science of descriptive geometry, and made a great contribution to the field of engineering drafting and graphical calculations.

Gaspard Monge's birth and a successful early education

Gaspard Monge was born on 9 May 1746 in Beaune, Bourgogne, France, into a merchant's family. His father, Jacques Monge, was a prosperous wine merchant from Haute-Savoie in southeastern France; and his mother, whose maiden name was Jeanne Rousseaux, was a native of Burgundy.

Gaspard Monge was brought up in the town of Beaune in Burgundy. He attended the Oratorian College in Beaune, which was intended for young nobles and run by priests; and learned many subjects, including the humanities, history, mathematics, and the natural sciences. He started to show his academic brilliance at early age. In 1762, at the age of 16, he went to Lyons to continue his education at the Collège de la Trinité (the Trinity College). In 1763, at the age of 17, he taught a course in physics. He completed his education there in 1764, and returned to Beaune. Since then, he started a brilliant career as a scientist, educator and government administrator.

Gaspard Monge's life and career

Gaspard Monge lived in a period of stormy social turmoil in French history. In addition to scientific research and teaching, he also served the public as a government officer; and he managed to navigate through difficult circumstances and to respond to the demands of his time, most times successfully, but sometimes in failure.

At the onset of the French Revolution after the storming of the Bastille on 14, July 1789, he was one of the leading scientists in Paris with an outstanding research record in a wide variety of sciences, serving as an examiner in school reforms since 1786. He joined various societies supporting the French Revolution. Although at times during the French Revolution his position was precarious and he once barely escaped the guillotine, Gaspard Monge continued to be influential. He subsequently served as Examiner of Naval Cadets (between 1783 and about 1789), as Minister of the Navy and Colonies (from 1792 to 1793), and as leader of various military projects relating to arms and explosives. He helped in the founding of many important institutions of higher learning in France, including the National Institute of France (in 1795), École Centrale des Travaux Publics (the Central School of Public Works, later renamed as the École Polytechnique or the Polytechnical School) which was originally for training engineers and which numbered Lagrange as one of its teachers; and the École Normale (the Teachers' school) for teacher training. Gaspard Monge served in 1791on the Committee of Weights and Measures at establishing the metric system (Système International or SI), the decimal system of measurement now used in most of the countries, including partially in the United States.

Gaspard Monge served French Emperor Napoleon Bonaparte during the Napoleonic Wars. He joined Napoleon's expeditionary force on 26 May 1798 and helped Napoleon Bonaparte in his military conquests of Italy, Egypt, and Malta, setting up institutions of learning in the conquered lands such as Institut d'Egypte (the Institute of Egypt) in Cairo, a cultural organization patterned after the National Institute of France (Institut de France), while continuing writing on his treatise *Application de l'analyse à la géométrie* (*the Application of Analysis of Geometry*). He was appointed as a Senator for Life on the Consulate by Napoleon. He acquired the aristocratic title of the Comte de Péluse later in his life under Emperor Napoleon Bonaparte in 1808. Due to his ardent support for Napoleon, he fell into disgrace politically in the last few years of his long life, after the fall of the Napoleon regime in 1814. With the fall from power of Napoleon in 1814, the restored monarchy of the Bourbons family deprived Gaspard Monge, a Bonapartist, of all his honors. On October 1815, Gaspard Monge feared for his life and fled from France. He returned to

Paris in March 1816. Two days after his return he was expelled from the Institut de France and from then on his life was desperately harsh. He was harassed politically and his life was continually threatened. Gaspard Monge died on 28 July 1818, in Paris, France, at the age of 72. On his death the students of the École Polytechnique paid tribute to him despite of the opposition of the French Government that insisted that no tributes should be paid to him.

Despite of the few years (1814-1818) of fall out from favor of the Restoration regime, the long career of Gaspard Monge is very successful and this great scientist is forever remembered as a man of invention, and a great contributor to the field of engineering.

Gaspard Monge's Contribution to Science and The Origin of Descriptive Geometry

Gaspard Monge's greatest contribution to science and technology is in the fields of engineering drafting and geometry. He invented the methods of orthographic projection known as descriptive geometry.

The development of descriptive geometry

Gaspard Monge worked as a drafter before he initiated the new science of engineering descriptive geometry. He was the drafter/designer of the plan of the city of Beaune, which was seen by a member of staff at the École Royale du Génie (the Royal School of Engineering) at Mézières, who was very impressed by his work. In 1765, he was appointed as a draftsman to the École Royale du Génie (the Royal School of Engineering), where he met Charles Bossut, professor of mathematics. At first Gaspard Monge's position did not require him to use his mathematical talents, but he worked in his own time developing his own ideas of geometry, which was later further developed into the science of descriptive geometry.

Around 1766, about a year after becoming a draftsman, Gaspard Monge was given a task which allowed him to integrate his mathematical genius with his drafting skills. He was asked to draw up a fortification plan which could prevent the enemy from either seeing or firing at a military position no matter what the position of the enemy. During the design and construction of the fortification project, rather than using the complicated methods then available, Gaspard Monge made full use of the geometrical and graphical techniques, which he explored in his own time.

The graphical method used to make engineering-related geometrical calculations by Gaspard Monge was the foundation of the science of descriptive geometry (géométrie descriptive), a generalized system now known as orthographic projection; it is the study of the mathematical principles of representing a solid in three-dimensional space on a two-dimensional plane by drawing the projections (known as plans, elevations, and traces) of the solid on a sheet of paper (a "flat" two-dimensional plane). Although this new branch of science is no longer an active discipline in mathematics, it is an important part of mechanical and architectural drawing, which is used by engineers to determine design parameters such as shortest distance between two lines in a 3D space, dihedral angles between adjacent surfaces, design of sheet-metal works, etc.; and it is one of the most important topics of engineering drafting courses since then. Engineering design was revolutionized by his orthographic projection methods.

Gaspard Monge was an esteemed teacher of descriptive, analytic, and differential geometry and he started to teach descriptive geometry on 9 November 1794 as an instructor at École Centrale des Travaux Publics (the Central School of Public Works, later to become the École Polytechnique or the Polytechnical School), which was founded by the National Convention on 11 March 1794, after the outbreak of the French Revolution. Since no texts were available at the time Gaspard Monge invented the methods of descriptive geometry, his lectures at the École Normale (the Teachers' School) were edited, titled *Géométrie descriptive* ("*Descriptive Geometry*") and published for student use, in 1799. Another textbook he published under the title of *Feuilles d'analyse appliquée à la géométrie* ("*Notes on the Analysis Applied to Geometry*," in 1801) was an expanded version of his lectures on differential geometry; a later edition incorporated his *Application de l'algèbre à la géométrie* ("*Applications of Algebra to Geometry*," in 1805) as *Application de l'analyse à la géométrie* ("*Applications of Analysis to Geometry*," in 1807). His successful texts and popular lectures made a significant contribution to the advances of mathematics and education. Many mathematicians were influenced by his work, notably Jean-Victor Poncelet and Michel Chasles.

Gaspard Monge's contribution to mathematics (geometry and calculus)

Gaspard Monge's exceptional abilities in both theoretical and practical subjects in the field of mathematics were recognized at the École Royale du Génie. His contributions to mathematics are notably significant in the area of geometry. In the years 1768-1769, he wrote on the evolutes of curves of double curvature; and after receiving support from Professor Charles Bossut, his mentor in mathematics at the Académie des Sciences (the Academy of Sciences), the summary of his writing was published on *Journal Encyclopédique* (*The Encyclopedic Journal*). His writing generalized the results obtained by Huygens on space curves (as part of Huygens's investigation of the pendulum) and added many important new discoveries. The completed work was submitted to the Académie des Sciences in Paris in October 1770; and read before the Académie in August 1771 and published by the Académie in 1785.

In the years 1770-1771, Gaspard Monge wrote and presented his writings on calculus of variations, infinitesimal geometry, the theory of partial differential equations, and combinatorics; and over the next few years he submitted a series of important papers to the Académie on partial differential equations which he studied from a geometrical point of view.

Gaspard Monge's contribution to practical sciences

In addition to his major contributions to engineering drafting and mathematics, Gaspard Monge also made contributions to practical sciences in the fields of chemistry, physics and engineering. After his marriage with Cathérine Huart, in 1777, Gaspard Monge became interested in metallurgy and organized the setting up of a chemistry laboratory at the École Royale du Génie at Mézières. In 1780, he was elected as adjoint géomètre (geometrician) at the Académie des Sciences in Paris and started teaching a course in hydrodynamics as a substitute for Professor Charles Bossut; and he participated in projects undertaken by the Académie in mathematics, physics and chemistry, including: the composition of nitrous acid, the generation of curved surfaces, double refraction and the structure of Iceland spar, the composition of iron, steel, and cast iron; the action of electricity sparks on carbon dioxide gas (1786); capillary phenomena (1787); the causes of certain meteorological phenomena (1788); and physiological optics (1789).

Reference

O'Connor, J. .J & Robertson, E. F. (n.d). *Gaspard Monge (1746 - 1818).* Encyclopædia Britannica. Retrieved January 12, 2006, from Encyclopædia Britannica Premium Service Website: http://www.britannica.com/eb/article-9053349

Vikipedia. (n.d.). *Gaspard Monge*. Retrieved January 12, 2006, from Vikipedia Website: http://en.wikipedia.org/wiki/Gaspard_Monge

APPENDIX B

List of Reference Books on Descriptive Geometry and Sheet-Metal Trade at CSULA John F. Kennedy Memorial Library

Descriptive Geometry Reference Books

Adams, J. Alan. & Billow, Leon M. (1988). *Descriptive geometry and geometric* New York : Holt, Rinehart and Winston, CSULA Call No. QA501 .A223 1988 North-3rd

Cleary, S. F. (1930). *Descriptive Geometry Drawing Room Problems*. New York, J. Wiley & sons, inc.; London, Chapman & Hall, limited. CSULA Call No. QA501.5 .C6 North-3rd

Douglass, Clarence, E. & Hoag, Albert L. & Alexander, Daniel E. (1971). *Descriptive Geometry, 2d ed.* San Francisco, Rinehart Press. CSULA Call No. QA501 .D58 1971 North-3rd

Earle, James H. (1971). *Descriptive Geometry.* Reading, Mass., Addison-Wesley Pub. Co. CSULA Call No. QA501 .E36 North-3rd

French, T. E. & Vierck, C. J. (1963). *Graphic Science; Engineering, Drawing, Descriptive Geometry, Graphic Solutions, 2d Ed.* New York, McGraw-Hill. CSULA Call No. T353 .F84 1963 Palmer-3rd

Grant, Hiram E (1965). *Practical Descriptive Geometry*, 2d Ed. *New York, McGraw-Hill* CSULA Call No. QA501 .G67 1965 North-3rd

Hawk, M. C. (1962). *Schaum's outline of theory and problems of descriptive geometry.* New York : Schaum. CSULA Call No. QA501 .H35 North-3rd

Hood, G. J., Palmerlee, A. S. (1958). *Geometry of Engineering Drawing Descriptive Geometry By The Direct Method. 4th Ed.* New York, McGraw-Hill, 1958 CSULA Call No. T353 .H772 1958 Palmer-3rd

Johnson, Lewis O. & Wladaver, I. (1953). *Elements of Descriptive Geometry.* New York, Prentice-Hall, 1953. CSULA Call No. QA501 .J62 North-3rd

Leighton, W. B (1957). *Technical Descriptive Geometry, 2d Ed.* New York, McGraw-Hill. CSULA Call No. QA501 .W4 1957 North-3rd

Lindgren, Carlos Ernesto S. (1968). *Four dimensional descriptive geometry [by] C. Ernesto S. Lindgren [and] Steve M. Slaby.* New York, McGraw-Hill. CSULA Call No. QA501 .L73 North-3rd

Millar, A. V. & Shiels, K. G. (1939). *Descriptive Geometry*. Boston, New York [etc.] D. C. Heath and Company. CSULA Call No. QA501 .M64 1939 North-3rd

Paré, E. G., & Loving , R. O. & Hill **,** I. L. (1997). *Descriptive geometry**,** 9th Ed.* New Jersey: Prentice Hall. CSULA Call No. QA501 .D387 1997. North-3rd

Rising, James S. & Almfeldt, Maurice W. (1964). *Engineering Graphics; An Integration of Engineering Drawing, Descriptive Geometry, And Engineering Problems Solution, 3d Ed.* Dubuque, Iowa, W. C. Brown Book Co. CSULA Call No. T353 .R57 1964 Palmer-3rd

Rowe, C. E. & McFarland, J. D. (1961). *Engineering Descriptive Geometry; The Direct Method For Students, Draftsmen, Architects, And Engineer, 3d Ed.* Princeton, N.J., Van Nostrand. CSULA Call No. QA501 .R79 1961 North-3rd

Schumann, C. H. (1946). *Descriptive Geometry, A Treatise On The Graphics of Space For The Scientific Professions, 4th Ed.* New York, D. Van Nostrand company, 1946 CSULA Call No. QA501 .S542 1946 North-3rd

Shariff, Abdulla. (1979). *Engineering Descriptive Geometry, 3d, rev. and enl. ed.* New York: Asia Publishing House, 1979. CSULA Call No. QA464 .S68 1979 North-3rd

Smutz, F. A. & Gingrich, R. F. (1950). *Descriptive Geometry; Essential Principles And Applications For Students of Engineering And Architecture, 3d Ed.* New York, Van Nostrand. CSULA Call No. QA501 .S55 1950 North-3rd

Street, W. E., & Perryman, C. C., & McGuire, J. G. (1963). *Descriptive Geometry Problems.* Dubuque, Iowa, Wm. C. Brown. CSULA Call No. QA501.5 .S7 North-3rd

Turner, W. W., & Buck, C. P. & Ackert, H. P. (1950). *Basic Engineering Drawing; A Text Integrating Engineering Drawing, Descriptive Geometry, Machine Drawing.* New York, Ronald Press Co. CSULA Call No. T353 .T793 Palmer-3rd

Warner, F. M. & Mcneary, M. (1959). *Applied Descriptive Geometry, 5th Ed*. New York, McGraw-Hill. CSULA Call No. QA501 .W27 1959 North-3rd

Watts, Earle F., & Rule, John T. (1963). *Descriptive Geometry*. *Englewood Cliffs*, N. J.: Prentice-Hall. CSULA Call No. QA501 .W34 North-3rd

Whitehead, A. N. (1960). *The Axioms of Descriptive Geometry.* New York, Hafner Pub. Co. CSULA Call No. QA501 .W59 1960 North-3rd

Sheet-Metal Trade Reference Books

Anderson, Algot E. (1959). *56 Graded Problems in Elementary Sheet Metalwork, 1st Ed.*. Bloomington, Ill.: McKnight and McKnight Pub. Co. CSULA Call No. TS250 .A54 Palmer-3rd

Anderson, Edwin P. (1965). *Sheet Metal Pattern Layouts*. Indianapolis: T. Audel CSULA Call No. TS250 .A56 1965 Palmer-3rd

Blackburn, R. G. & Cassidy, J. (1957). *Sheet Metal Work For The Intermediate Examination of The City And Guilds of London Institute*. London: E. Arnold. CSULA Call No. TS250 .B55 pt.1 Palmer-3rd

Blandford, Percy W. (1981). *The Master Handbook of Sheet-Metal Work With Projects, 1st Ed*. Blue Ridge Summit, Pa.: Tab Books. CSULA Call No. TS250 .B56 Palmer-3rd

Bretz, Howard (1971). *Sheet Metal Shop Drawing*. New York: Industrial Press. CSULA Call No. TH7683.D8 B74 Palmer-3rd

Bruce, Leroy F. (1959). *Sheet Metal Shop Practices, 2nd Ed. Rev*. Chicago: American Technical Society. CSULA Call No. TS250 .B86 1959 Palmer-3rd

Bruce, Leroy F. & Meyer, Leo A. (1965). *Sheet Metal Shop Practice, Rev. 3rd Ed.*. Chicago: American Technical Society. CSULA Call No. TS250 .B86 1965 Palmer-3rd

Budzik, Richard S. (1969). *Precision Sheet Metal: Blueprint Reading, 1st Ed.*. Indianapolis: H. W. Sams. CSULA Call No. TS250 .B866 Palmer-3rd

Budzik, Richard S. (1971). *Sheet Metal: Technology, 1st Ed.*. Indianapolis: H. W. Sams. CSULA Call No. TS250 .B875 Palmer-3rd

Budzik, Richard S. (1972). *Practical Sheet Metal Layout; Today's 40 Most Frequently-Used Fittings*. Chicago: Practical Publications. CSULA Call No. TS250 .B8652 Palmer-3rd

Daugherty, James Sharkey, & Powell, Robert E. (1961). *Sheet-Metal Pattern Drafting And Shop Problems*. Peoria, Ill.: C. A. Bennett Co. CSULA Call No. TS250 .D4 1961 Palmer-3rd

Dickason, Alfred (1967). *Sheet Metal Drawing And Pattern Development*. London: Pitman. CSULA Call No. TS250 .D52 Palmer-3rd

Eary, Donald F. & Reed Edward A. (1958). *Techniques of Press Working Sheet Metal: An Engineering Approach To Die Design*. Englewood Cliffs, N.J.: Prentice-Hall. CSULA Call No. TS250 .E15 Palmer-3rd

Kaberlein, J. J. (1947). *Short Cuts For Round Layouts; A Textbook And Working Guide, With Practical And Modern Methods For Laying Out And Forming Patterns For Round And Oblong Fittings, T's, Elbows, And Hoods, Mathematical Formulas Applies To Sheet-Metal Work*. Milwaukee: Bruce Pub. Co. CSULA Call No. TS250 .K33 Palmer-3rd

Kaberlein, J. J. (1948). *Triangulation Short-Cut Layouts: A Textbook And Working Guide With Practical And Modern Methods For Laying Out And Forming Patterns Used For Blower-Exhaust Systems, Heating And Air Conditioning, Mathematical Formulas Applied To Sheet-Metal Work*. Milwaukee: Bruce Pub. Co. CSULA Call No. TS250 .K333 Palmer-3rd

Kaberlein, J. J. (1954). *Air Conditioning Metal Layout: A Textbook And Working Guide With Practical And Shortened Methods For Laying Out And Forming The Patterns Used In Air Conditioning, Heating, And Ventilating, Mathematical Formulas Applies To Sheet-Metal Work*. Milwakee: Bruce Pub. Co. CSULA Call No. TS250 .K3 1954 Palmer-3rd

Meyer, Leo A. (1961). *Sheet Metal Layout*. New York: McGraw-Hill. CSULA Call No. TS250 .S542 Palmer-3rd

Morris, R. C. (1971). *Air Conditioning Cutter's Ready Reference*. Birmingham, Mich.: Business News Pub. Co. CSULA Call No. T250 .M618 1971 Palmer-3rd

Paull, James H. (1938). *Industrial Sheet Metal Drawing*. New York: D. Van Nostrand. CSULA Call No. TS250 .P3 Palmer-3rd

Ron & Fournier, Sue (1989). *Sheet Metal Handbook, 1st Ed.*. Los Angeles, Calif.: HP Books. CSULA Call No. TL255 .F64 1989 Palmer-3rd

Sachs, George (1966). *Principles And Methods of Sheet-Metal Fabricating, 2nd Ed.*. New York: Reinhold Pub. Corp. CSULA Call No. TS250 .S25 1966 Palmer-3rd

Sehn, F. J., & Clemons, M. M., & Wilson, F. W., et al., American Society of Tool and Manufacturing Engineers National Book Committee. (1955). *Die Design Handbook: A Practical Reference Book On Process Analysis, Product Design, Metal Movements, Materials, And Proved Die Designs For Every Class of Sheet-Metal Press-Working, 1st Ed.*. New York: McGraw-Hill. CSULA Call No. TS253 .A45 Palmer-3rd

Sheet Metal and Air Conditioning Contractors' National Association (1983). *Guide For Steel Stack Design And Construction*. Vienna: Sheet Metal and Air Conditioning Contractors' National Association TH2281. CSULA Call No. G85 1983 Palmer-3rd

Silvius, G. Harold, & Baysinger, Gerald B., & Bedell, Earl L. (1948). *Safe Work Practice in Sheet Metal Work*. Chicago: American Technical Society. CSULA Call No. TS250 .S53 Palmer-3rd

Smith, Robert Ernest (1952). *Sheet Metal Work*. Bloomington, Ill.: McKnight & Mcknight Pub. Co. CSULA Call No. TS250 .S57 1952 Palmer-3rd

Stieri, Emanuele, & Marinac John G. (1953). *Sheet Metal Principles And Procedures*. New York: Prentice-Hall. CSULA Call No. TS250 .S73 Palmer-3rd

Strasser, Federico & Fees, Charles E. (1959). *Practical Design of Sheet Metal Stampings with 555 Especially Drawn Illustrations*. Philadelphia: Chilton Co., Book Division. CSULA Call No. TS250 .S75 Palmer-3rd

Texas. University. Division of Extension. Dept. of Industrial Education. (1948). *Related Instructional Sheets in Sheet Metal Work*. Austin, Texas: Industrial and Business Training Bureau, Division of Extension, The University of Texas, and The Texas State Board for Vocational Education, Trade and Industrial Division. CSULA Call No. TS250 .T45 Palmer-3rd

Townsend, G., & Dalzell J. R. & McKinney, J. (1955). *How To Estimate Carpentry, Masonry, Lath And Plaster, Marble And Tile, Air Conditioning, Electrical Wiring, Sheet Metal, Plumbing, Linoleum, Glass, Painting, Hardware, 2nd Ed., Rev.* Chicago: American Technical Society. CSULA Call No. TH435 .T6 1955 Palmer-3rd

U.S. Dept. of Commerce, Economics and Statistics Administration, U.S. Census Bureau (1999). *1997 Economic Census, Manufacturing, Industry Series, Sheet Metal Work Manufacturing (Electronic Resource)*, Washington, D.C.: GIS Electronic. CSULA Call No. C 3.24/4: EC 97 M-3323 E Palmer-3rd

Vezzani, A. A. & Atwell, J.T. (1948). *Job Sheets For Sheet Metal Die Design*. Chicago: Goodheart-Willcox. CSULA Call No. TS250 .V45 Palmer-3rd

Welch, Robert Louis (1952). *Elements of Sheet Metal Work*. Milwaukee, Wis.: The Bruce Pub. Co. CSULA Call No. TS250 .W4 1952 Palmer-3rd

Wendes, Herbert (1983). *Sheet Metal Estimating Handbook*. New York: Van Nostrand Reinhold. CSULA Call No. TS250 .W44 Palmer-3rd

Wissell, Stewart G. (1965). *Sheet-Metal Work, An Introduction To The Craft in Keeping With Modern Trade Practice*. Adelaide: Rigby. CSULA Call No. TS250 .W58 Palmer-3rd

Zinngrabe, Claude J. (1971). *Sheet Metal Blueprint Reading For The Building Trades*. Albany, N.Y.: Delmar Publishers. Co. CSULA Call No. T379 .Z55 Palmer-3rd

APPENDIX C

The Application of CAD/CAM & Simulation/Analysis programs in Industry & Educational Institutions

The Final Report by

Student: Edward Locke

Tech 502 – Modern Industry

Professor: Dr. Virgil Seaman

The Department of Technology

College of Engineering, Computer Science & Technology

California State University, Los Angeles

Summer Quarter, 2004

Objective of the Report

The objective of this technology report is to present an analysis of the application of CAD/CAM and associated programs used for mechanical and electronic engineering, in industry and educational institutions, especially local community colleges and universities, in southern California. Details of the educational curriculum related to CAD/CAM and associated programs in local community colleges in southern California are available in Appendix D: *Integration of CAD/CAM Technology And Engineering/Technical Education Programs At Community Colleges In Southern California*.

Part One
CAD/CAM Program Features Analysis & Comparison

Two major categories of CAD/CAM: design-centric and process-centric

The objective of this part of the Final Research Report is to present an analysis of the features of CAD/CAM and associated programs, and their application in engineering design communication.

Computer-Aided Design and Computer-Aided Manufacturing (CAD/CAM) and associated programs for Finite Element Analysis (FEA) and kinematics simulation are now widely used in industry. CAD/CAM programs are taught at high schools, two-year community colleges and four-year universities; while FEA analysis and kinematics simulation programs are taught at for-year universities all over the world. These programs can be used to digitally design and simulate mechanical and electronic engineering projects before physical working prototypes are built; and they can produce working and presentation drawings and even “walkthrough” animation videos in the user’s chosen field:

- For mechanical design - parts (orthographic multi-view working drawings, isometric presentation drawings, details and sections), assembly and explosion;

- For electronic and electrical engineering – electrical diagrams, schematics, etc.

According to a classroom lecture by Dr. Virgil A. Seaman, Chair of the Department of Technology at CSULA, there are two broad categories of CAD/CAM programs used in modern manufacturing process, namely, the “design-centric” and the “process-centric:”

- **Design-centric:** Design-centric CAD programs have tools and features related to 2D and 3D design and drafting, and in most cases today, some Finite Element Analysis (FEA) and assembly kinematics simulation capabilities. They are usually low-end or mid-range packages. Examples include: AutoCAD, Mechanical Desktop, Inventor, SolidWorks, and SolidEdge. AutoCAD, Mechanical Desktop, Inventor, and SolidWorks are the most used in mechanical design. For electronics engineering, simulation and manufacturing, Electronic Workbench family products (MultiCAP, MultiSIM, UltiBOARD, UltiROUTE and CommSIM) are widely used as an industry standard. Prices for these design-centric software range from $2,000 to $6,000 approximately. For their affordability, they are used to different extent by almost all companies; and are favored by small to medium-sized companies, as well as individual engineers and designers. For mechanical design, SolidEdge is the most powerful; and SolidWorks is, after Autodesk products, the most popular. SolidWorks uses a core technology called “Parasolid Kernel” that is developed by Unigraphics, the maker of SolidEdge. Files created in any of these programs can be placed in finite element analysis (FEA) or kinematics simulation software such as MSC.Nastran/Patran, COSMOSWorks, COSMOSDesignStar, and ANSYS for engineering evaluation; and after the evaluation, they are imported into computer aided manufacturing (CAM) and/or Computer Numerical Control (CNC) programs such as Mastercam or GibbsCAM and reworked if needed for final manufacturing of the real physical product. Occasionally, CAM programs can be used as 3D engineering design modeling tools as well. Some mechanical CAD programs such as SolidEdge, also include mold-making interface that can automatically generate the design of mass production molds, with all real world features as well as correct material shrinkage tolerance and other parameters, from existing 3D part geometry.

- **Process-centric:** 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 ProMechanica, 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.

Evolution of CAD standards

The standards for CAD are evolving from traditional standard based on AutoCAD to new standards based on parametric 3D modeling:

Before 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 are based on 2D drawing geometry; and products are represented with separate 2D orthographic (top, front, right, auxiliary) and isometric views. 3D wireframe models are 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 wireframe 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 wireframe 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 wireframe 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.

Part Two
Low-end to Mid-range CAD Programs

The Autodesk Family: AutoCAD, Mechanical Desktop, Inventor and Others

Autodesk was funded and started to ship AutoCAD® software in 1982; and it went public in 1985. The company acquires Discreet Logic in 1999; VIA Development; Linius Technologies and truEInnovations, Inc in 2003; and MechSoft Technology in 2004. It launched Autodesk Inventor® software in 1999; Architectural Studio in 2002; CAiCE™ Software and Revit® Technology in 2002.

Autodesk, Inc. has the largest clientele in the world CAD market (five million customers, including two million manufacturing customers, and 300,000 Mechanical Desktop licenses, plus over 500,000 Inventor licenses), and is the world's leading design software maker. 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. A progressive, forward-looking and far-sighted marketing and educational strategy allows Autodesk to maintain its leading role in the field of design and presentation all over the world. Although it does not offer the most high-end tools in 3D modeling, its 3D modeling tool sets are nevertheless more than adequate for most of manufacturing and construction companies, as well as design firms. Its pricing policy is reasonable and affordable (usually around or under $3,000 for any field of engineering design). Due to the fact that AutoCAD was originally created as a 2D drafting program, its 2D drafting tools are the most capable among all CAD programs the author of this paper has ever tested (including both "design-centric" and "process-centric" categories); and are the most suitable for teaching 2D engineering drafting and multi-view projection theory. AutoCAD is also supported by the greatest amount of educational materials (textbooks, courseware, etc.) in the field of CAD/CAM.

Table 1: Partial List of Autodesk Products Based on the AutoCAD Platform

Name, Application & Pricing	Basic Features of the Software & Evaluation
AutoCAD® Mechanical A 2D mechanical engineering design and drafting application based on AutoCAD with additional tools for automatic creation of the 2D graphical representation of frequently used mechanical parts and features.	**Provides significant productivity gains over standard AutoCAD software with:** • Standards-based libraries of parts and content; • Tools for automating design tasks; • Associative linking to Autodesk Inventor® parts. **Preferred System Requirements** for production-level 2D assembly modeling (hundreds of parts or more) with heavy use of standard parts, associative 2D hide, or Autodesk Inventor® associativity: Pentium 4, Xeon, or Athlon processor, 1.8 GHz or higher; Windows XP (Professional or Home Edition, SP1) or Windows 2000 (SP2 or later); 1 GB or more RAM (1 GB or greater recommended when running the Autodesk Vault client); 500 MB or more free disk space; 64 MB or more OpenGL workstation-class graphics card, 1280x1024x32-bit true color or better; Microsoft Internet Explorer 6 or later.
AutoCAD Electrical 2004 A program based on AutoCAD® 2004 foundation with special tools for electrical engineers, designers, and detailers to create electrical designs.	**AutoCAD Electrical 2004 provides:** • Extensive electrical controls design functionality; • Wire data reports that can be leveraged directly by the cable and wire harness functionality in Autodesk Inventor® Professional software to further accelerate and simplify the design process. For more information on AutoCAD Electrical, visit www.autodesk.com/autocadelectrical.

Table 2: Partial List of Autodesk Products That Complement AutoCAD Software

Name, Application & Pricing	Basic Features of the Software & Evaluation
Autodesk® VIZ (formerly 3D Studio VIZ®), and VIZ Render A 3D modeling, rendering, and animation software for creation of photo-realistic design visualization rendering and motion-picture quality animation, with the capability of importing 3D models created in AutoCAD drawing files for rendering and animation projects. This program is the combination of a light version of Discreet's 3ds MAX and some features of AutoCAD such as layers.	**Highly recommended for powerful rendering and animation capabilities** (for architectural and engineering presentation): • 3D modeling of complicated features such as springs, helix, NURBS, mesh surfacing, etc., which are not readily available in regular AutoCAD 3D environment; • Exploded assembly of parts; • Lightscape lighting functionality; • Import and incorporation of 3D models created in regular AutoCAD files; • Layers, materials, and Schematic View tools for efficient data management; • Image creation technologies, such as mental ray®; and rendering features such as displacement, bump maps, for photo-realistic special effects; • Animation capabilities (camera and light); • Ability to connect or import directly to DWG source files created in AutoCAD or in the industry-specific applications based on AutoCAD and Autodesk Inventor, for further development, with enhanced File Link feature, which allow changes made to the original linked DWG files to be updated in the Autodesk VIZ file. Autodesk Architectural Desktop 2005 includes **VIZ Render**, a simplified version of VIZ, which provides basic rendering capabilities. Architectural Desktop model can also be directly imported into Autodesk VIZ 2005 through the File Link feature for further enhancements. Revit users can export a 3D DWG file from Revit and then link to the resulting file in Autodesk VIZ. If Autodesk Inventor 8 is installed on the same computer as Autodesk VIZ 2005, then the Autodesk Inventor–3ds MAX® import plug-in supplied on the Autodesk Inventor product CD can directly import Inventor files. Autodesk VIZ 2005 can import data directly from Autodesk Land Desktop and Autodesk Civil 3D files by using the included LandXML importer; • Supports data exchange with all industry design solutions that use DWG, DXF™, SLA, and IGES formats. **Recommended System Requirements for Autodesk® VIZ 2005 with Lightscape:** **Primary operating systems:** Microsoft® Windows® XP (Professional or Home Edition), Windows 2000 (Service Pack 3) Microsoft Internet Explorer 6; DirectX 8.1 (DirectX 9 Recommended), OpenGL®. **Hardware System Requirements:** Intel® or AMD® based Pprocessor at 300Mhz minimum (Dual Intel Xeon® or dual AMD Athlon® system recommended); 512MB RAM and 500MB swap space minimum (1GB RAM and 2GB Swap Space Recommended); Graphics card supporting 1024x768x16-bit color with 64MB RAM. (OpenGL® and Direct3D® hardware acceleration supported; 3D graphics accelerator 1280 X 1024 24-bit color with 256MB RAM preferred); Microsoft Windows-compliant pointing device. (Specific optimization for Microsoft Intellimouse®.), Wacom Intuos or similar pressure sensitive tablet recommended for 3D Paint; CD-ROM drive; optional: sound card and speakers; cabling for TCP/IP-compliant network; 3D hardware graphics acceleration; video input and output devices; joystick; midi-instruments; 3-button mouse.

Table 2 (Continued):

Name, Application & Pricing	Basic Features of the Software & Evaluation
Discreet® 3ds MAX One of the world's mid-range to high-end leading 3D modeling, photo-realistic rendering and animation software. Recent version 6 has made major advances in its capability to get closer to other high-end but far more expensive programs such as Maya. Discreet (www.discreet.com) is based in Montréal, Québec, and is a division of Autodesk, Inc.. Commercial Price: $3,495 Academic Price*: around $500 Teacher Training Price*: $150 (Commercial Upgrade pricing is US $795 from 3ds MAX 5**,** and US $1,295 from the 3ds MAX 4 release).	**Highly recommended for powerful rendering and animation capabilities.** This software include more tools than Autodesk® VIZ for better rendering and animation, especially for entertainment industry. "Autodesk VIZ 2005 derives much of its new feature set from discreet® 3ds MAX® 6 software. As a result, Autodesk VIZ 2005 is directly compatible with 3ds MAX 6. You can open any Autodesk VIZ 2005 file in 3ds MAX 6 with no loss of data. Any 3ds MAX 6 file can be opened in Autodesk VIZ 2005, as long as the file does not require functionality unique to 3ds MAX 6 (for example, particles, real-world physics, subobject animation, and character animation)." In addition to all of the modeling and animation capabilities of Autodesk VIZ, Discreet's **3ds MAX®** and **combustion®** software can create more advanced 3D animations incorporating sophisticated character animation, environmental forces (such as gravity and wind); sub-object animation (for life-like actions from curtains swaying in the breeze to an earthquake simulation); and event-driven particles that mimic environmental effects (rain, snow, dense fog, fountains, fluid surfaces) with stunning realism for maximum "wow-factor" client presentations. "New features in **3ds MAX 6** software include an advanced schematic view for complex scene management; integrated mental ray® 3.2 renderer; a new event-driven particle system; **reactor® 2** stuntman dynamics; unmatched design workflow with Autodesk® solutions through .DWG import/export with ObjectARX support; vertex painting; enhanced modeling and skinning tools; HDRI support; performance optimizations designed in conjunction with Intel® Corporation; and extensive focus on enriching the reliability of existing features. The release also incorporates a new CD-ROM complete with software from strategic partners such as Criterion Software® RenderWare Visualizer®, Bionatics® EASYnat™, Okino Computer Graphics PolyTrans™ OpenFlight, and ArchVision™." **Applets or plug-ins for 3ds MAX®** include the following: **character studio**® for character animation; **combustion® 2.1** for movie compositing (a winner of Animation Magazine's "*Seal of Excellence*" award, Macworld '*4 and ½ Mouse*' rating, and CreativeMac.com's "*Must Buy*" distinction); **Cleaner™ XL** for video content encoding, Academy Award®-winning **flame® 8** for visual effects and compositing that has been used in Terminator 3, The Hulk and Rhinoceros by some of the industry's most talented visual effects artists from Industrial Light + Magic and others; **finalToon**, a cartoon and technical illustration renderer, which allows users to add stylistic shading or other effects and adjust line styles in real-time without the need to re-render scenes over and over again, and is made by Turbo Squid from cebas, GmbH (Germany); **DreamScape 2**, a high quality plug-in for creating realistic landscapes, seascapes, skies, clouds, outdoor lighting and more made by Sitni Sati; **AfterBurn 3**, a production proven volumetric particle effects engine for the creation of pyroclastic smoke, dust, superb explosion effects, liquid metals, water, and various procedurally defined "hard" objects, made by Sitni Sati; and **Human IK**, a companion to Discreet's character studio that includes an array of character animation tools to make characters walk, run, and jump in minutes, made by Kaydara. A complete list of plug-ins from Discreet and Turbo Squid may be found at www.discreet.com/products and www.turbosquid.com/dcp.

Table 2 (Continued):

Name, Application & Pricing	Basic Features of the Software & Evaluation
Autodesk Inventor Series A 3-for-1 bundled deal that includes: • Autodesk Inventor for 2D and 3D design and documentation; • AutoCAD Mechanical (2D drawing and detailing with a rich set of customizable 2D mechanical parts and features drawing blocks; • Autodesk® Vault (A data management software) with the ability to consolidate product information in a single location. Inventor® has Interoperability feature with AutoCAD Mechanical that allows AutoCAD® Mechanical to create Autodesk Inventor® drawings just by opening native part files. In addition, Inventor can import AutoCAD 2D legacy files. Inventor® supports industry-standard data transfer for importing and exporting design and drawing information. Importable file formats are DWG, DXF™, ProE®, SAT, IGES, and STEP. Exportable part assembly file formats include SAT, IGES, STEP, STL, and Autodesk Streamline®. Exportable drawing file formats include DWG (with full layer mapping), DWF™, and DXF. Inventor® allows nonusers without the application to open part files (IPT), assembly files (IAM), and drawing files (IDW), and to share design data with widely available DWF (Design Web Format™) files. Inventor can even create AutoCAD drawing files.	**Autodesk Inventor® is highly recommended for a user-friendly interface, a comprehensive sets of powerful parametric 3D modeling tools, which can accomplish more than 75% of what mid-range programs can do. Inventor is easy to learn and use, intuitive in user interface, rich in features, and offers the following work environment:** • **Part (3D)** can import AutoCAD 2D drawing for sketch. 3D parts can be created upon 2D sketch or applied on existing 3D parts as features. Parts can be made into iFeature and saved as a program feature for repeated and customized uses. Several configurations of the same parts can be created using parametric tables; a library of more than 500,000 components including nuts, bolts, and screws helps to automate a substantial part of design process. Equipped with intelligent diagnose tool called the Design Doctor™ that provides direct feedback (for example, a fillet is too big or a shell isn't thick enough). • **Assembly (3D)** has a comprehensive set of assembly mating tools; capacity to design large complex machines with tens of thousands of components (for example, the Robotic Technology Systems PLC designed the largest 3D project to date with 12,000-part assembly, as reported by Autodesk website); and to create kinematic simulation. "Design engines for parametrics and adaptivity cut down design steps by propagating changes instantly throughout your design. The parts of your design are associated in such a way that a change to one part in an assembly automatically causes those changes to ripple through all associated parts" (AutoCAD, 2004). Interference Analysis tools can test for part interference and measure parts for proper fit, and vary component tolerance to validate manufacturing flexibility. • **Sheet-metal (3D)** can create folded-up sheet-metal parts with face, flange, punches, other industry-standard features and their derived flat pattern drawings (in Inventor or AutoCAD formats); • **Weldment Assembly** can attach welding symbols to assembly; • **Drawing (2D)** can automatically create all orthographic, sections, details, assembly and explosion views, isometric views, in both standard line works and shaded modes, BOM or Parts List, Hole Chart and other annotation features in drawing documentation; • **Presentation** can create animation movies of assemblies; • **Finite Element Analysis (FEA) functionality** powered by industry-leading ANSYS technology, and compatibility with COSMOS to enable customers to execute stress and structural and strain analysis directly in the Autodesk Inventor application. Autodesk Inventor® uses the Autodesk® ShapeManager 3D modeling kernel that is based on ACIS 7.0. Autodesk Inventor offers compatibility with AutoCAD and Mechanical Desktop: • 3D feature-based designs and associated 2D drawings, as well as the intelligent assembly association made in Mechanical Desktop, can be migrated into Autodesk Inventor; • Inventor files can be saved in AutoCAD DWG format with complete geometric accuracy.

* Commercial Price for most of Autodesk products is under $3,000 per seat. Academic Price and Teacher Training Seminar Price are available through Thomas & Paton Associates (www.paton.com) for $150 (single software or bundled deal that combine several items, such as Inventor Series with AutoCAD and Inventor, Revit seris with Revit and VIZ)

** Recommendation based on Edward Locke's own experience with the program.

Autodesk's marketing is a great success story. According to news release on Autodesk website, on May 18, 2004, the company's financial results for its first fiscal quarter ended April 30, 2004 are as follows: net revenues of $298 million (a 41 percent increase over $211 million reported in the first quarter of the prior year), net income of $43 million, or $0.36 per diluted share on a GAAP basis. "Net revenues for the second quarter of fiscal 2005 are expected to be in the range of $260 million to $270 million. Earnings per diluted share for the second quarter of fiscal year 2005 are expected to be in the range of $0.22 to $0.26 on a GAAP basis." For the Fiscal Year 2005, "annual revenue is expected to be in the range of $1.1 billion to $1.125 billion. Earnings per diluted share for the full year are expected to be in the range of $1.29 to $1.36 on a GAAP basis (Autodesk, 2004)"

Industry recognition for Autodesk family software products received in 2004 includes the following awards:

- The Control Magazine (www.controlmag.com) Readers' Choice Award for Software, Design/Documentation (featured in January issue) for AutoCAD Electrical 2004

- The Control Engineering 2003 Editors' Choice Award (featured in January issue) for AutoCAD Electrical 2004

- The 2003 Cadalyst (www.cadalyst.com) Labs All Star Award (featured in December issue) for Cadalyst magazine's December issue names AutoCAD Mechanical 2004 software as a 2003 Cadalyst Labs All Star award winner, for a rating of five out of five stars on a thorough hands-on review of the product, and outstanding features such as standard parts libraries, mechanical line objects, the ability to perform simple FEA calculations, and seamless Autodesk Inventor interoperability;

- The Cadalyst semiannual Editors' WOW! Award (featured in December issue) for Discreet 3ds MAX 6 (www.discreet.com);

- The Computer Graphics World magazine Innovation Award (featured in December issue) for Discreet 3ds MAX 6

AutoCAD in mechanical engineering:
AutoCAD Mechanical, Mechanical Desktop and Inventor

AutoCAD® Mechanical is a special program based on AutoCAD and tailored to meet the challenges of mechanical designers, with interactive 2D mechanical drawing features that save the users a lot of design time by automating cumbersome and tedious manual tasks such as:

- Automatic creation of **balloons** and **bills of materials** based on the 2D structure of the design, a Browser for the organization of 2D data;

- **Hole Charts -** this function can create two types of lists - a hole table and a list of coordinates;

- **Dimensioning and Annotations -** AutoCAD® Mechanical contains powerful dimensioning tools (Automatic, Power, and Smart) that create dimensions with abbreviated dialog boxes to easily control only the relevant dimension variables, as well as tools to create standards-based surface texture symbols, geometric dimensioning and tolerances, targets, and weld symbols;

- **Contextual menus** - for easy access to item properties and common editing tools;

- **Screw Connections** - for intelligent selection of the right sizes for nuts, washers, and holes, creation of whole fastener assemblies, as well as automatic insertion of screw information into the BOM at once;

- **2D Standard Parts, Features, and Holes** - more than 700,000 predrawn, standards-based parts including screws, nuts, washers, pins, rivets, bushings, and many other commonly used components, plus 100,000 predrawn standard features like undercuts, keyways, and thread ends, as we as more than 8,000 predrawn holes, including through holes, blind holes, and oblong holes to select, insert and custom edit for mechanical design. At insertion point, the area where the user inserted a predrawn part is automatically cleaned up;

- **2D Structural Steel Shapes -** more than 11,000 predrawn standard structural steel shapes, including common structural shapes such as U-shape, I-shape, T-shape, L-shape, Z-shape, round and rectangular bar, and round and rectangular tube, for incorporation into mechanical design through drag-and-drop;

- **Shaft Generator –** This tool not only can create features commonly found in shafts, such as center holes, chamfers, and wrench fittings, and standard parts, such as bearings, gears, retaining rings, and seals, but also can automatically generate and update side views of the shaft from the front view;

- **Spring Generator -** this intelligent tool can help the user to select, calculate, and insert compression springs, extension springs, torsion springs, and Belleville spring washers into your design, and to control the representation type of the spring;

- **Belt and Chain Generator -** the Drive System Generator included in the standard libraries makes it easy to create chain and sprocket, design belt, and pulley systems; calculate optimal lengths for chains and belts;

- **Cam Generator –** this tool helps the user to make calculation on, and design linear, circular, and cylindrical cams, based on the input border conditions and other parameters set by the designer, such as the cam follower's position, size, and direction of movement, velocity and acceleration, as well as the cam curve path, and to couple driven elements to the cam and create NC data via the curve on the path;

- **Moment of Inertia and Deflection Calculation -** the available commands within this tool set are moment of inertia of a cross section, which includes a number of predefined cross sections, and deflection of a profile given forces and supports;

- **2D Finite Element Analysis –** this tool set can help the user to quickly identify potential areas of failure on parts, and analyze their integrity under various loads. The 2D FEA feature is a powerful tool for determining the resistance capability of an object put under a static load;

- **Integrated Data Management -** AutoCAD® Mechanical 2005 include Autodesk® Vault, a file management system that allows the user to organize drawing sets and to set levels of access for specific users and files, and to allow only one person at a time to work on an aspect of a part or assembly, so as to avoids duplication of work;

- **Inventor Associativity –** this function allows the AutoCAD Mechanical to browse through your Autodesk Inventor 3D part files, open the 3D part file, establish a link, document and detail the part as a DWG drawing.

With an unparallel ease of customization and short learning curve, as well as an affordable price (full version is priced for AutoCAD 2005 at US$3,750; and upgrading cost to AutoCAD 2005 from AutoCAD 2004 at US$495), AutoCAD® software is still the world's leading customizable and extendable CAD software. It is the most popular CAD software with the best 2D drawing tools. AutoCAD 2005 received a Rating of 5 Stars (out of 5) from the Cadalyst magazine, an autority in CAD-related publications (Fane, 2004). This high rating is largely credited to the newly introduced Sheet Set Manager features. However, in terms of 3D solid modeling and wire-frame surfacing, AutoCAD's capabilities are rather limited if compared with other mid-range and high-end packages such as SolidWorks, SolidEdge, ProEngineering, CATIA, or even Autodesk's own Mechanical Desktop and Inventor. Nevertheless, the 3D tools of AutoCAD are more than adequate for most of small to medium-sized companies.

AutoCAD is a foundation program that provides a common interface and basic set of tools for several programs dealing with mechanical, civil, architectural and electrical designs; and AutoCAD 2005 family of software products includes AutoCAD 2005, AutoCAD® LT 2005, Autodesk® Architectural Desktop 2005, Autodesk® Building Systems 2005, AutoCAD® Mechanical 2005, Autodesk® Mechanical Desktop 2005, AutoCAD® Electrical 2005, Autodesk® Land Desktop 2005, Autodesk® Survey 2005, Autodesk® Raster Design 2005, Autodesk® Civil Design 2005 and Autodesk® Map™ 3D 2005. The comprehensiveness of the Autodesk family provides unmatched potential for team collaboration among diverse categories of design professionals.

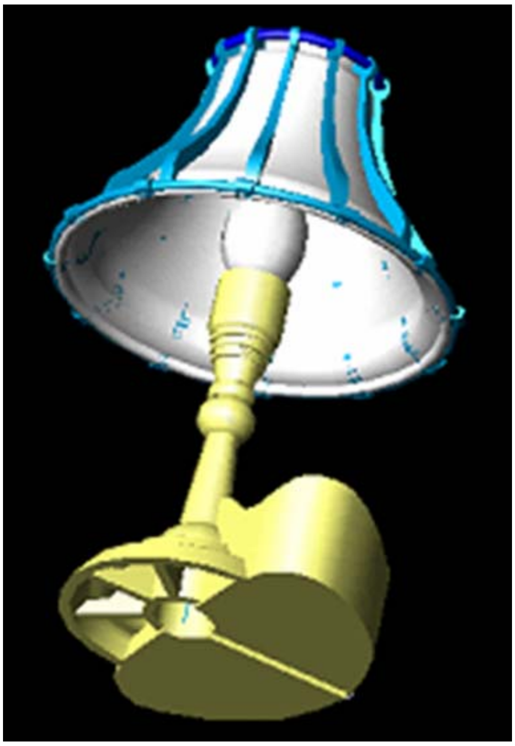


Figure 1(Right): Stylish lampshade and base designed in AutoCAD 2004 (left) and salad shooter attachment designed in Mechanical Desktop (Edward Locke, 2004)

There are hundreds of third party developers creating customizable add-ons or applets based on AutoCAD, for specialized industry applications. "Hundreds of thousands of Autodesk's five million customers use add-on software with their Autodesk® products, according to an Autodesk 2002 International Customer Survey." According to a news release by Autodesk on March 25, 2003, and titled *Leading Autodesk Software Development Partners Introduce More than Fifty Add-On Applications for AutoCAD 2004,* there are hundreds of authorized partners who had released more than 300 add-on applications based on AutoCAD 2004 (Autodesk, 2003). According to a new release titled *AutoCAD 2005 Users Increase Their*

Efficiency with Software Partner Innovation Members of the Autodesk Developer Network Deliver Nearly 300 Specialized Applications, and posted on April 06, 2004, third party companies who base their software products on the AutoCAD 2005 platform software include the following:

Table 3: Autodesk partners (Autodesk, 2004)

Partner	Headquarters	Product
Albacore Research Ltd.	Canada	ShipConstructor for ship design
ALFATEC	Japan	ACAD-DENKI/ACAD-EL for electrical/electronic design
ARCHIBUS, Inc.	USA	ARCHIBUS/FM for facilities management
C.A.D. Co.	Japan	SEQUENCECAD for electrical design
C-Plan AG	Switzerland	TOPOBASE for utilities management (works with Autodesk Map™ 3D 2005)
Chuden CTI	Japan	INAZUMA Series for electric equipment
COADE, Inc.	USA	CADWorx for process plant design, for the chemical, power, utility, food, and pharmaceutical industries
CYCO Software	Netherlands	AutoManager Meridian and AutoManager TeamWork for document management
Geomap Systems	France	GEOMAP GIS for mapping and infrastructure management (works with Autodesk Map™ 3D 2005)
Imao Corporation	Japan	IM-Tool/AC for designing mechanical parts
IT Frontier Corporation	Japan	Brain Gear for electrical equipment design
KOZO KEIKAKU ENGINEERING	Japan	adpack-PRO for architectural design
KUBOTA	Japan	K-CAD PEDRAS AC for mechanical design
Mighty Net	Japan	EQ for electric equipment design
SOFiSTiK AG	Germany	SOFiCAD for structural design and analysis
Systems Research & Development (SRD)	Japan	AutoMech2005 for mechanical and electronics design
Toyobo Engineering	Japan	CATV Designer Pro for cable TV equipment design
Universal Marine Systems Corporation	Japan	Easy CAD for tooling design
WACOM	Japan	ProfDENKI for electrical design

Autodesk products' low cost and smooth learning curve are very attractive to small to medium-sized firms and companies that make up the majority of Autodesk's client base. In addition, thanks to the fact that Autodesk is among the earliest CAD software developers, it also has an important place in high-tech research and development world, as well as in public institutions. AutoCAD-based products have very diverse clients; and according to Autodesk website, these clients include: merchandizing chain stores and consumer product designers, high-tech institution, transportation system, equipment manufacturers, entertainment industry

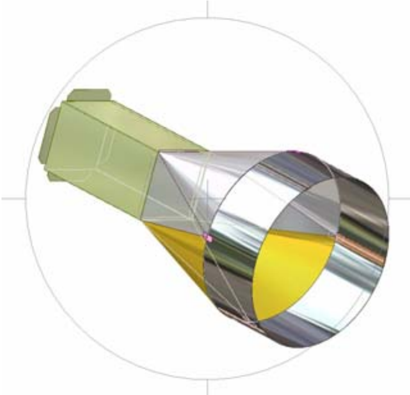


Figure 2: Mechanical assembly in Inventor (Edward Locke, 2004)

Figure 3: Photo-realistic rendering in 3D Studio MAX (Edward Locke, 2004)

Parametric 3D Modeling - the new CAD design standard with SolidWorks, SolidEdge, Autodesk Inventor and others

Great changes have occurred in CAD industry in the last decade with the birth of a new technology called "parametric modeling", which is based on a new generation of 3D geometry coding system such as the Parasolid Kernel owned by Unigraphics, a maker of high-end CAD/CAM program. As In parametric modeling technology, creation and editing of either solid or surface 3D models are performed through the application of parametric values (sizes or dimensions) on a 2D sketch, and/or on a 3D feature that is created on top of the 2D sketch. Parametric 3D modeling CAD programs allow easy, interactive and intuitive creation and modification of 3D parts and assembly models. Typically, the whole process of parametric design is described in the following paragraphs.

First of all, in several "part" files, a 2D sketch is created and constrained first with dimensioning tools; then a 3D "sketched feature" (3D solid such as extrusion, cut, revolution, loft, sweep, etc.) is created based on the constrained 2D sketch; then a "placed feature" (fillets, chamfers, holes, etc.) is added on top of the 3D "sketched feature." The original 2D sketch, the "sketched feature" and the "placed feature" are all stored in a design history recorder interface called "Browser" in Mechanical Desktop, "Feature Manager" in SolidWorks, or "Specification Tree" in CATIA for future editing. When editing is needed, the designer can double-click in the design history recorder either the sketch or the feature to open an editing dialog box and change the parametric values (sketch or feature dimensions); and the 3D model will update.

Next, "assembly" or "presentation" files are created to import and assemble the parts from several part files created so far with geometric constraints; to perform kinematics simulation; to check for tolerance, and to create animated presentation movies.

Next, 2D orthographic multi-view working drawings or isometric presentation drawings are created based on 3D model files.

Thanks to an inter-file 3D data transmission functionality called "associativity," any changes made in the original 3D part files created in the first step will be updated in the assembly and drawing files. In addition, part name, number and other "property" information entered in the part files can be compiled into a BOM (Bill of Materials) in the 2D drawings.

Another outstanding feature of parametric modeling packages is the inter-part size-accommodation functionality called "adaptivity," which allows changes made to a strategic size of a part in an assembly to trickle corresponding changes to the size of another part that is set to an "adaptive" mode with the first part.

In parametric modeling, the relationship between parts and assemblies can be either "bottom-up" or "top-down." In a "bottom-up" relationship, individual parts are created first in separate files; then an assembly file is created to bring in and put together all separate parts with appropriate constraints. In "top-down" relationship, an assembly file is created first; individual parts are created separately but within the same assembly file with appropriate constraints; then individual parts are saved as separate part files along with the assembly file, preferably in the same folder in the computer's storage system.

Parametric CAD programs such as Autodesk Inventor include tolerance allocation features that assist in the evaluation of the relationship between mating parts in the assembly, under real world conditions, but in a virtual digital space.

In real world practice, due to the fact that the modern manufacturing process is complicated and involves the collaboration of professionals from related field in a team-work environment, the above-mentioned three stages of the in most cases overlap and interact in most manufacturing organizations. "It is now generally accepted that the deliberate planning of such interaction - leading to what is known as *concurrent engineering* - is beneficial in improving product quality and reducing the time from design to production" (US Government, 2000).

Thanks to their separate but well integrated or "associated" working environment (such as Inventor's division of the whole design, drafting and presentation into Standard.ipt for parts, Standard.iam for assembly, Standard.idw for drawing), parametric modeling technology provides a great convenience for cooperation in teamwork and concurrent engineering. The recent versions of Autodesk Inventor also contain the Design Notebook, another feature that allows engineers to attach notes to 3D part features and helps engineers and engineering department supervisors to communicate ideas for changes.

Another strength of parametric modeling technology is its ability to create a series of components with different sizes but all based on a master component with same features, all within the same part files, through the use of an internal database or a linked external database file from a third party program such as Microsoft Excel. This is very handy for manufacturers of stock items, such as screws and fasteners, beams, channels, and others. All parametric programs come with libraries of standard parts and design features (holes, notches, cutouts, and many others) that can be easily incorporated and edited into the design process, saving engineers and designers tremendous amount of time, allowing them to spend more energy on overall strategic creative thinking and product planning rather than on some technical routine details that can now be automatically generated by a computer. Due to the fact that the key to parametric modeling and editing is the changes in 2D sketch or 3D feature dimensional parameters, parametric modeling is also called "constraint-based modeling" or "feature-based modeling."

Mechanical Desktop, Inventor, SolidWorks, SolidEdge, ProEngineer, CATIA, and Unigraphics are all parametric programs. Due to the fact that the parametric programs need to store the design history data, both the programs and the files demand more storage space than non-parametric products such as AutoCAD. However, the convenience gained in the design and modification process well justifies the increased demand for digital storage space.

The most popular mid-range parametric modeling program is SolidWorks. The most powerful mid-range parametric modeling program is SolidEdge (website: www.solidedge.com; tel: 800-807-2200), developed by Unigraphics as a mid-range offer. AS mentioned before, SolidWorks uses Parasolid Kernel owned by SolidEdge's parent company; it is natural and logical that SolidEdge should be more powerful than SolidWorks. In high-end market, CATIA, Unigraphics and ProEngineer are parametric and 'process-centric" "total solution" programs. CATIA is now replacing the others as the most popular. Our next discussion will be focused on SolidWorks and CATIA.

Different parametric 3D modeling programs use different names for tools performing similar functions. The following table shows some equivalent tools or features across different programs:

Table 4: Names of Equivalent Tools and Features

AutoCAD	Mechanical desktop	Inventor	SolidWorks	CATIA
None	Browser	Model History Tree	Feature Manager Design Tree	Specification Tree
None	Assembly Constraint	Assembly Constraint	Assembly Mate	Assembly Constraint
Extrude	Extrude	Extrude	Extrude	Pad
Extrude and Subtract	Extrude -Cut	Extrude -Cut	Cut	Pocket

Table 4 (Continued):

AutoCAD	Mechanical desktop	Inventor	SolidWorks	CATIA
Revolve	Revolve	Revolve	Revolve	Shaft
Polar Array	Polar Pattern	Circular Pattern	Circular Pattern	Circular Pattern
Rectangular Array	Rectangular Pattern	Rectangular Pattern	Linear Pattern	Rectangular Pattern
Mirror	Mirror Part	Mirror Feature	Mirror	Symmetry

SolidWorks® technology

SolidWorks Corporation (www.solidworks.com, info@solidworks.com, 1-800-693-9000), founded in 1993, and headquartered at 300 Baker Avenue, Concord, MA 01742, is 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 offers great versatility of features and affordable price; and has been the largest supplier of 3D mechanical design software for the mainstream market with a user base of more than 325,000 product designers and engineers worldwide by 2004. However, since 2003, its position on the 3D parametric solid modeling market is somehow challenged by a greatly enhanced Autodesk Inventor, which can do at least 75% what SolidWorks can do at about half the price (about $2,000 for Inventor commercial license verses about $5,000 for SolidWorks), and recently has outsold SolidWorks.

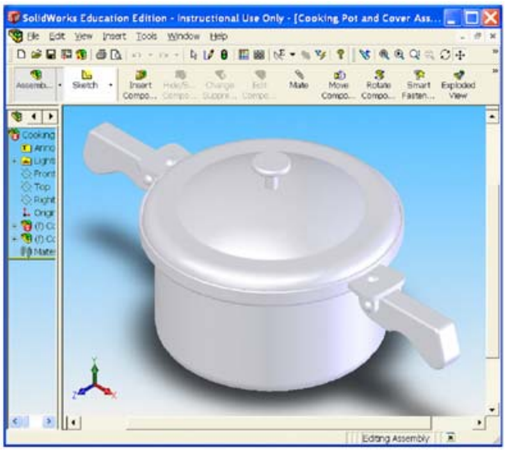
SolidWorks® is based on Parasolid kernal owned by Unigraphics, which offers a more powerful program called SolidEdge, and typically include three “templates” or work environment: Part, Assembly and Drawing. Through fully associative integration, any changes made on a part file is automatically updated in the associated assembly and drawing files. SolidWorks can be used for solid modeling of parts, assembly, sheet-metal forming and pattern development, weldment, and surface modeling with a high capability that rivals CATIA; and besides its design capability, it can make structural and stress analysis of mechanical components (through SolidWorks-owned COSMOSMotion and COSMOSWorks), kinematical simulation of mechanical assembly to predict real-world conditions and test multiple “what if” scenarios, rendering and animation (SolidWorks Animator). COSMOS products are effective industrial simulation tools. “A 2003 study by MIT's Sloan School of Management found that 67 percent of COSMOS users credit it with improving product quality; 59 percent with avoiding field failures, and 15 percent with avoiding product recalls. Most COSMOS customers build 50 percent fewer physical prototypes and roll out product in half the time they did before COSMOS. COSMOS users range from small and medium-sized firms to more than 30 Fortune 500 corporations, and include companies such as Toshiba, Cannon, InFocus, and EchoStar, and government agencies such as the Jet Propulsion Lab. They use COSMOS to analyze designs for products ranging from camera mounts to remote controls, cellular phones, and DVD players. COSMOS helps engineers determine whether assemblies will generate too much heat; whether enclosures can handle required voltages; and whether parts will mesh smoothly during operation" (SolidWorks, 2004).

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. Besides a comprehensive set of engineering design tools with most if not all imaginable options as well as specialty design tools, SolidWorks also offers product data management (PDM) solutions, internet-based design communication and collaboration tools (SolidWorks eDrawings); SolidWorks® 3D PartStream.NET® service, which allows customers to enter a supplier's online catalog and download 3D models to see how they fit into their product designs; and CAD productivity tools that simplify frequently performed design tasks, online catalog solutions.

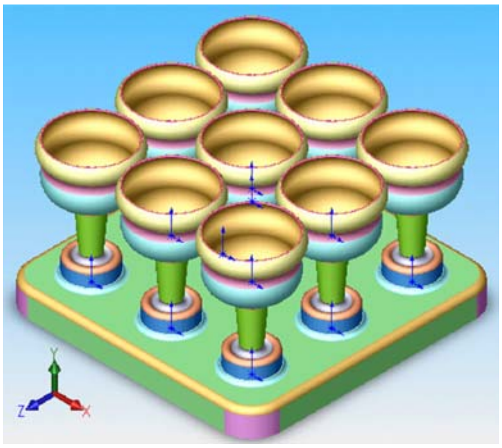
SolidWorks® bridges the gap between electrical and mechanical design through its Routing software with Harnessing tools, which can be used in the design of routes (the paths for wires, cables, tubes, and pipes) and harnesses (wire groups that connect electrical subsystems). According to a company's website article titled *New routing and harnessing enhancements from SolidWorks power automated electrical assembly design: New SolidWorks Harnessing tool and additional SolidWorks Routing features speed design of wire connections between electrical subsystems* at http://www.solidworks.com/pages/news/viewrelease.html?prid=184, "Chief among new electrical assembly design enhancements is SolidWorks Harnessing, which allows users to map out how each wire - complete with connectors and heat-shrink tubing – will fit into the group that is harnessed together along a path created in SolidWorks Routing. For example, an engineer would use SolidWorks Routing to model the path of electrical wires, cables, and harness segments in a car, and SolidWorks Harnessing to flatten the harness and provide specific details for each component and wire within the harness (as well as for cables and harness segments). This capability will help engineers build the car's electrical systems quickly. Previously, engineers either used complex, high-priced 3D computer-aided design (CAD) systems or 2D products that forced them to spend hours building prototypes out of plywood, cardboard, or other materials. They then had to use string and/or tape measure inside the prototype to determine cable/wire paths and lengths, re-building prototypes and re-measuring with each significant design change. SolidWorks Routing and SolidWorks Harnessing eliminate excessive prototyping with automated routing and harness detailing (automatic sizing and dimension calculation) that help engineers get the design right the first time." These tools can calculate the amount of wire and the number of associated components a design requires and make automated wire and component summaries. SolidWorks® software comes in the following packages:

- SolidWorks® Office - a complete product design solution that includes 3D mechanical design software and a full range of design communication and productivity tools, such as: SolidWorks® 3D mechanical design software; design communication tools including eDrawings Professional, 3D Intent Website, 3D Meeting, PhotoWorks™, and SolidWorks Animator; and productivity tools including SolidWorks® Toolbox library of standard parts, SolidWorks® Utilities productivity enhancement software, and FeatureWorks® feature recognition software.

- SolidWorks® Office Professional - the complete product design solution with all the mechanical design, communication, and productivity tools available with SolidWorks Office, plus PDMWorks™, an easy-to-set-up-and-use product data management (PDM) solution that is uniquely adapted to the requirements of SolidWorks engineering workgroups.



Figures 4: Pot designed in SolidWorks (Edward Locke, 2004)



Figures 5: Drinking glasses and holder designed in SolidWorks (Edward Locke, 2004)

New features in SolidWorks 2005

SolidWorks 2005, available in midsummer for purchase in 12 languages worldwide, includes important new features for machine designers, mold designers, and consumer product designers:

- SolidWorks Toolbox, a library of hundreds of the most used pre-designed parts including ports, seal grooves and rings, and slots consistent with Society of Automotive Engineers (SAE) specifications, 2D annotations and blocks; parts from the SolidWorks 3D ContentCentral SM service repository; and parts consistent with the authoritative *Machinery's*

Handbook. These parts can be readily dragged-and-dropped into the design.

- New weldment features with automatic creation of cut lists, determination of mitred/angled cuts, and creation of curved segments.

- Unique Mold Design tools under MoldflowXpress, with the first mold design validation tool built into a solid modeling environment, which enables mold designers to quickly and easily validate whether a plastic injection-molded part can be filled; and a "side core" feature for automatic creation of all side core and lifter geometry necessary to extract finished parts from molds.

- Enhanced and new features for more attractive, functional consumer product design. According to SolidWorks website, "These new features automate the design of companion parts, ultra-sleek curves, and bodies that are bent, stretched, twisted, or tapered. An industry-first Indent feature lets users automatically form a recess in a specified part based on a tool body. For example, SolidWorks 2005 can automatically design the base for an electric toothbrush using the toothbrush body for reference. The user need not specify additional inputs. Enhanced loft features automate the design of smooth, sleek, stylized surfaces to generate products with high consumer appeal. A new Flex feature lets users bend, stretch, twist, or taper solid bodies at any point or region in any direction, enabling dramatic changes to geometry in fewer steps."

- A new Task Pane for collection of all files, folders, and content in a single window on the SolidWorks 2005 interface, enabling users to work efficiently without the frustration of hunting for the resources they need.

- New productivity features including an Auto-Dimensioning feature that automatically adds chain, ordinate, or baseline dimensions to all entities in a drawing vie; a new DrawCompare tool highlighting changes to any two drawings; the new Design Binder allowing multiple usersto insert text or voice comments, files, and links into a SolidWorks file to track design intent and progress.

- A new Application-Specific User Interface with functionality specific to the user's industry segment, e.g., consumer, machine, sheet metal, mold design, etc.

- A Copy Project feature that allowing users to copy all the documents from an existing project into a new one.

- A new Displacement Value feature in COSMOSXpress with automatic provision of precise measurements for the movement of any object that displaces, shifts, or bends during design.

- Enhaced interoperability with Autodesk products, such as the DWGEditor™ tool with the ability to edit 2D DWG files in their native format in an AutoCAD-like interface, with Autodesk-like functionalities of snaps, crossing select and repeat; as well as the capability of automatically creating editable and updateable associative part files and drawing files from Autodesk® Mechanical Desktop® files imported into SolidWorks, including assemblies and assembly drawings.

- PDMWorks® data management software, a simple but powerful product data management (PDM) solution that lets workgroups control project data securely and efficiently; and

- eDrawings ™ Professional**,** the first email-enabled communication tool that dramatically eases the review of 2D and 3D design information across extended product development teams.

Industry recognition and honors for SolidWorks

On July 6, 2004, *Start* magazine, one of the industry's most widely read publications with the reputation of "The Voice of The Manufacturing Executive", named SolidWorks Corporation one of the "Hottest Companies of 2004" four the third time in four years for helping manufacturing engineers more quickly bring new products to market. "The editors considered SolidWorks' pioneering efforts to break down communication barriers in the manufacturing industry by providing a way for engineers to share 3D models and 2D drawings electronically with customers, suppliers, and colleagues, regardless of each party's platform. SolidWorks eDrawings™ e-mail-enabled design communication tool lets users transmit easily viewable design files created in such popular CAD formats as SolidWorks® 3D mechanical design software, AutoCAD®, Pro/ENGINEER®, CATIA, Unigraphics®, and others. Recipients can pan, zoom, rotate, and animate a product in eDrawings as if they were holding it in their hand, without additional viewers, installs, or time-consuming file conversions on their end. In fact, they don't need CAD software at all" (SolidWorks, 2004). Other honors won by SolidWorks include:

CADALYST Magazine's Editor's Wow! Award for SolidWorks 3D Skills Program;

NASA Tech Briefs' Product of the Year Award for SolidWorks 2003;

CADENCE Magazine's Editor's Choice Award for SolidWorks 2003;

CAD CAM Germany's Innovator of the Year 2003;

CADENCE Magazine's 2002 Show Stopper Award;

CADALYST Magazine's 2002 Best of Show Award;

CADALYST Magazine's 2002 Cadalyst Labs All-Star Award.

Part Three
High-end process-centric "Total Solution"CAD/CAM Program: The Dessault Family with CATIA and DELMIA

CATIA family products: an overview

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 much more tools and options than any mid-range packages such as SolidEdge and SolidWorks. At the beginning, like any other software, CATIA's GUI is not so user-friendly. The most recent releases (Version 5 Release 8, 9, 10, and 11) are very user-friendly and intuitive in their GUIs. CATIA is, like other high-end CAD software such as Unigraphics and ProEngineer and I-DEAS, a "Process-centric" package, that includes not only engineering design, analysis and simulation, synthesis and optimization solutions, but also manufacturing and management or "process" capabilities. Of all high-end packages currently available, CATIA is probably the most user-friendly with the best organized GUI. It is "totally integrated with DELMIA, the Company's solution for defining and simulating lean digital manufacturing processes, ENOVIA, its solution for managing product lifecycle information, including digital mockup configuration, processes knowledge and resources information, and SMARTEAM, its rapidly implemented, cost-effective solution for managing product lifecycle collaboration" (Dessault, 2004). 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 Lockheed 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.

CATIA supports concurrent engineering with top-down assembly capability with associativity functionality. CATIA offers solutions for mechanical design (including parts, mold tooling and dies), electronic design, weld design, product synthesis, analysis, shape design & styling, equipment & systems engineering, infrastructure, and machining; and its tools sets are divided into categories of working environments called “Work Benches”, and further sub-grouped into “Tool Bars.” Users can switch among all of these working environments during the process of design, analysis and simulation. Basic “Work Benches” include: Sketcher (2D sketch), Part Design (3D model), Drafting (2D orthographic working and isometric presentation drawings), Assembly Design, Generative Shape Design (surface modeling), Wireframe and Surfaces, DMU (Digital Mock-Up), Navigator (3D animation), Real Time Rendering, DMU Kinematics (assembly motion simulation), Generative Structural Analysis (FEA), Sheet Metal Design, Aerospace Sheetmetal Design, Sheetmetal Production, Composite Design, Prismatic Machining, 3-Axis, Multi-Axis, and Lathe Surface Machining, STL Rapid Prototyping. Specialty “Work Benches” and tool sets include: Structure Design, Equipment Support Structures, Tubing Design and Tubing Diagrams, Waveguide Design and Waveguide Diagrams, Raceway & Conduit Design Raceway & Conduit Design, Hanger Design 2 and HVAC Diagrams with 2D/3D integration, Piping & Instrumentation Diagrams/Piping Design, Structure Conceptual Design 2 (SCD), Structure Preliminary Layout 2 (SPL), Structure Functional Design 2 (SFD) and Ship Structure Detail Design 2 (SDD) for shipbuilders and designers of large equipment, Plant Layout 1 (PLO) for manufacturing plant layout, DMU Space Analysis, DMU Fitting Simulator, DMU Optimizer, DMU Space Engineering Assistant, and DMU Kinematics Simulator with 16 types of joints (Revolute, Prismatic, Cylindrical/Actuator, Planar, Rigid, Spherical, Universal, Point-Surface, Point-Curve, Roll-Curve, Slide-Curve, Screw, Gear, Rack, Cable and Constant Velocity) for assembly simulation, optimization and synthesis, Circuit Board Design, Electrical Harness Installation, Electrical Wire Routing, Electrical Library, Electrical Cableway Routing, Electrical Connectivity Diagrams and Electrical 3D Design and Documentation 1 (EC1) for electrical and electronic design, and many others.

CATIA’s ergonomic analysis tools: digital manikins and VirtualHands with VirtualGloves

As a unique and outstanding feature environment, CATIA’s ability to create human manikins for the DMU testing of the interactive ergonomic interface between humans and machines is very powerful and comprehensive as well. It is designed with a user-friendly interface for non-specialists in ergonomics and includes the following tool sets: Human Builder 2 (HBR), Human Measurements Editor 2 (HME), Human Posture Analysis 2 (HPA), and Human Activity Analysis 2 (HAA). These products are combined to create a fully integrated Human Engineering Design and

Review solution, in terms of creation and manipulation of accurate standard digital humans, male or female, young or old, of any race, American, Asian or European. These tools address the needs of design engineers, managers, maintainability engineers and concept designers from the aerospace, automotive, plant design, heavy engineering, ship building and electrical goods industries, for early human-product biomechanics interaction analysis, static and dynamic simulation, through advanced detailed digital human creation and analysis, so as to predict the human performance, ensure conformance to health standards and optimize the human comfort and safety. They can define manikin postures and positions for manikin manipulation, with respect to existing parts of the environment (reach capability); perform and analyze virtual human laboring tasks such as lifting, lowering and carrying loads, pushing and pulling. These tools can also be used to analyze the manikin vision to enabling a better understanding of what an operator would see in a task environment; simulates the motion of humans and their interaction with virtual products. “Manikin structure consists of 99 independent links, segments and ellipses. Fully articulated hand, spine shoulder, and neck models to accurately reproduce natural human movement. […] Manikins can be interactively positioned using the DMU compass, or by selecting objects to be reached. Direct kinematics manipulators can be employed to accurately ‘fine tune’ the manikin posture by manipulating individual segments in each degree of freedom. Seven default Inverse Kinematics handles manikin motion and accurately predict natural posture. 148 degrees of freedom also take into account limits of joint mobility and coupled range of motion. […] Manikin vision assessment permits a designer to understand what an operator or maintainer would ‘see’ in a task environment. A separate vision window displays the vision field from the manikin perspective. Lines of Sight, as well as vision cones in three separate formats, can also be displayed. Visual disability or limitation can be simulated. Visual characteristics are displayed as cones that permit the user to gain an insight into the manikin's view within the virtual environment” (CATIA, 2004). The CATIA human manikin tools can be integrated with Knowledgeware for user customization. **“**Manikin anthropometry parameters can be used to create Knowledgeware formulas, in order to capture ergonomic rules for product design, and to further enhance human-product interaction, through the use of Design Tables.

VirtualHand® for V5 Design or VirtualHand for V5-Digital Mockup (DMU), third party programs made by IMMERSION CORPORATION, allows the engineers and designers to “reach and touch” CATIA digital prototypes and to intuitively evaluate the ergonomics and assembly of the products, wearing an Immersion CyberGlove® instrumented glove. Users wearing a CyberTouch glove additionally feel tactile feedback.

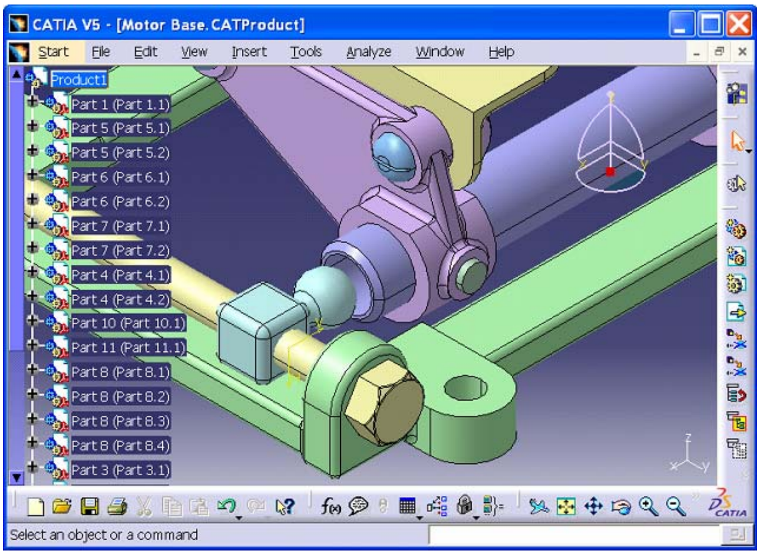


Figure 6: Assembly in CATIA (Edward Locke, 2004)

DELMIA, a "process-centric" extension of CATIA design capabilities into manufacturing management

DELMIA's Digital Manufacturing Solutions are used in automotive, aerospace, and shipbuilding from process planning to general assembly processes and factory simulation across all manufacturing segments. They allow complete design and validation of the manufacturing processes through digital mock-up, and management of the manufacturing process, including creation of kinematics models of manufacturing tooling, such as fixtures, clamps, and other articulated mechanisms; visualization, query and filtering of mechanical dimensioning and tolerancing; and the programming of robot motion on the shop floor. This helps to decreases the study time, providing a realistic simulation model that optimizes the assembly line and cuts production costs. DELMIA is used in large manufacturing corporations such as the Boeing Corporation's Long Beach aerospace assembly plant.

CATIA's industrial application and education in Southern California

CATIA family products are used in Europe, Asia, Northern States in the United States. In Southern California, besides engineering schools at four-years universities such as California State University at Los Angeles, community colleges such as El Camino College offers CATIA courses. The Industry and Technology at El Camino (www.elcamino.edu, 16007 Crenshaw Blvd., Torrance, CA 90506), located in the City of Torrance, close to Lockheed Martin, four courses are offered every semester:

Table 5: CATIA Courses at El Camino College

Number, Name and Units of the Course	Textbook Used
Computer Aided Design/Drafting 31abcd – Orientation to CATIA (2 Units) This course covers 2D sketch, 3D solid modeling and creation of 2D drawings from 3D models. This course can be unconditionally repeated four times.	*CATIA V5 Workbook Release 10 & 11,* by Richard Cozzens. SDC Publications. Cedar City, UT. www.schroff.com. ISBN 1-58503-138-X
Computer Aided Design/Drafting 32abcd – Solid Modeling CATIA (2 Units) This course covers advanced 3D solid modeling and 3D wireframe and surface modeling. This course can be unconditionally repeated four times.	Wichita State University CATIA Version 5 Wireframe & Surfaces, by CAD/CAM Laboratory of the National Institute for Aviation Research, Wichita, KS. www.cadcamlab.org
Computer Aided Design/Drafting 37abcd – Advanced CATIA Functions (2 Units) This course covers advanced functions such as DMU and FEA. This course can be unconditionally repeated four times.	*Advanced CATIA V5 Workbook Release 8 & 9,* by Richard Cozzens. SDC Publications. Cedar City, UT. www.schroff.com. ISBN 1-58503-102-X
Machine Tool Technology 10G – Numerical Control Graphics Programming with CATIA (3 Units) This course covers CNC programming with CATIA.	*Advanced CATIA V5 Workbook Release 8 & 9,* by Richard Cozzens. SDC Publications. Cedar City, UT. www.schroff.com. ISBN 1-58503-102-X

Versatility and comprehensiveness of CATIAA tool: a review of FEA in CATIA

Although individual tools with various options in CATIA are easy to learn, the basics of CATIA still takes about one year to learn due to the large numbers of tools and options in the CATIA program. The FEA (Finite Element Analysis) and kinematics analysis environment in CATIA is a typical example. CATIA comes with its own FEA and kinematics simulation tool sets called Analysis Workbench, tools that provide easy and fast structural analysis of any type of assembly facilitates a wider number of mechanical behavior and sizing assessments earlier in the product development process, through an analysis and simulation environment called “Digital Mocke-Up”. They include Toolbars: Generative Part Structural Analysis; Generative Assembly Structural Analysis; Dynamic Response Analysis, Tolerance Analysis of Deformable Assembly 3 (TAA), ELFINI Structural Analysis, FEM Surface, and FEM Solid. In addition, CATIA can be integrated with high-end third party simulation software such as MSC.Nastran and MSC.Marc, ABAQUS, ANSYS and MatLab, can import I-DEAS data; and its CAAV5 based Analysis Products include the following developed by third party partners, according to CATIA website:

LMS Virtual.Lab Cavity Meshing by LMS Numerical Technologies SA (Gold Partner), LMS Virtual.Lab FRF-based System Level Response Prediction by LMS Numerical Technologies SA (Gold Partner), LMS Virtual.Lab Vibration Response Prediction By LMS Numerical Technologies SA (Gold Partner), SimDesigner Gateway for STEP AP209 (GWS) by MSC.Software Corporation (Gold Partner), SimDesigner Motion (SMO) by MSC.Software Corporation (Gold Partner), SimDesigner Linear (SDL) by SC.Software Corporation (Gold Partner), SimDesigner

Gateway for MSC.Nastran (GWN) by MSC.Software Corporation (Gold Partner), ICEM CFD Hexa CAA V5 Based by ICEM CFD Engineering Inc (Partner), LMS Virtual.Lab Motion Standard by LMS Numerical Technologies SA (Gold Partner), CATFORM3D CAA V5 Based by Forming Technologies Incorporated (FTI) (Partner), TEA Mecano CAA V5 Based (Transparent Extended Analysis) by SAMTECH (Partner), LMS Virtual.Lab Durability by LMS Numerical Technologies SA (Gold Partner), LMS Virtual.Lab Ansys Interface by LMS Numerical Technologies SA (Gold Partner), SimDesigner Gateway for ANSYS (GWA) by MSC.Software Corporation (Gold Partner), SimDesigner Gateway for ABAQUS (GWQ) by MSC.Software Corporation (Gold Partner), SimDesigner Gateway for MSC.Marc (GWM) by MSC.Software Corporation (Gold Partner), SimDesigner Thermal (SDT) by MSC.Software Corporation (Gold Partner), LMS Virtual.Lab CATIA V5 Kinematics Transfer by LMS Numerical Technologies SA (Gold Partner), LMS Virtual.Lab Acoustic Response Prediction by LMS Numerical Technologies SA (Gold Partner), LMS Virtual.Lab Desktop by LMS Numerical Technologies SA (Gold Partner), LMS Virtual.Lab MSC.Nastran Interface and Driver by LMS Numerical Technologies SA (Gold Partner), LMS Virtual.Lab I-DEAS Universal File Interface by LMS Numerical, Technologies SA (Gold Partner), TEA Thermal CAA V5 Based (Transparent Extended Analysis) by Samtech (Partner), LMS Virtual.Lab Path Contribution Analysis by LMS Numerical Technologies SA (Gold Partner), ABAQUS FOR CATIA V5 by ABAQUS, INC (Partner), LMS Virtual.Lab I-DEAS Interface by LMS Numerical Technologies SA (Gold Partner), LMS Virtual.Lab Motion Advanced by LMS Numerical Technologies SA (Gold Partner), LMS Virtual.Lab EASY5 Interface by LMS Numerical Technologies SA (Gold Partner), LMS Virtual.Lab IGES Interface by LMS Numerical Technologies SA (Gold Partner), LMS Virtual.Lab Matlab Interface by LMS Numerical Technologies SA (Gold Partner), LMS Virtual.Lab Pro-E Interface by LMS Numerical Technologies SA (Gold Partner), LMS Virtual.Lab Pre-Acoustics by LMS Numerical Technologies SA (Gold Partner).

With a versatile set of built-in and plug-in third party tools, CATIA offers a total solution to FEA and kinematics simulation problems. The above list is an example of CATIA’s comprehensive capability with its own and allied third party tools and features.

Another example of CATIA’s feature strength is its mold design environment. The Mold Design and Mold Tooling Design Workbenches of CATIA - Mold Tooling Design Product “allows rapid, cost effective creation of mold tooling for the plastic injection process thanks to the use of predefined components from standard catalogs with specific functionality to define mold components and instantiations.” The standard locating, guiding, ejection and connection, split of core, cavity plate, split of mold component feature-generation tools such as Slider, Angle Pin, Leader Pin, Dowel Pin, Bushing, Sleeve, Stop Pin, Screw and Locating Ring, Clamping, Upper Bar, Cavity Support, Cavity, Core, Core Support, Ejector Sleeve , Core Pin , Knock-Out, Riser, Setting, Ejector A, Ejector B, Ejector Pin, Flat Ejector, Cap Screw, Countersunk Screw and Locking Screw, Eyebolt, Sprue Bushing, Sprue Puller, can automatically create all needed features at desired positions in mold design. "The non standard Mold Base can be completed with some standard or non-standard components (as Leader Pin, Bushing, etc.), and stored in a user catalog that will be accessible as the standard one." The updated standard catalogs of components and Mold Bases made of a set of plates include all main standards of the market, such as HASCO, DME, DME-AMERICA, RABOURDIN, STRACK, FUTABA, MISUMI, EOC, NATIONAL, PEDROTTI, PCS, MEUSBURGER, with thousands of configurations. "Users can access these catalogs, including many thousands configurations, and retrieve Standard Mold Base with their plates definition. They can also search those configurations and retrieve the appropriate ones thanks to a set of main parameters like Nomenclature, Mold Length and Width, Overhang value, etc" (CATIA, 2004).

Comprehensiveness, versatility and thoroughness, meticulousness, sophistication, are excellent characteristics of CATIA tools and features, which include practically everything needed in real-world industry practice. For example, the Generative Aerospace Sheetmetal Design in the CATIA Aerospace Interface features all possible and familiar aerospace features tools for every imaginable design situation, such as Web, Flange (curved, double curved or planar), Flange cutout, Flanged Hole, Flanged Slot, User Flange, Joggle Slot Cutout, Stiffening Bead, Stiffening Rib, Corner Relief, Hole Stamp, Planar Flange, Tear Drop and Hem. This great tool set is more than enough for designers to concentrate on their design project. CATIA Version 5 is available in the following national languages: English,French, German, Italian, and Japanese.

CATIA's built-in compliance with engineering standards, conventions, real-world industry practice, and compatibility with other CAD platforms and standards

As a leading high-end "Total Solution" package encompassing a broad scope of design, analysis and simulation, manufacturing and management serving a global-wide, cross-continental audience, CATIA and associated products conform with all major international engineering design conventions and standards. CATIA's Drafting work bench, for example, supports most CAD drawing standards such as ISO, ANSI, and JIS (Japanese Industrial Standards), and offers both 3rd Angle Projections (for USA) and 1st Angle Projection (for Europe and Japan) drawing view arrangements, and includes tools such as Text, Datum, Datum targets, Geometrical tolerances, Flag-note, Roughness for automatic creation of drawing annotations and symbols. CATIA projects can be saved as or exported into, and CATIA program can open or import from all popular CAD formats, such as DXF (AutoCAD ASCII format), DWG (AutoCAD native format), JPEG, PDF, AVI, for documentation, presentation, and archiving purposes.

CATIA is an open system allied with a growing army of third party partners and its programming capabilities are compatible with popular programming languages such as C++, Visual Basic, and Java.

In recent years, Dassault Systeme has made great progress in bringing CATIA GUI in line with Windows environment the American and international audience is familiar with; making its GUI much as user-friendly as all other popular American software, and much more intuitive and interactive than before. In addition, its user-friendly American-style outlook is coupled with a French-style mathematically strict forward thinking, and a pro-active globally expanding foresight. In order to increase its market share and make learning opportunity more available to ordinary people, CATIA Student Edition is now sold at US$100 per seat through www.engineering.com. Comparing different offerings in CAD market today, we can say that CATIA is an enlightened aristocrat while Inventor and SolidWorks are both people's choice. CATIA's main shortcoming is its expensive price as well as lack of textbooks available in the publication market; however, its great power is worth of the bucks. If Dassault Systeme can further democratize CATIA in terms of price drop and abundance of textbooks and other teaching and learning materials, its potential for marketing growth would be very brilliant. In summary, CATIA is the recommended high-end CAD package in this report.

Stringent software and hardware requirements for CATIA

CATIA is very demanding on hardware. The following Tables, compiled from data provided by CATIA website, show the general requirements for all systems and particular requirements for particular systems.

Table 6: CATIA V5's Basic Hardware and OS Requirements for Particular Platform

Feature	**Platform**				
	Windows	**IBM AIX**	**HP-UX**	**SGI IRIX**	**Sun Solaris**
Disk drive for installing all CATIA V5 Products	2.0 GB	2.4 GB	2.7 GB	2.5 GB	2.3 GB
System Unit (CPU)	Intel Pentium III or Pentium 4 based workstations.	RS/6000, based on PowerPC 604 (166 MHz), Power2 or Power3 or Power4 processor families.	B-Class, C-Class or J-Class work-station based on a PA8000 processor family.	O2, Indigo2, Octane, Octane2, Onyx2, Fuel or Onyx3000 workstations with R5000, R10000, R12000 or R14000 processors.	Ultra1, Ultra2, Ultra10, Ultra30, Ultra60, SUN Blade 100, SUN Blade 150, SUN Blade 1000, SUN Blade 1500, SUN Blade 2000 or SUN Blade 2500 workstation with UltraSPARC processor.

Table 6 (Continued):

Feature	Platform				
	Windows	IBM AIX	HP-UX	SGI IRIX	Sun Solaris
Operating System Software (Minimum level required)	Microsoft Windows 2000 Professional Ed. with Service Pack 2 or higher, or Windows XP Professional Ed. with a Microsoft implementation of OpenGL libraries delivered with Windows 2000 or Windows XP*.	AIX Version 4 Release 3.3, or AIX Version 5.1 with the following: IBM C Set++ for AIX Application Runtime (5765-F56) at a minimum level of 6.0.0., IBM XL Fortran Runtime Environment for AIX (5765-E03) at a minimum level of 7.1.1., OpenGL and GL3.2 Runtime Environment, Common Desktop Environment, all delivered with the operating system). With Release 13, AIX 4.3 is no longer supported	HP-UX Version 11.0 ACE (Workstation Additional Core Enhancements for HP-UX 11.0 November, 1999), or HP-UX 11.11 (HP-UX 11i), with the following: ANSI C++ Runtime Environment (aC++, at a minimum level of 3.30), HP Fortran 90 Runtime Environment, HP-UX 700 OpenGL 3D API Runtime Environment CDE, all delivered with the operating system.	IRIX 6.5.15m, with the following: C, C++ and Fortran77 standard execution environment (delivered with the operating system), OpenGL (delivered with the IRIX execution environment), IRIX Interactive Desktop (delivered with the operating system), WorldView when the selected installation locale differs from ISO-1.	Solaris 8 Operating System. H/W 02/02, with the following: C and C++ runtime environment, OpenGL runtime environment, CDE, all delivered with the operating system, and Fortran runtime environment (delivered with CATIA Version 5). A localized version of the operating system may be required when the selected installation differs from ISO-1
Graphic Adapter	A graphic adapter with 3D OpenGL accelerator, with 24 bits, true color, double buffered visual 24 bits Z-buffer, Stencil buffer, minimum supported resolution of 800x600 and recommended supported resolution of 1280x1024.	GXT500P, GXT550P, GXT800P, GXT800M, GXT2000P, GXT3000P, GXT4000P, GXT4500P, GXT6000P, or GXT6500P.	Visualize-FXE, Visualize-FX2, Visualize-FX4, Visualize-FX5, Visualize-FX6, Visualize-FX10, or Fire GL-UX	Integrated graphic adapters on O2 workstations, Solid Impact, or SI/SE Super Solid Impact, or SSI/SSE High Impact. MAXimum Impact, or MXI/MXE VPro V6, VPro V8, VPro V10, VPro V12, InfiniteReality, Infinite, Reality 3, or InfinitePerformance.	Creator3D, Creator3D Series III, Elite 3D (U10-440 Mhz only, for U10 workstations), Expert3D Lite, Expert3D, XVR-500, XVR-1000, or XVR-1200.

Note:
* These libraries may have to be modified to accommodate the selected graphic adapter when installing the graphic adapter and its associated drivers. For recommendations related to driver levels based on tested graphic adapters, visit: http://www.ibm.com/solutions/plm/
A localized version of the operating system may be required when selected installation differs from Latin 1.
For remote access from networked clients, Terminal Server is supported by Windows 2000 Server, Windows 2000 Advanced Server and Windows XP Profesional. Access through standard browsers requires Citrix MetaFrame 1.0 to also be installed on the server.

Table 7: Basic CATIA V5 Hardware Requirements for All Platforms

RAM Memory	Minimum of 256 MB of RAM recommended for all applications. Minimum of 512 MB of RAM recommended for DMU applications on large assemblies and for the DSE product for all platforms.
Disk drive	4 GB minimum required for storage of program executables.
Internal/ External Drives	CD-ROM drive required for program installation and access to the online documentation for all platforms.
Display monitor	17 inches minimum recommended size color monitor compatible with the selected platform-specific graphic adapter. Minimum resolution for Windows workstations: 1024x780. for Minimum resolution for UNIX workstations: 1280x1024.
Keyboard	Specific keyboard compatible with selected installation locale may be required for national language support.
Pointing device	3-button mouse or IntelliMouse (two buttons plus wheel) recommended. SpaceBall and SpaceMouse can be used, in addition to the mouse, to perform graphic manipulations (zoom, pan, rotate, etc.); necessary drivers are delivered with the device. Those devices can be used with DN1, SP1 and all CATIA P2 Products*.
Network Adapter	Active LAN adapter (Ethernet or Token Ring) required for licensing purposes**.

Note:
* Windows and UNIX hardware configurations certified by Dassault Systemes for running CATIA Version 5 products are published at http://www.ibm.com/solutions/plm/.
** Supported Configurations on Windows2000 and Windows XP: an updated list of hardware configurations, certified at Dassault Systemes for running CATIA Version 5 products, is published on the CATIA V5 Web site at URL: http://www.ibm.com/solutions/plm/.

Customer base of CATIA family products

Due to its high cost, CATIA's audience is usually restricted to the elite core leadership of modern industry, or large and usually multinational corporations, or other established and financially resourceful companies. Besides most of the aerospace and automobile manufacturers, the following are members of the growing CATIA VIP Club:

Pratt & Whitney, Canada (P&WC), founded 75 years ago, one of the world's leading designers and manufacturers of turbofans, turboprop and turboshaft engines for regional, business, utility and military aircraft as well as helicopters, and a subsidiary of United Technologies Corporation, employs approximately 9,000 people worldwide, based in Longueuil, Canada, with a global presence in Australia, Brazil, China, Germany, Poland, Russia, Singapore, South Africa, the United Kingdom and the United States, with a production portfolio of over 55,000 engines for customers in more than 190 countries, and prestigious clients such as Agusta, Airbus, Bell Helicopters, Boeing, Cessna Aircraft Company, Dassault Aviation, Embraer, Eurocopter, Raytheon Aircraft and many more;

Nissan Diesel Motor, a user of both CATIA and I-deas, software from EDS in the design process; and ENOVIA DMU navigator, DELMIA's digital manufacturing tool, to check collisions and validate assemblies;

GRANDSOLEIL, a French-owned European manufacturer of toys and garden furniture in steel, cloth and plastic setup in 1963 near Mantua, with a 380-strong workforce, and an annual turnover of 55 million euros;

Serra Soldadura, an automated welding solutions provider founded in 1934, as a family-owned company in Barcelona, Spain, and currently a world-class enterprise with plants in Spain, France, Portugal and Brazil, with 800 employees worldwide, serving major automotive manufacturers, such as Volkswagen AG and General Motors, Daimler Chrysler AG, Renault SA and PSA or aeronautics companies such as AIRBUS;

The Italian-based Maschio Group, formed in 1998 as a merger of Maschio S.p.A., Gaspardo Seminatrici S.p.A. and Terranova S.p.A., and a world leader in agricultural machinery, such as power harrows, rotary tillers and shredders, seed drills, row-crop cultivators, and finger-blade mowers for sowing perations, with a 580-strong workforce, and an annual turnover of 82 million euros in 2002.

Part Four
Electronic Design and Simulation programs: Electronics Workbench Family Products

Fundamentals of Electronic Design Automation (EDA) and Virtual Instruments

Traditionally, electronics engineering design always involved a lot of trigonometry and calculus based mathematical computations, breadboard testing and expensive equipment; and design projects usually took months to complete through a series of trials and errors; and when using testing equipment, technicians had to make sure that appropriate equipments with correct testing range are used, otherwise, there might be damage to the equipment or even risks to human life. The birth of Virtual Instruments since the 1980’s with the founding of electronics design automation (EDA) software programmers such as Electronics Workbench in Canada has brought about a revolutionary change to all of these traditional practices. Electronic circuit development and evaluation/testing software allows electronic engineers to design and test electronic circuits in a “virtual” environment, i.e., in a personal computer, risk-less and damage-free, with amazingly accurate prediction of potential results in the real physical world. This allows designers to try out different options until an ideal one is reached and "virtually" tested for safety and functionality before they put components on a breadboard or a bench top to build a physical circuitry. "Virtual instruments" within circuit design software can imitate familiar features and operations of common bench top test equipment, and come up with testing results with great precision. Three simple steps are used to perform an electronic design automation task: the first step is to create the electronic circuit schematic; the second step is to "virtually" turn on the circuitry; the third step is to connect "virtual" testing equipment to the circuitry to get a testing result. The designers can perform all of theses steps in Electronics Workbench software by simply clicking appropriate icons in appropriate toolbars and then placing the virtual components and equipment in the design schematic screen with drag-and-drop mouse action. "If you want to measure the behavior of a physical prototype, you can use virtual instruments as an interface to the simulation engine, making the simulator much easier to use. After finishing with a virtual prototype, you can then make a physical prototype and transfer knowledge you've gained about the circuit to simplify testing of the physical prototype" (Sheffield, 1997). In Electronics Workbench as well as many other companies' EDA programs, the graphic user interface (GUI) of all virtual Instruments match those of their real world counterparts with photo-realistic window screens and graphs display for testing results.

History and overview of Electronics Workbench and MultiSIM

There are many software programs used to design and simulate electrical and electronic projects. They include Orcad Capture®, PSPICE®, Ulticap®, Circuit Maker and Electronics Workbench.

Overall, Electronics Workbench with its latest tool set called MultiSIM is among the world's most widely used and most powerful circuit design software with more than 160,000 licenses sold. Electronics Workbench's Windows-based Electronic Design Automation (EDA) design tools are used for schematic capture, simulation, layout and routing of printed circuit boards (PCBs), and for electronic design analysis and simulation. Founded in 1982, Electronics Workbench (formerly known as Interactive Image Technologies, Ltd.) is a privately held corporation. Important milestones in the history of the Electronics Workbench Inc. include the following:

- March 22, 1999 - Electronics Workbench merges with Ultimate Technologies.

- September 20, 1999 - Electronics Workbench acquires one of the largest EDA distributors in Germany with the acquisition of Compro GmBH, Electronics Workbench strengthens its leadership position in the German EDA market.

- May 29, 2000 - Electronics Workbench and PartMiner provide EDA industry with web access to world's largest component database.

- January 29, 2002 - Electronics Workbench's CommSIM 2001 solution recognized by EDN Magazine as Hot Product.

- August 12, 2002 **-** Electronics Workbench creates StudentSuite for the electronics education market and announces exclusive distribution agreement with Pearson Prentice Hall.

- February 25, 2003 **-** Electronics Workbench and National Instruments deliver new circuit design educational tools.

The company is headquartered in Toronto, Canada (address: 111 Peter Street, Suite 801, Toronto, Ontario M5V 2H1; Sales: 800-263-5552; Fax: 416-977-1818; website: www.electronicsworkbench.com); and it has offices in New York (address: 60 Industrial Park, #068, Cheektowaga, NY 14227), Toronto, Amsterdam, Stuttgart, London and Paris, as well as a network of local sales and support services in over 35 countries throughout the world, has over 15 years of EDA experience and is one of the original pioneers of PC-based electronics design tools. General information websites of Electronic Workbench are listed below:

General Inquiries: ewb@electronicsworkbench.com;

North America Sales: nasales@electronicsworkbench.com;

International Sales: isales@electronicsworkbench.com;

Training: training@electronicsworkbench.com.

Electronics Workbench products and educational institutions

Electronics Workbench products are not only great design tools, but also wonderful teaching tools. They are written with a far-sighted goal of improving the quality of education in the first place; and over the years, due to their easy-to-learn and easy-to-use interface, as well as its affordable price, they have become “The Standard in Electronics Education Software.” The company claims in its website that “Electronics Workbench is the only company to design its products specifically for academia.” Although it is beyond the scope of this report to prove the validity of this exclusionary claim as “the only company,” personal trials by the author of this report does fully support the fact that the company’s products are very useful to and oriented towards electronics educational programs. “More educators rely on Electronics Workbench for circuit analysis, design and simulation software than any other vendor […] As a result, the company generates significant revenue earnings from this market segment. Entire countries have standardized their colleges and universities on Electronics Workbench products, most recently Belgium where eight of the country's universities now use MultiSIM exclusively in teaching labs. Electronics Workbench is committed to providing the tools that will help create topnotch engineering talent to fill the needs of the global electronics workplace" (Electronics Workbench, 2004). In Southern California, four-year universities such as California State University at Fullerton, and two-year community colleges such as Cerritos College and Los Angeles Trade Technical College employ MultiSIM and other Electronics Workbench as instructional tools for electronics courses, or offer courses totally dedicated to teaching the skills of using Electronics Workbench programs.

Market dominance of MultiSIM

Electronics Workbench products have received high remarks for its strong design and simulation capabilities, from professional EDA (Electronic Design Automation) publications, such as Electronic Design (http://www.elecdesign.com), etc. In an online article titled *What's Hot At DAC: New tools and methodologies to be unveiled span system-level design to post-layout analysis* published on May 26, 2003, on Electronic Design, David Maliniak states that "Designers of pc-boards will be interested in MultiCAP 7 and MultiSIM 7, the latest versions of Electronics Workbench's schematic capture and simulation tools for pc-board design. For those performing schematic entry without simulation, MultiCAP 7 performs pure schematic entry, drives simulation, and/or feeds pc-board layout. It offers model-less operation, eliminating the need to switch between part placement and wiring modes; autowiring (just click on two pins and the tool automatically creates a connection); and more. With the MultiSIM 7 Spice simulator, users can verify circuits and correct errors before they appear in later design stages. It includes an integrated version of MultiCAP, allowing users to create and then instantly simulate circuit designs" (Maliniak, 2003).

On June 1, 1999, New MultiSIM from Electronics Workbench delivers multiple simulation technologies; and on May 5, 2003, Electronics Workbench announces MultiSIM 7 for Professional Circuit Engineers and Designers. MultiSIM offers solutions for all major steps in the circuit design flow: schematic capture, simulation, PCB layout, auto-routing and CAM preparation, all within a single well integrated interface, eliminating the need for data integration and ensuring a smooth design and analysis/simulation flow. With continued growth in R&D investments, an industry renowned ease-of-use and user-friendly GUI, flexible licensing options and multiple price points, which allow clients to choose from two tiers of every product to match any budget (Professional and Power Pro), and choose the whole integrated Electronics Workbench Suite or any product individually, powerful analysis and simulation features, the company's printed circuit board (PCB) design system incorporates schematic capture; co-simulation of analog and digital circuits using SPICE, VHDL and Verilog; RF design tools; PCB layout and routing; and CAM verification tools. MultiSIM was voted a "Top 10 EDA Product of the Year" by Cahner's Electronic's industry yearbook, the only mainstream product to achieve this honor, and is used by a lot of prestigious corporations as listed alphabetically below, according to data provided by the company's website at http://www.electronicsworkbench.com/html/proabt.html:

3M, AT & T, Advanced Micro Devices, Agilent, Alcatel, Allen-Bradley, Allied Signal, AMP, Analog Devices, Atmel, Bang & Olufsen, BMW, Boeing, Bombardier, Celestica, Cisco Systems, Compaq, Dow Chemical, Eastman Kodak, Ericsson, Fairchild Semiconductor, Ford, Fujitsu, General Electric, General Motors, Harris Semiconductor, Hewlett Packard, Hitachi, Honeywell, Hughes, IBM, Intel, Johnson Controls, Lockheed Martin, Los Alamos National Labs, Lucent Technologies, Microchip Technologies, Mitel, Motorola, NASA, National Semiconductor, Nortel Networks, Northrop Grumman, Philips, Procter & Gamble, Raytheon, Rohde & Schwarz, Robert Bosch, Rockwell Collins, Rolls-Royce, Sandia National Labs, Scientific Atlanta, Siemens, Sony, Texas Instrument, and Xerox.

The selling and pricing policy of Electronics Workbench is very flexible and "personalized." The company provides the customers with the freedom to configure the ideal solution for their design needs, with a number of company recommended Suites such as the Electronics Workbench PCB Suite simulation and autorouting; the combination MultiCAP/UltiBOARD suite for capture and layout software; a complete Design Suite integrating MultiCAP, MultiSIM, UltiBOARD and UltiROUTE, for the creation of more complex designs as an "end-to-end solution;" and the PCB and Design Suites in Professional and Power Pro tiers to match the customer's project requirements and budget. If the Electronics Workbench's recommended Suites don't match their exact requirements, then the customers also have the option of building their own "Suites," choosing from the four main products, each available in two tiers, as well as multiple add-on modules that address specific design requirements. For great features, Electronics Workbench restricts its prices at affordable level. For example, in 2001, the cost for educational versions of CommSIM is $89 for students and $399 for educational use. Lab licenses are also available; the cost for Commercial versions is $995 for the CommSIM Pro, with a MAXimum of 100 blocks per system diagram, and $4995 for PowerPro with unlimited system blocks per system diagram. MultiSIM is available in Personal, Professional, and Power Pro Editions at prices from $399 for the Personal edition, to $995 for Professional, up to $6995 for Power Pro. For UltiROUTE, the Personal Edition sells for $299 and contains complete grid and gridless autorouting; the Professional Edition at $995 adds autoplacement. In addition, the company sometimes offers free upgrades or add-ons to existing customers. The company also offers free version of MultiSIM Demo software to students; the only limitation is that files cannot be saved.

Fundamentals of MultiSIM interface and operating methodology

Electronics Workbench is an intuitive, easy-to-learn, easy-to-use no-brainer's tool. Tools for the creation of virtual electronic components such as diodes, resistors, capacitors, etc., as well as a large library of over 16,000 parts and Virtual Instruments that operate just like their real world counterparts, such as ohmmeters, ammeters, voltmeters and potentiometers, logic analyzer, scopes, spectrum analyzer, and even simulated “real” Agilent® instruments, etc., which are grouped in different tool bars; and the users can easily click on the tool icons and then on the screen to create a virtual electronic circuit board layout, and conduct a hazardless virtual testing or simulation, in a highly integrated design flow. In addition to the master library that ships with the product, users can set up corporate or user libraries.

All Electronics Workbench products benefit from an integrated Component Database System, which stores all component data in a single repository, which links all elements of a design (including schematics, PCB layouts, simulation settings, component libraries, reports and any supporting non-EDA files like Microsoft® Word) hierarchically in a Project File to facilitate project management and multi-user team collaboration. Electronics Workbench has built-in intelligence such as Electrical Rules Check that prevents schematic errors from propagating further down the design flow. Electronics Workbench include five design and analysis/simulation environments, each of the them can either operates as a stand-alone application or combine to offer a tightly integrated “end-to-end” total design, simulation, and analysis solution:

MultiCAP 7 for schematic capture, simulation and capture - a capture program for schematic entry, driving simulation, or feeding PCB layout, with powerful wiring algorithms that allow both manual and automatic wiring, as well as drag-and-drop placement and connection of electronic components and devices, which are stored in an integrated database along with their simulation models and PCB footprints, automatically ready to simulate at the click of a single button, and transferable to PCB layout. With cross-probing functionality, engineers can select a symbol in MultiCAP and instantly see the corresponding footprint highlighted in UltiBOARD; and changes made at any stage in the design process can be annotated - either forwards or backwards; and in addition, sophisticated Design Rules can be created during capture or layout, and recognized and observed by all downstream steps. MultiCAP’s innovative and timesaving features include modeless operation, powerful autowiring and a comprehensive database organized into logical Parts Bins on the desktop for creating complex designs in less time than the user thought possible. Parts can be found by using searches on any electronic parameters. Filters can limit results to certain manufacturers or families. Other good features are Symbol Editor for customization of electronic symbols; and Project manager for navigation of the structure of hierarchical schematics, for collating schematics, simulation data, PCB files and documentation together into a single project, and for locking the files to allow other users to view files but not to make unauthorized changes. Another outstanding feature is the Electrical Rules Check that allows the users to define what MultiCAP sees as a schematic error. “It can search for errors such as outputs connected together, inputs connected together, an input pin driving an output and I/O pins incorrectly connected to power. The Schematic Statistics report summarizes the number of parts, nets, unconnected pins and more, while the Spare Gates report shows unused gates in multi-section parts.” MultiCAP can automatically generate a fully customizable Bill of Material (BOM) report that displays information about all the components used in the design, which can be printed, saved to file or loaded into Microsoft® Excel®. The program also includes a documentation editor to insert text, graphics, sound or movies. MultiCAP can export to third party PCB layout programs, such as Orcad®, Protel®, Eagle®, P-CAD®, Cadstar® and PADS®.

MultiSIM 7 for simulation and capture **-** a powerful SPICE simulator for design entry leading to simulation with the ability to co-simulates SPICE, VHDL, Verilog and RF devices for complete analysis of boards containing devices not practically modeled in SPICE, as well as to verify circuits and locate errors during the design process, with an array of virtual testing instruments and interactive "change-on-the-fly" simulation. For example, the Trace Width Analysis tool uses simulated current to determine minimum required trace widths in UltiBOARD. Other high-end Virtual Instrument generators include Multimeter, Bode Plotter, Word Generator, Logic Analyzer, Logic Converter, Spectrum Analyzer, Network Analyzer, Distortion Analyzer, Wattmeter, Frequency Counter, Instant Measurement Probe, Function Generator 33120A, Multimeter 34401A, Mixed Mode Oscilloscope 54622D. MultiSIM has built-in intelligence that automatically generates wires between the components ("autowiring"), sort devices into families and subgroups and stored in logical Parts Bins on the desktop, for quick searches through certain electronic parameters. MultiSIM has a Database Manager that aids in managing libraries and parts, while a Component Wizard guides you through the creation of new devices. In addition, MultiSIM also includes edaPARTS.com, the world's largest on-line component database with over 12 million parts. MultiSIM automatically generates the schematic symbol for the part selected from edaPARTS.com. "The creation of edaParts.com, a partnership between Electronics Workbench and PartMiner Inc., gives MultiSIM users quick and easy access to the Design Center, the world's largest electronic component database. Just click a single button in MultiSIM and instantly be connected to information on over 12 million components in a searchable database. Benefits include regularly updated parts information that includes schematic symbols, footprints, datasheet information and commercial detail including pricing and availability. MultiSIM customers that access edaParts.com will find that they have the option of downloading part information directly into MultiSIM. Search by part number and download pin label data for automated symbol generation. Advanced research capabilities are also available by a subscription service from PartMiner." In addition, with the advanced Component Editor system, MultiSIM users can edit, import or create new parts for their own component database. MultiSIM's virtual and "real" simulated function generators operate just like real world equivalents; provide an easy way to generate source signals; and the user can also change the instruments' waveform shape, frequency and amplitude while a simulation is running and instantly see the changes at measurement points. It comes with an extensive collection of sources including DC, Sine, Triangle, Square, Pulse, Arbitrary, AM, FM, FSK, Exponential, Clock, Polynomial and One Shot. In addition, the piecewise linear source lets the user define the shape of a signal, or use real data as the source for your simulations. MultiSIM contains unique, advanced wizards for automatic creation of specialized circuitry, such as the famous 555 Timer, a versatile chip that is used to assist with appropriately configuring and to produce the desired behavior. The Virtual Instruments of MultiSIM are more powerful and “real” than real world instruments; they have fully customizable graphers for plotting circuit simulation analysis results, and with a suite of powerful analysis functions, make measurements that are difficult or impossible to perform in the real world. Its powerful analysis tools include: 3 dB Point**,** AC Sensitivity, DC Sensitivity**,** AC Frequency Sweep, Batched Analysis, DC Operating Point, DC Sweep, Distortion, Fourier, I-V Analyzer, Model Parameter Sweep, Monte Carlo, Nested Sweep, Noise, Pole-Zero, Temperature Sweep, Trace Width, Transfer, Function, and Transient. (Electronics Workbench, 2004).

UltiBOARD 7 for PCB layout - a program for the creation of error-free boards for production, with a unique Real-time Design Rule Checking (DRC) feature for real-time updates and instant feedback, which flags rule violations as they occur, letting the designer prevent mistakes rather than finding and fixing them later. It supports simple to advanced boards, high-speed designs, up to 64 layers, 1 nanometer resolution, microvias and today's most complex packages (such as BGAs); and includes manufacturing optimization features with CAM functionality. On November 11, 2003 Electronics Workbench announces its NEW UltiBOARD 7 for professional circuit engineers and designers. UltiBOARD contains one of the industry’s largest footprint libraries, with nearly 4,000 pre-defined, common board shapes, which can be edited in the Footprint Editor; allows the users to create boards with any shape, including cutouts, up to 2 x 2 meters in size; to import board outlines as DXF files from mechanical CAD programs; to define the outline using the Advanced Board Outline Wizard; to assign keep-in/keep-out areas to components only, traces only or both, including height restrictions. UltiBOARD respects any constraints set in MultiCAP, including minimum and MAXimum trace length, minimum and MAXimum separation and parallelism. UltiBOARD can transfer and load MultiSIM schematics data. MultiSIM has a part library with 16,000 items, all of them have matching UltiBOARD footprints so that the user will never experience transfer errors. UltiBOARD has built-in intelligence that helps the designer to place components in their proper locations, to rapidly place parts with a Component Sequencer; and to automatically move interfering parts aside. “It even features ‘Springback’ from the board outline. Real-time ‘Force Vectors’ guide placement for routability, analyzing the ratsnest and advising where to move the component. UltiBOARD’s Placement Density display shows unconnected pins to determine the best component placement. Alignment and Equi-spacing functions aid in the placement of regular arrays of components. Ruler guides assist in accurate and precise placement; simply snap a part to the guide and slide it to an exact coordinate.” Other unique features of UltiBOARD include three powerful “follow me,” fully gridless and interactive trace placement techniques, which combine the power and automation of an autorouter with the flexibility and control of manual placement; and a built-in standard autorouter utilizes a grid-based, “rip-up and retry” algorithm and is sufficient for basic boards. In addition to all of the above, UltiBOARD produces output in all popular formats for manufacturing; UltiBOARD’s 3D Viewer can provide a realistic 3D rendering of a complete, populated board, including components, traces, pads and silkscreen, with exceptional precision (even color-coded bands on resistors); and UltiBOARD coontains a built-in Mechanical CAD module for the design of front panels, enclosures and many other mechanical pieces related to the boards. There is full forward and backward annotation between MultiSIM and UltiBOARD. Annotation supports: RefDes changes, component value changes, new or removed components, new or removed pins and net name changes. UltiBOARD 7 can import legacy files from Orcad Layout®.

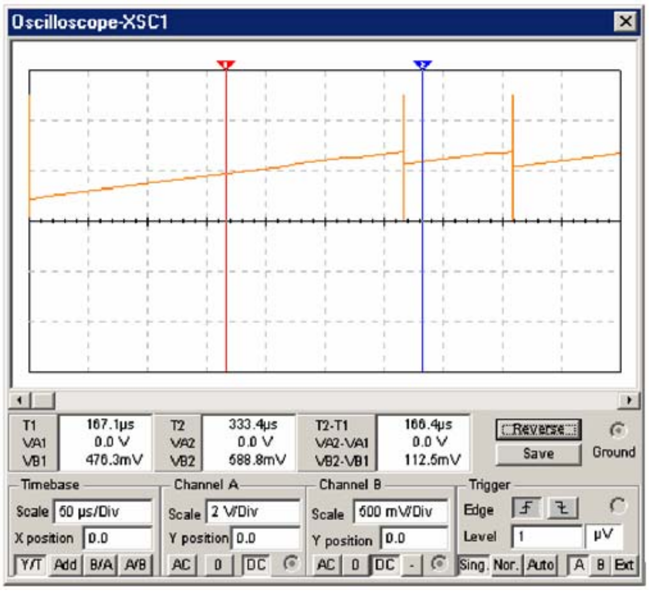


Figure 7: Circuit simulation with Oscilloscope XSC1 in MultiSIM (Edward Locke, 2004)

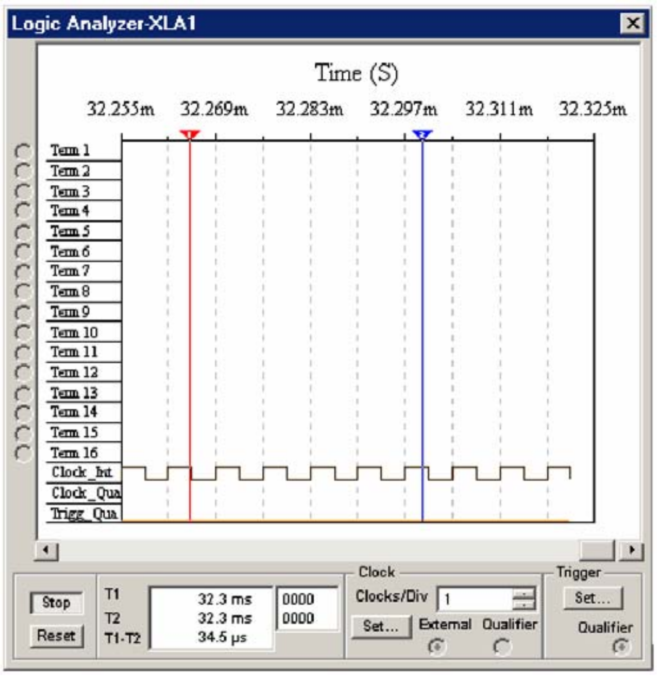


Figure 10: Simulated circuit using Logic Analyzer XLA1 in MultiSIM (Edward Locke, 2004)

UltiROUTE 7 for autorouting - a state-of-the-art autorouting and autoplacement program using a breakthrough “Progressive Routing” technology that combines grid and gridless (or shape-based) routing techniques into a single engine, for better board layouts with higher completion, shorter trace lengths, and fewer vias through gridless routing. UltiROUTE 7 is designed for today’s high-density, high-complexity, large multi-layer boards and high-pin-count components such as BGAs, which makes manual component and trace placement techniques impractical.
On March 22, 1999 Electronics Workbench delivers leading-edge autorouting technology with new UltiROUTE; and on November 11, 2003 Electronics Workbench announces its NEW UltiROUTE 7 for professional circuit engineers and designers. UltiROUTE is tightly integrated with UltiBOARD 7 and uses all of the design rules set for the project within MultiCAP and UltiBOARD. UltiROUTE contains many outstanding features. With UltiROUTE 7, the designers “have complete control over autoplacement with the ability to pre-place parts, constrain certain components to pre-defined areas, set separation values and enable surface-mount device mirroring and pin and gate swapping. UltiROUTE also uses height restrictions to create intelligent keep-out areas based on component z-axis values. Choose the right amount of automation for each portion of your design: manual, semi-automatic (click on component and it is appropriately placed) or fully automatic […] UltiROUTE uses Design Analysis to examine each design file before routing and adjusts the router settings based on the characteristics of the design. This results in optimal router performance every time […] UltiROUTE 7 provides highly sophisticated yet incredibly easy-to-use Automatic Bus Routing. This feature allows you to specify the pins for each bit of the bus and have UltiROUTE automatically route the entire bus exactly as you would expect with each bit’s trace parallel to the others. UltiROUTE automatically routes differential pairs, creates fan-outs for complicated components and can insert testpoints automatically for you. Net shielding is automatically added to specified traces. UltiROUTE easily handles microvias, vias inside SMD pads, custom pad shapes and multiple powerplanes.” In addition to its strong design capabilities, UltiROUTE 7 contains features for the improvement of manufacturing process, such as the optimization routines that reduce production costs and improve manufacturing yields, through a fully customizable cleanup routine that enhances the design layout by reducing via counts, mitering corners, smoothing traces and removing any wire bends created during autorouting.

CommSIM 7 for communications system design – an “end-to-end,” “real time” and customizable simulation tool for analog, digital and mixed mode network communications systems design, simulation, and feedback, capable of viewing signal waveforms at any point in the system, via a natural sequence of steps, an intuitive “drag and drop” interface, a library of over 200 blocks, time domain simulation engine and models for the latest technologies like Wireless LAN. On April 15, 2004 Electronics Workbench delivers CommSIM 7, its next generation simulation software for communication systems. CommSIM 7 can model the latest wireless LAN technologies including the following three categories: Bluetooth (GFSK Modulator, Bluetooth Hopping Pattern Generator, Shortened Hamming Encoder, Shortened Hamming Decoder, Bluetooth data scrambler, and Bluetooth data descrambler); 802.11 (Barker Sequence, CITT CRC-16, GFSK 2 Level, GFSK 4 Level, Low Rate Hop Pattern Generator, Scrambler, and Descrambler); 802.11a (Convolutional Encoder, Interleaver, OFDM Modulator (Scalar & Vector), OFDM Demodulator (Scalar & Vector), OFDM Pilot Mapper, OFDM Pilot Extractor, Puncture, Depuncture, Scrambler, and Descrambler); and 802.11b/Wi-Fi (CCK Modulator, CCK Demodulator, DBPSK Modulator, DQPSK Modulator, and High Rate Hop Pattern Generator). CommSIM 7 supports continuous time, discrete time, vector, matrix and complex-number simulation. The results of simulation runs can be displayed as time domain, frequency domain, xy plots (phase, scatter, etc.), log scale, BER, eye diagrams and power spectra; and furthermore, exported to and integrated with several third party math and display packages such as MathCAD, MatLab and any .WAV or OLE compliant software. The CommSIM 7 library of blocks can perform single encoding to increase the reliability of information transfer; and can include companding and quantization (analog signals) or forward error correction (using convolutional or trellis coding on digital signals). It includes the following encoders/decoders: Block Interleaver, Convolutional Encoder, Convolutional Interleaver, Gray Map, Gray Reverse Map, Hamming Decoder/Encoder, Puncture, Depuncture, Reed-Solomon Decoder/Encoder, Trellis Encoder, Trellis Decoder, and Viterbi Decoder (Hard & Soft). CommSIM provides a library of analog and digital modulation/demodulation or encoding/decoding blocks, a subset of which use coherent methods (require phase synchronization in demodulation), which include: AM, Differential PSK (B, Q, pi/4-Q, 8, 16, 32), FM, FSK, I/Q, MSK, PM, PAM (4, 8, 16), PPM, PSK (2, 4, 8, 16), QAM (16, 32, 64, 256), SQPSK, GFSK, GMSK, Differential PSK Demodulator (B, Q, pi/4-Q, 8, 16, 32), FM Demodulator, I/Q Detector, PPM Demodulator, PSK Detector (2, 4, 8, 16), PAM Detector (2, 4, 8, 16) and QAM Detector (16, 32, 64, 128, 256). "Modeling the medium through which a transmitted signal must pass is essential to accurately capture delay and distortion effects. Channels include copper wire, fiber, free space, etc. Channels are modeled in CommSIM with the following blocks: Additive White Gaussian Noise (Complex & Real), Binary Symmetric Channel Jakes Mobile, Mobile Fading, Multipath, Propagation Loss, Rice/Rayleigh Fading, Rummler Multipath, TWTA and Vector AWGN."

CommSIM also provides many other communication blocks and general mathematical functions as shown in the table below:

Table 8: CommSIM Complex Math, Filters and RF Components Features

Complex Math	Filters	RF Components
Addition	Adaptive Equalizer (Complex & Real)	Amplifier
Conjugate	FIR	Attenuator
Conversions (Complex, Real, Mag/Phase)	Sampled FIR	Coupler

Table 8 (Continued):

Complex Math	**Filters**	**RF Components**
Division	File FIR	Double Balanced Mixer
Inverse	Sampled File FIR	Splitter/Combiner
Multiplication	Pulse Shaping Filter	Switch
Power	IIR	Variable Attenuator
Square Root	MagPhase	

Source: Electronics Workbench website.

In addition, **"**CommSIM offers over 90 blocks for linear, non linear, continous, discrete-time, time varying and hybrid system design. Their families are listed below: Active X, Animation, Annotation, Arithmetic, Boolean, DDE, Embedded blocks, Expressions, Integration, Linear Systems, MathCAD, MatLab Interface, Matrix Operations, Nonlinear, OLE Object, Optimization, Random Generator, Real Time Data I/O, Signal Consumer, Signal Producer, Time Delay, and Transcendental."

Although Electronics Workbench product family is powerful and resourceful in tools and features, their hardware and operating system requirements are relatively low, as illustrated by Table 9 below:

Table 9: Minimum System Requirements for Electronics Workbench

Operating System	Windows 98/NT/2000/XP
CPU	Pentium II or greater
RAM Memory	64MB (128MB recommended)
Hard Disk Space	250MB (MultiSIM), 250MB (UltiBOARD), 250MB (MultiCAP), 200MB (CommSIM), and 250MB (UltiRout).
Drive	CD-ROM
Monitor Screen Resolution	800 x 600 minimum

Cooperation of Electronics Workbench with third party vendors

MultiSIM can import and transfer schematics files from Orcad Capture®, PSPICE®, and Ulticap®. This capability allows users of legacy capture tools from other vendors to transit to MultiSIM quickly and smoothly. MultiSIM can also export to third party PCB layout programs: Orcad®, Protel®, Eagle®, P-CAD®, Cadstar® and PADS®.

"By combining the schematic capture, simulation and analysis tools available in MultiSIM with the data acquisition (DAQ) and measurement features provided by National Instruments® DAQ devices and LabVIEW®, real world analog and digital signals are easily sampled and then incorporated into simulations," with a free-download interface called the MultiSIM/LabVIEW ExpressVIs. MultiSIM contains OLE integration to automatically transfer your simulation results to Microsoft Excel and Mathsoft Mathcad, so as to perform further analysis or investigation of the simulation data in these popular spreadsheet and math applications.

Part Five
Mechanical FEA and
Kinematics Simulation Programs: COSMOS and others

Finite Elememt Analysis (FEA and simulation, COSMOSWorks and COSMOS DesignStar – a great analysis and simulation software for parametric 3D CAD

In order to generate optimal designs, many companies increase automation of the design process by linking their CAD systems to various types of design analysis software, for a variety of virtual testing purposes such as structural, vibration, thermal and fluid flow analyses. Many such virtual testing programs provide tools to assist the user in the necessary conversion of CAD models to FE (finite element) models. "Originally developed for the aerospace and nuclear industries to study the safety of structures," in the mid-1990s, and greeted by analysts with acute skepticism - mostly focused on fears that non-experts would misuse the tools (Elliott, 2003), Finite Element Analysis or FEA "now has advanced to allow engineers to simulate the mechanical, electrical, and chemical forces that act on a part" (Thilmany, 2002).

The practice of integrating analysis with everyday design is still relatively new. This is primarily due to the following reasons: FEA programs are expensive (ranging from $6,000 to more than $10,000 per seat); because traditional FEA courses, except statics and dynamics, are offered only as upper division courses in four-year engineering schools, courses on FEA software are usually offered only in some four-year universities but generally not in community colleges, therefore, opportunity of learning is rather limited; in addition, the integration of FEA with CAD is still in need of improvement. However, FEA software is a promising technology: before the marketing of FEA software, FEA analysis are performed by highly trained and expensively paid analysts with Ph.D.s in the field, and kinematics simulation can only be done after one or successively several costly physical prototypes are made. If analysis showed weaknesses in the design, the engineering team scrapped those parts, and started the process all over again, from scratch. This is a costly and time-consuming process. New development in Windows' GUI technology as well as many years of self-improvement allow today's FEA software packages to be quick, affordable and easy to use by non-specialist engineers (Clarke, 2003).

Therefore, although up to this point, most of small companies do not use FEA software due to expensive pricing, more and more companies are considering using them if they can afford, because "one thing is certain: The demand now for faster and faster product turnaround time means that engineers must use every technology available to them to help meet compressed design schedules. By allowing mechanical engineers to simulate a variety of physical phenomena acting on a part and show the results via an intuitively understood graphical representation, FEA offers a means to help reduce design cycle time […] By running analyses, engineers can predict, before physical prototyping, that a proposed design will meet specifications. If a design doesn't meet specifications in simulation, the engineer can modify the CAD drawing and analyze it again to see if the changes helped."(Thilmany).

According to an online article titled *Guidelines for NONLINEAR ANALYSES: Here's when to use linear-static FEA and when to use a nonlinear program* by Ramesh Ramalingam, on May 2004 issue of Machine Design magazine available at http://www.machinedesign.com/ASP/viewSelectedArticle.asp?strArticleId=56799&strSite=MDSite&Screen=CURRENTISSUE, non-linear analysis of 3D solids generally include:

"Geometric nonlinearities. These come from a model with large displacements or rotations, large strain, or a combination of those, such as in metalforming processes.

Material nonlinearities. Rubber and elastics are nonlinear materials. The nonlinearities often occur when the material's stress-strain relation depends on the load history (as in plasticity problems), long load durations (as in creep analysis), and when temperature can influence the outcome (as in thermoplasticity).

Contact nonlinearities. These occur when a structure's boundary conditions change because of the applied loads, such as in gear-tooth contacts and threaded connections."

The same article points out that: "FEA use is growing at smaller companies that cannot afford to keep an analyst on staff. The growth is attributable to the rapid advances in computer technology in recent years. Commercial software now exists that can solve for sophisticated analysis. And engineers can use the software for more than structural analysis, which is what FEA was originally developed to do, according to Dermot Monaghan, a design engineer in Ireland with a Ph.D. from the finite element modeling group at Queens University in Belfast. Monaghan writes often about his engineering experience with FEA.". An example is Fanuc Robotics North America Inc. of Rochester Hills, Mich., a high tech company that supplies robotic systems to a variety of industries. The company integrated FEA and CAD in order to run analysis on every part. "The move commonly saves about 28 days of design development time, according to Don Bartlett, a Fanuc Robotics senior staff engineer."

There are many FEA software offered by different companies for different purposes; however, MSC Nastran/Pastran, ANSYS, ALGOR InCAD Designer for Autodesk Inventor and other 3D CAD, FEMAP, ProMechanica, LS-Dyna, ABAQUS, COSMOSWorks for SolidWorks and COSMOSDesignSTAR for Inventor, SolidEdge, etc., are the most popular in the United States and have the most comprehensive usage coverage. The Table 10 below, based on information from Daratech, a market-research and analysis firm in Cambridge, Mass., and quote in Thilmany's online article, lists some of the more important FEA developers:

Table 10: Developers of FEA Software

Company Name, Phone No. and Website	Company Address
Algor Inc.: (412) 967-2700; www.algor.com	150 Beta Drive, Pittsburgh, PA 15238
Altair Engineering; (248)614-2400; www.altair.com	1820 E. Big Beaver, Troy, MI 48083
Ansoft Corp.: (412)261-3200; www.ansoft.com	Four Station Square, Suite 200, Pittsburg, PA 15219
Ansys Inc.: (724) 514-3304; www.ansys.com	275 Technology Drive, Canonsburg, PA 15317
Dassault Systemes S.A. (Owner of COSMOS): 9 33-1-40-99-40-99; fax 33-1-42-04-45-81; www.dassault-systemes.com. EDS: (972)604-6000; www.eds.com	Dassault: Quai Marcel Dassault, B.P. 310 92156, Suresnes Cedex, France; EDS, 5400 Legacy Drive, Plano, TX 75024
EASi: (248) 582-3800; www.easi.com.	1551 E. Lincoln Ave., Madison Heights, MI 48071
FEDEM Technology Inc.: (303) 650-5480; www.fedem.com	8700 Turnpike Drive, Suite 475, Westminster, CO 80031
Hibbitt, Karlsson & Sorensen Inc.: (401)727-4200; www.abaqus.com	1080 Main St., Pawtucket, RI 02860
Imagine Software Inc.: (212)317-7600 www.imagine-sw.com	233 Broadway, 17th Floor, Manhattan, NY 10279
LMS International: (248)952-5664; www.lmsintl.com	1050 Wilshire Blvd., Suite 250, Troy, MI 48084;
MSC.Software Corp.: (714)540-8900; www.mscsoftware.com	2 MacArthur Place, Santa Ana, CA 92707;
MTS Systems Corp.: (952)937-4000; www.mts.com	14000 Technology Drive, Eden Prairie, MN 55344;
PTC: (781)370-5000; www.ptc.com.	140 Kendrick St., Needham, MA 02494
SolidWorks: (978)371-5011; www.solidworks.com	300 Baker Avenue, Concord, MA 01742
SRAC: (310) 207-2800; www.cosmosm.com	12121 Wilshire Blvd., Suite 700, Los Angeles, CA 90025

Most Finite Element Analysis (FEA) analysis simulation programs, such as MSC Nastran/pastran, ANSYS, ALGOR and COSMOSWorks, as well as built-in tools within Autodesk Mechanical Desktop etc, can perform FEA in terms of linear and nonlinear analysis, which describe stress and deflections in complex models; and can predict at pinpoint accuracy the troubled spot where a crack would develop in the component. "While most engineering problems contain nonlinear effects, linear analysis results often provide sufficient information. However, linear static analysis assumes induced displacements will be small, changes in structural stiffness caused by loading will be negligible, and no change will occur to the magnitude and direction of the load while the structure deforms. Thus, it assumes a linear relationship between the loads and the induced response. For example, it assumes that doubling the load doubles the response of the model (displacements, strains, and stresses). In addition, linear analysis is generally more conservative than nonlinear analysis. The results it provides may cause over-design, which always results in additional weight. […] Companies can realize significant savings with even slight material reduction in mass-produced products. Nonlinear analysis works better in such cases, as well as in situations where linear analysis fails to model real-life behavior. For instance, take a common steel paper clip. Its design requires it to be elastic; i.e., it should go back to its original shape when removed from the sheets of paper it holds. However, if you use the clip for holding too many sheets, the sides will not go back to the original shape, meaning that the clip has undergone permanent deformation. Nonlinear analysis provides the information needed to verify the design will have no permanent deformation" (Ramalingam, 2004, *de-feedback@helmers.com*). In the beginning, FEA programs' graphical user interface is not very attractive. In recent years, developers of high-end FEA tools are learning from design analysis to make their GUIs easier to use. This holds true even in the cases of MSC.Nastran for Windows and NE/Nastran, even though they don't fit neatly into the design analysis category. All design analysis programs now work with CAD models, and ANSYS, ALGOR, and COSMOS all use design analysis interfaces to access more complex tools (Elliott, 2003).

FEA simulation typically display the stress and other conditions with a "rainbow"-look color range on the 3D solid model, and if desirable, with mesh-like surface segmentation, as shown on the two ANSYS' FEA screen shots below, which are retrieved from Vince Adams's online article, titled *A Convergence of Disciplines Finite Element Analysis is spreading over the land and the developers are working like mad to make sure everybody benefits:*

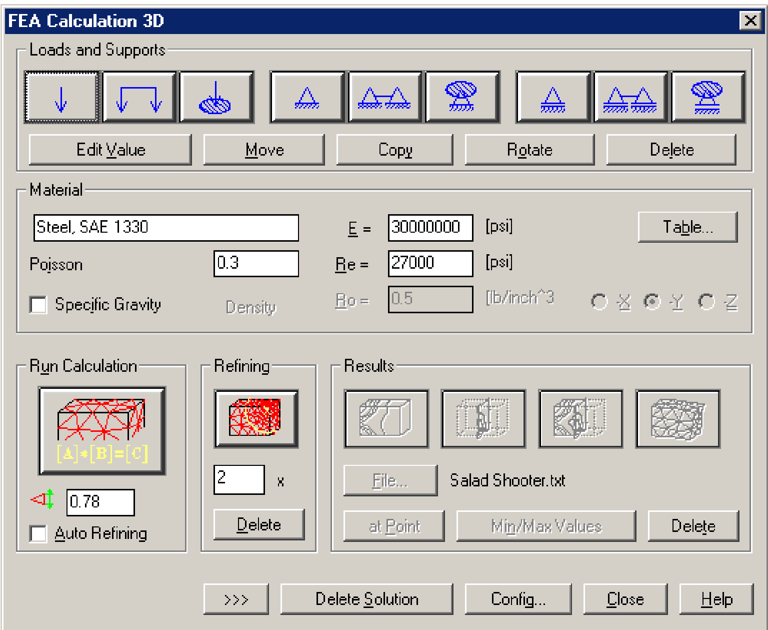
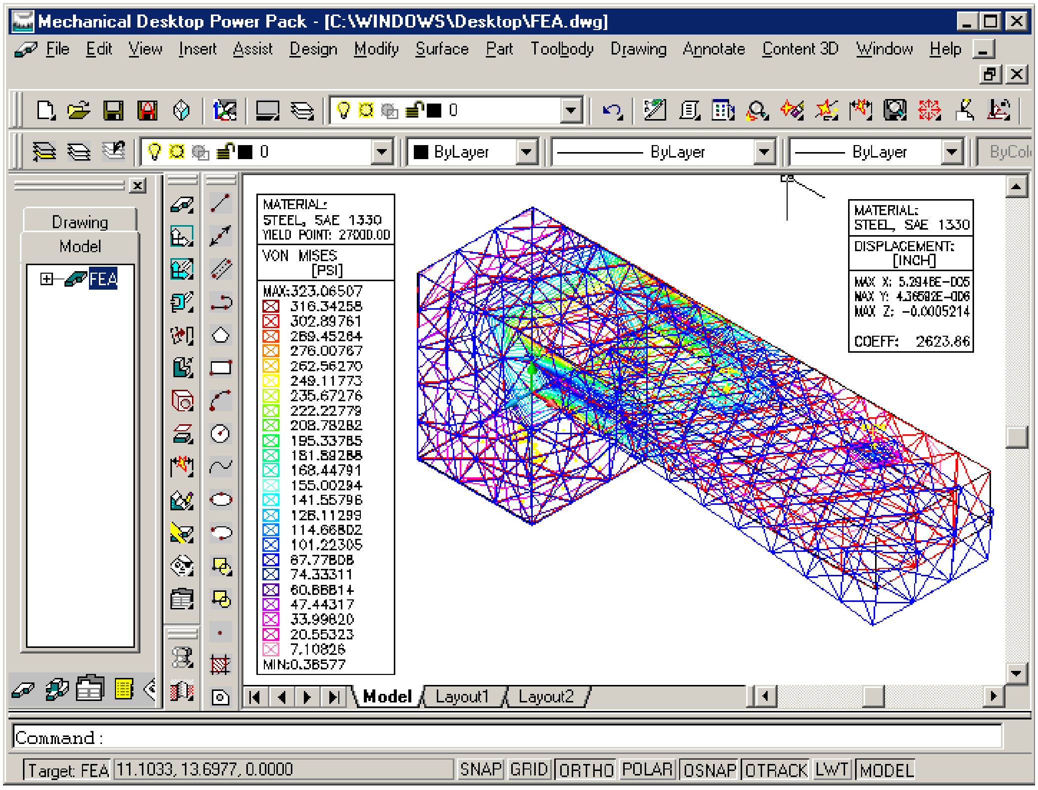


Figure 11: FEA window in Mechanical Desktop (left); Display of FEA results (bottom) (Edward Locke, 2004)



The application of digital FEA can help companies save time and money, by making the design process more flexible and keeping the design options open for a longer time before a physical prototype is ever built and tested. As pointed out by Greg Brown, product manager of Interactive Products for ABAQUS, "The challenge for companies is to find better ways of implementing FE tools to improve their bottom line. Once the strategic value of analysis is recognized in a company's business and processes, analysis quality is usually better and it becomes more widely deployed." According to Ravi Kumar, manager of New Business Development at ANSYS, users of FEA and simulation software "seek three things in a simulation solution: a solution that solves their problem with reasonable approximation; a solution that fits their CAD and user environments; and a solution that fits within their process and workflow" (Adam, 2004, *de-feedback@helmers.com*).

COSMOS: a popular FEA program

Founded in 1982, and headquartered at 12121 Wilshire Blvd., Suite 700, Los Angeles, CA 90025 (Phone: 800-469-7287 and 310-207-2800; Fax: 310.207-2774; Email: info@srac.com), the Structural Research & Analysis Corporation (SRAC), develops and markets finite element analysis (FEA) software, the COSMOS™ product line, for the mechanical computer-aided engineering market worldwide through a network of over 400 resellers in 57 countries. The SRAC is aquired by SolidWorks Corporation as a wholly owned subsidiary of Dassault Systemes S.A. in recent years. COSMO family products include the following:

- **COSMOSWorks™ -** for design analysis and optimization for engineers who need analysis but are not specialists in FEA, including linear stress, thermal, kinematics, fluid flow, design optimization, nonlinear, and other features; it comes with the purchase of SolidWorks® free-of-charge.

- **COSMOSDesignSTAR™** - for users of CATIA® Version 5, Revision 11, Autodesk® Inventor Version 8, AutoCAD, Mechanical Desktop, Solid Edge® Version 15, and other popular parametric 3D modeler with same features as in COSMOSWorks™. It can also read geometry files from such other popular solid modeling programs as Pro/ENGINEER®, CADKEY®, and IDEAS®. COSMOSDesignSTAR is based on the Parasolid modeling kernel and also supports ACIS Kernel and STEP AP203 standards. Price is about $6,000 for a commercial license and 10% of this price or $600 per seat for educational institutions. All COSMOSDesignSTAR bundles are scaleable, in other words, the users only pay for the tools they need.

- **COSMOSMotion™** - for checking interference among the components in an assembly in kinematical motion, helping engineers to check if the sizes of the parts are correct and if moving parts such as gears and cams, will interfere with each other, to determine power consumption, to test motors, actuators, springs and dampers, as a virtual “prototype” before the actual physical prototype is built for testing purposes. COSMOSMotion is powered by ADAMS®, the most widely used mechanical simulation software in the world.

- **COSMOSFloWorks™** - for flow analysis and fluid simulation, used in product design analysis involving heat transfer or flow of gas or liquid for diverse application in the design of automobile, airplane wing, or exhaust valve.

- **COSMOSEMS™** - for low frequency ElectroMagnetic and ElectroMechanical Simulation as implied by the abbreviation EMS, and fully integrated into the COSMOSDesignSTAR interface. It can calculate torques, forces, fields, currents, inductances, capacitances, flux linkages, current losses and electrical stresses and other important physical parameters; contains the following modules: Electrostatic and Electric Conduction, Magnetostatic, AC Magnetic, Transient Magnetic; and can be used as an add-on solution to COSMOSWorks or COSMOSDesignSTAR.

- **COSMOSM™** - for parts and assembly analysis including modeling, meshing and visualization, and other high-end features.

The future release of COSMOSDesignSTAR™ 4.5 software will support the popular motion controllers CadMan®, SpaceBall®, SpaceMouse®, and SpaceTraveler™ from 3Dconnexion. “3Dconnexion's controllers operate together with a traditional mouse to provide a very efficient and intuitive way to work with 3D geometry. Instead of using a “normal” mouse with one hand as an input device for all activities - including zoom, pan, rotate, select, and click on icons and menus - users of 3Dconnexion's motion controllers can use one hand to move and rotate the part or assembly, and see CAD models and analysis results from all sides and angles, while using the other hand to perform all the normal selection tasks with the mouse” (COSMOS, 2004). 3Dconnexion, headquartered in Silicon Valley, California (www.3dconnexion.com), a Logitech Company specialized in 3D input devices for more than 250,000 users in the field of 3D motion control in the computer aided design), geographic information systems, product lifecycle management, and digital content creation markets, offers industry-leading controllers such as SpaceBall®, SpaceMouse®, CadMan®, and SpaceTraveler™.

SolidWorks Corporation owns and offers COSMOSWorks, an analysis and simulation package, which is free for SolidWorks users, and its equivalent, COSMOStar, for Inventor, AutoCAD, Mechanical Desktop, SolidEdge and CATIA for a price of $6,000 commercial and $600 scholl educational license. The COSMOS product line includes COSMOSWorks, an analysis application that tests parts and assemblies in a virtual environment; COSMOSMotion™, a virtual prototyping application that simulates a design's mechanical operation; and COSMOSFloWorks, a fluid dynamics application that simulates the flow of fluids, gasses, and heat through and around designs for products ranging from exhaust valves to aircraft wings. COSMOSXpress, a quick design validation tool, is integrated with SolidWorks. According to a news release by SolidWorks on July 12, 2004, titled *COSMOS spans electronics design analysis from remote controls to satellite components: More than 800 companies in 35 countries use COSMOS to speed production, eliminate costly design errors and bolster profit margins, at* http://www.solidworks.com/pages/news/viewrelease.html?prid=209, “The global electronics industry has embraced COSMOS widely, with more than 800 companies in North America, Europe, Asia, Australia, and New Zealand using COSMOS products to catch errors early in the design process. Analyzing throughout the product development process, rather than just at the end, moves electronics products to market faster and with fewer problems such as overheating or parts that don't mesh properly. COSMOS users can expect to cut 20 percent from the cost of product field failures per year; improve overall time to market 30 percent; and increase profit margins 8 percent. A 2003 study by MIT's Sloan School of Management found that 67 percent of COSMOS users credit it with improving product quality; 59 percent with avoiding field failures, and 15 percent with avoiding product recalls. Most COSMOS customers build 50 percent fewer physical prototypes and roll out product in half the time they did before COSMOS.

COSMOS users range from small and medium-sized firms to more than 30 Fortune 500 corporations, and include companies such as Toshiba, Cannon, InFocus, and EchoStar, and government agencies such as the Jet Propulsion Lab. They use COSMOS to analyze designs for products ranging from camera mounts to remote controls, cellular phones, and DVD players. COSMOS helps engineers determine whether assemblies will generate too much heat; whether enclosures can handle required voltages; and whether parts will mesh smoothly during operation. Steve Hess, CAD engineering manager at $1.4 billion test equipment manufacturer Teradyne, has used COSMOS products, including COSMOSWorks™ and COSMOSFloWorks™ , since 1997, COSMOS applications help Teradyne's engineering staff predict deformation of robotic arms equipped with electronic testing devices and heat flows in circuit board cooling equipment. Hess credits COSMOS with helping eliminate physical prototyping and making the design process faster and more efficient."

In recent years, COSMOS family products have received many awards from industry groups and publications, including:

- *Desktop Engineering*'s November 2002 issue "Reader's Choice Award" for COSMOSWorks 2003, COSMOSFloWorks 2003, and COSMOSMotion 2003;

- *Product Design and Development*'s nomination of COSMOSWorks as a "2002 Engineering Award" finalist;

- *Desktop Engineering*'s June 2002 "Reader's Choice Award" for COSMOSWorks 6.0 and COSMOSWorks 7.0 software;

- *Los Angeles Business Journal*'s nomination as one of "Top 15 Companies in Los Angeles," in January 2001;

- *Design News* magazine's nomination of three COSMOS™ products as finalists for the "Best Products of 2000," in December 2000 (COSMOSWorks™ 6.0 and COSMOSDesignSTAR™ for SolidEdge were nominated for Analysis; COSMOS/Flow was nominated for Computational Fluid Dynamics);

- *Sandia National Laboratories* E-source team's "Exceptional Partner Award" in June 2000;

- *Design News Magazine*'s nomination of COSMOSWorks as the "Best New Products" in December 1999.

COSMOS and educational institutions

For its compatibility with many different 3D parametric CAD modelers, COSMOSDesignSTAR™ has been chosen as the software tool for a Society of Automotive Engineers (SAE) professional development seminar entitled "Finite Element Analysis for Design Engineers" and held on January 26-27, 2004 in Troy, MI. By January 2004, 14 universities around the world have chosen COSMOSDesignSTAR to educate engineering students, they include: University Du Quebec in Canada; University P&M Curie in France; Technical University of Denmark; Czech Technical University in Prague; Osaka University; Tokyo Medical & Dental University; and Asahikawa National College of Technology - all in Japan; Kazan State Technical University and Bauman State Technical University, both in Russia; and additional educational facilities in South Korea, the Republic of China, the United Kingdom, and the United States (COSMOS, 2004).

Due to the fact that FEA courses are generally offered at upper division level in four-year universities, community colleges normally do not teach COSMOS software.

Part Six
Ready For the Automatic Manufacturing Process: Computer aided Manufacturing with Mastercam and others

History of CAM and Mastercam

CAM or computer-aided manufacturing is based on computer numerical control (CNC) technology. In 1964, DAC-1, a proto-CAM system developed with software programming technology from IBM went into real world usage at General Motors plants. Since then, CAM software started to proliferate. Currently, there are hundreds of CAM programs around the world, some of them contain more features to cover most is not all possible industry needs and can work with most CNC machines, while others might be written for a particular machining equipment with only limited functions. The most popular one in the United States are Mastercam, which is now a recognized standard in both industry and education, GibbsCAM, a good choice for small to medium-sized companies, CNC Workshop and SurfCAM.

Mastercam software is made by CNC Software Inc. (address: 671 Old Post Road, Tolland, CT 06084, USA; phone: 860-875-5006; fax: 860-872-1565; website: http://www.mastercam.com). "Founded in 1984, CNC Software is one of the oldest companies in the PC-based CAD/CAM industry. The company was built on the concept of providing an inexpensive PC-based CAM system at a time when most other systems were expensive CAD oriented products. CNC Software was one of the first companies to introduce CAD/CAM software designed for the machinist and the engineer, providing a practical solution to both markets […] Shortly after CNC Software got its start in Massachusetts, the company moved its base of operation to an office in Vernon, Connecticut. Today, the CNC Software corporate headquarters and training facility is located in a company-owned 40,000 sq. ft. building in Tolland, Connecticut, midway between Boston and New York City. In addition to over 85 employees working at the corporate facility, CNC Software also has an office in the state of Washington dedicated to the educational market" (Mastercam, 2004). The company has sold 80,000 licenses of Mastercam through a global dealer network, which translates to over 13.3% of all CNC/CAM software used worldwide, the largest percentage of all; and it has formed "partnership" with many third party software and hardware developers as well as its customers. Mastercam has 20 years of CNC programming experience and has been recognized as an industry leader for over a decade. "Mastercam offers solutions for designers and NC programmers involved in milling, turning, wire EDM, plasma cutting, lasers, and 3D design and drafting. CNC Software's customers range from one-person job shops to Fortune 100 manufacturers. The same software that is utilized by corporations such as Boeing, IBM and Sikorsky is still affordable enough for the small job shop" (Mastercam, 2004).

Mastercam and institutions of education

"To ensure a new generation of trained metalworking personnel, Mastercam is available to educational institutions at sizable discounts" (through http://www.mastercamedu.com/). Mastercam is taught in high schools, two-year community colleges and four-year universities throughout the United States and worldwide; and local institutions of higher education in Southern California include the manufacturing technology departments at Cerritos College, Santa Ana College and El Camino College, and the Industrial Design Department at Art Center College of Design in Pasadena, an internationally renowned private art school.

Mastercam technology

"The original version of Mastercam was founded in two-dimensional (2D) CAM. Mastercam was one of the first micro-based CAM packages to include CAD capabilities, which allowed the user to construct his or her own parts quickly and easily" (Mastercam, 2004). Mastercam is a fast, straightforward solutions for milling, turning, wire EDM and 3D mechanical design fully integrated with Parasolid®-based solid modeler; and it boasts an award winning ease-of-use GUI. Mastercam's flagship software delivers full 2- through 5-axis machining and design, as well as full design and programming for 2 and 4-axis wire EDM parts, plus specialty add-on tools for CNC manufacturing. Mastercam is a CNC (computer numerical control) program used on lathe, mill, router, and other equipments for the production of industrial molds, fixtures and components, using integrated solids, surfaces and wireframe, in 2D and 3D tool paths. It can be used to create its own 3D models or import outside models created in other 3D CAD programs for the generation of machining paths. Applications of Mastercam in manufacturing industry include production machining, mold-making, prototyping, and electrode creation. Mastercam is widely used in CNC manufacturing of metal, plastic mechanical components, furniture, as well as wood, metal, plastic and foam engravings.

Types of machining operations Mastercam can perform include: 2 and 2 1/2 axis milling, 2 and 2 1/2 axis high speed machining, 2 and 2 1/2 axis router cutting, 2-axis turning, 2 and 3-axis router mill/turn, 2 and / or 4-axis wire EDM, 2-axis plasma cutting, as well as 2 and / or 5-axis laser cutting.

Mastercam's solids solid modeling interface contains all popular tools found in most mainstream CAD software such as AutoCAD (revolve, extrude, loft and sweep, shell, draft, trim, Boolean addition, subtraction and common volume calculation, etc.); and it integrate its solid modeling capabilities with NURBS and parametric surface modeling and wireframe generation tools in a seamless, streamlined and flexible hybrid environment for practical design of mechanical parts.

Mastercam's integration with popular 3D modeling CAD programs

In terms of file management and data exchange, Mastercam includes built-in data translators for IGES, Parasolid®, SAT (ACIS solids), AutoCAD® (DWG, DXF™ and Inventor) CADL, STL, VDA, and ASCII. Direct translators for STEP, CATIA, and Pro-E®; and it can import from or export to Parasolids®, SAT and Inventor™ files as solids, surfaces and/or wireframe; and it can open SolidWorks® and SolidEdge® files directly.

On January 2004, The SolidWorks World 2004 Conference introduced the Mastercam® Direct for SolidWorks add-in, which offers seamless integration of SolidWorks files into Mastercam environment. "Free to the Mastercam and SolidWorks communities, Mastercam Direct allows users to open a model in Mastercam while in a SolidWorks session, and then apply existing toolpaths to that model. With the latest release of Mastercam Direct for SolidWorks, users can now import the model into Mastercam, complete with the solids history tree intact. Furthermore, the direct interface can detect changes made to the original file when re-imported to Mastercam. Mastercam will flag the user of any changes, thus allowing the user to modify any associated data such as geometry or toolpath information. Also enabled in Mastercam Direct is support for SolidWorks file type .SLDDRW, which is a drawing file. There is no Feature tree output, but it can pass the 2D drawing data onto Mastercam" (Mastercam, 2002).

The machining operations Mastercam can drive include Pocketing, Contouring and Drilling, in 2D, and 2½D ranges from the very simple to the very complex. Pocketing styles include high speed, zigzag, one way, true spiral, constant overlap spiral and "morph" pocketing, each with optional finish passes. Contour and Pocket re-machining use a smaller tool to automatically clean out material left from a previous cut. Mastercam can easily machine 2D and 3D contours including parametric and NURBS splines; and make solid features such as drilling holes on solid models complete with pre-drill operations. Mastercam can perform fast efficient bulk material removal with a variety of roughing techniques, including rough cut on multiple surfaces or solid models or a combination of both, with constant Z contours or pockets. In addition, Mastercam can perform a variety of finishing tasks with robust tool paths, on multiple surfaces, solid models, or a combination of both, to create a constant finish. 3D project machining creates a consistent, smooth finish while following the natural curves of multiple surfaces or solids. The Cleanup Machining feature in Mastercam automates leftover material identification and removal, resulting in a finer finish, using a hybrid leftover machining technique that changes the cut method as the slope of the model changes, in a single tool path.

Other machining capabilities of Mastercam include High Speed Machining (HSM), a powerful machining method that combines high feed rates with high spindle speeds, specific tools, and specific tool motion for faster turnaround and a superior finish; and Multiaxis Machining which adds an extra level of flexibility to machining operations; automatic parting line calculation for mold making; and many more.

In addition to its capability of manufacturing components made through engineering design process, Mastercam can perform the following two artistic tasks:

Mastercam's optional Engraving can produce the effect of classic hand-carved art using CNC machine; and Rast2Surf, a function that converts a bitmap/photo into an embossed surface. The artist can set the height range and it will sort the points by grayscale into the correct Z level, creating a relief surface. The artist can output STL or Mastercam surfaces for physical production.

Part Seven
Recommendation for Educators and Students of CAD/CAM

Application of CAD/CAM/FEA programs in industry: a summary

There is a variety of CAD/CAM and associated software such as FEA analysis and kinematics simulation packages. The selection of software depends on the size, the financial resource, the personnel resource and the nature of business of the company or institution.

The following Table 11 illustrates the major CAD/CAM and associated software products used in the United States:

Table 11: CAD/CAM and Associated Software for Engineering

Field of Engineering	Low-end to Mid-range	High-end
Mechanical engineering	AutoCAD Mechanical, Mechanical Desktop, Inventor, SolidWorks, and SolidEdge, Autodesk VIZ, 3ds MAX	ProEngineer, CATIA, and Unigraphics
Electrical and electronics	AutoCAD Electrical	Electronic Workbench MultiSIM
Manufacturing		MasterCAM, GibbsCAM
FEA	COSMOSWorks and COSMOSDesignStar, ANSYS, etc.	MSC.Nastran/Patran

In order to prepare for a successful career, I recommend that every student should learn at least two programs in his or her field of choice: AutoCAD plus another mid-range or high-end package, depending on what type of companies or institutions he or she will work for. In addition, due to rapid changes in market conditions of CAD/CAM and associated software, as well as in job market, engineering professionals should be always ready to learn new skills through life-long education.

Bibliography

Autodesk. (2004). *Autodesk Advances Lifecycle Management for Building, Infrastructure and Manufacturing Markets - The Introduction of AutoCAD 2005 and Family of Products Paves the Way for Autodesk Customers Across All Industries to Realize MAXimum Productivity Gains During Design Creation, Management and Collaboration.* Retrieved August 8, 2004, from http://usa.autodesk.com/adsk/servlet/item?siteID=123112&id=4180740&linkID=2475212

Autodesk. (2004). Autodesk Inventor and Autodesk Inventor Series Reign as the #1 selling 3D Mechanical Design Software for the Third Year in a Row: *Integrated 2D and 3D Design and Data Management Capabilities Are Unparalleled for Leveraging Design Data throughout Today's Complex Manufacturing Processes*. Retrieved August 8, 2004, from http://usa.autodesk.com/adsk/servlet/item?siteID=123112&id=4061429&linkID=2475212

Autodesk. (2004). *Autodesk Manufacturing and Visualization Solutions Receive the Industry's Top Awards from Magazine Editors and Readers - AutoCAD Electrical 2004, AutoCAD Mechanical 2004, and 3ds MAX 6 Deliver on Innovation and Real-World Productivity*. Retrieved August 8, 2004, from *http://usa.autodesk.com/adsk/servlet/item?siteID=123112&id=3847971&linkID=2475212*

Autodesk. (2004). Discreet Ships 3ds MAX 6 Professional 3D Animation Software: The Industry Leading 3D Software Application for Film Makers, Game Developers and Designers Just Got Better—With Significant Leaps in Character Animation, Rendering, and Dynamics*. Retrieved August 8, 2004, from http://usa.autodesk.com/adsk/servlet/item?siteID=123112&id=3649461&linkID=3353183*

Autodesk. (2004). *Malmkvist AB Develops Industrial-Strength CAD System with Mechanical Desktop Software.* Retrieved August 8, 2004, from http://usa.autodesk.com/adsk/servlet/item?siteID=123112&id=560265&linkID=2475197

Autodesk. (2004). *Strategic Partners*. Retrieved August 8, 2004, from http://usa.autodesk.com/adsk/servlet/index?siteID=123112&id=2998980

Autodesk. (2004). *World Trade Center Design Team Partners with Autodesk to Help Facilitate Freedom Tower Design and Construction Process - Autodesk Collaboration Services and Design Software Serve as Technology of Choice for Skidmore, Owings, & Merrill LLP on the Nation's Highest Profile Project.* Retrieved August 8, 2004, from http://usa.autodesk.com/adsk/servlet/item?siteID=123112&id=561076&linkID=2475197 and from http://usa.autodesk.com/adsk/servlet/item?siteID= 123112&id=4418374&linkID=2475212

CATIA. (2004). *Equipment & System Engineering. RetrievedJuly 2004 from* http://plm.3ds.com/10+M5d09d4be281.0.html

Maliniak, David (2003). *What's Hot At DAC: New tools and methodologies to be unveiled span system-level design to post-layout analysis.* Electronic Design. May 26, 2003. Retrived July 1, 2004 from http://www.elecdesign.com/Articles/Index.cfm?ArticleID=3557&pg=2

Sheffield, Nancy. (1997). *Advances in Virtual Instruments*: *PC-based systems speed design by integrating device setup, data acquisition and simulation.* EDN Products Edition, March 12, 1997. Retrieved July 1, 2004 from *Electronic Workbench Press Releases* at http://www.electronicsworkbench.com/html/pronews1.html

Wignall, William J. (2001). *Electronics Workbench launches powerful, affordable simulation solution f*or Communication Systems Design: *Easy to Use Windows-Based Environment Enables Modeling and Simulation With No Coding-Shortens Design and Development of Mixed-Signal Communications Systems*. Electronics Workbench. July 16, 2001. Retrieved July 1, 2004 from http://www.electronicsworkbench.com/html/pronews1.html

APPENDIX D

Integration of CAD/CAM Technology and Engineering/Technical Education Programs at Community Colleges in Southern California

The Final Report by

Student: Edward Locke

TECH 505 – Seminar: Industrial Studies

Professor: Dr. William Gray

The Department of Technology

College of Engineering, Computer Science & Technology

California State University, Los Angeles

Summer Quarter, 2004

Objective of the Report

The objective of this report is to present an analysis of the integration of CAD/CAM programs and engineering technology curriculum in local community colleges in southern California.

Part One
Introduction To History and Functions of Articulation and Integration

Connecting institution of learning with real world work place - integration of academic and technical subjects

The objective of this part of the Final Paper is to present the concepts and practice of articulation and integration of technical educational programs in the

United States among high school, community colleges and universities, in a historical perspective.

Before the Industrial Revolution, opportunities for systematic formal education through established schools are generally limited to the well-to-do, but also to the poor in very limited scope; and is constrained to the teaching of “academic” subjects, leading towards the training of new generations of the “elites” (political, cultural or religious leaders), although small-scale training program for artists and craftsmen were also available through sponsorship from the imperial courts, the churches and wealthy merchants. This lack of opportunity for learning hands-on technical skills can be illustrated by a statement of Mensius, a students of Confucius, an ancient Chinese scholar: “Xue Er You Zhe Shi”, which can be translated as “Excel in schooling and become an officer of the Imperial Court.” In the beginning of civil service system in Great Britain (similar to the so-called “Chinese Examination System” or Ke Ju Zhi), similar pattern existed. People were able to change their class status (in terms of income, prestige and political power) through mastery of “academics” (through passing of a civil service exam), but generally not with possession of hands-on skills. Teaching of job skills were done through work, not through formal schooling. Vocational and technical education through formal schooling was started after the Industrial Revolution in England and the United States, due to the need for training skilled workers for industry, farm and national defense, and to reduce unemployment.

In the USA, Smith Hughes Act (1917) was the first major influence for secondary and post-secondary programs. This Act aims at preparing youth for employment and leads to separation of vocational and academic education. The Smith Hughes Act, later sharply criticized by academic as well as industry leaders for its separation of academic and vocational programs, or even worse, for its supposedly “elitist” tracking system that allowed students of upper-class background to go to academic programs while confining students of working-class backgrounds to low-paying semi-skilled jobs, was actually the best possible choice for that particular period of time. During that period, the United States was an industrial society with plentiful of skilled and semi-skilled jobs in manufacturing industry and agriculture, but the production is not as automated as today, and productivity was low in today’s perspective; therefore, the economy could neither afford too many people going to white-collar “academic” jobs, nor dedicate enough tax-based financial resource to support it; therefore, the economic conditions at that period did well justify the two-tiers system of tracking. Another factor that contributed to the negative effects of separation is lack of precedents to refer to. United States is the first democratic nation in modern world with a strong commitment to provide education opportunity for the “masses,” with the earliest universal public school system for all citizens since Thomas Jefferson’s time, and the highest rate of college graduation per population in the entire world today (25% in United States versus 15% in Europe); and the United States pioneered higher education at large scale, and had to come up with an imperfect system under Smith Hughes Act and allow its gradual improvement through further legislative process. Therefore, the Smith Hughes Act was actually very revolutionary at the time of its inception.

With the dramatic expansion of American economy through the use of new technology that resulted in higher productivity through automation, especially after the invention and widespread application of computers, Internet and robots, which propel United States into the post-industrial society in the 1970s, the whole landscape of American economy and education changed. Two unavoidable phenomena of the post-industrial society in the United States are:

1. In the sphere of education, a movement from narrow, restricted, overemphasis on hands-on skills training to broader-scope education that prepares students to work in increasingly high-skilled, technical work places;

2. In the economic arena, the globalization of American economy with loss of primary manufacturing jobs and gains in secondary manufacturing jobs (mold-making, custom manufacturing, etc.), customer service and maintenance sector jobs (commonly referred to as “Third Sector” jobs).

The reality of global division of labor and possession of natural resources such as raw materials also favors export of blue-collar manufacturing jobs to developing countries by American-owned multinational corporations, for lower labor cost, cheap raw materials, greater profit margin and less market competition, as well as creation of more white-collar jobs in the United States (for managers, engineers, chemists, educators, etc). In addition, the American economy today can afford to support education and research with more tax and grants. Under these new conditions, the Smith Hughes Act system of educational apartheid has run out of its historical progressive and functional benefits, and needed major overhaul. To meet to this changing need, Perkins I, II, III (1984, 1990, 1998) leads to re-integration of vocational and academic education. This Act is very revolutionary in terms of the freedom it provides to students to choose academic, technical or a hybrid path for their career development.

The concept of integration of hands-on technical training with teaching of “academic” subject knowledge is by and large based on the proven assertion that “learning is enhanced by doing, that we master knowledge and skills by applying them to practical problems encountered in the daily course of working and living […] The idea that students learn more quickly and thoroughly if they understand how people use academic knowledge and skill in the worlds of work has been around for some time. Almost a century ago, John Dewey (1916) wrote in *Democracy and Education* , ‘Education through occupations...combines within itself more of the factors conducive to learning than any other method.’ […] Integrating academic and vocational/technical education is one of the major policy objectives of the Carl Perkins Vocational Education Act, expressed first in 1985 and subsequently restated in the 1990 and 1998 reauthorizations. It is also a policy hallmark of the School to Work Opportunities Act." (Gary, 1999).

Connecting high schools with two-year community colleges and four-year universities – articulation of equivalent courses

The articulated secondary-postsecondary program that provides technical preparation in an occupational field, integrates academic and vocational education, and leads to placement in employment, has emerged in response to the call for reform of educational systems. Starting with Carl D. Perkins Vocational and Applied Technology Act of 1990 federal funds are available for tech prep in every state. According to a research paper funded in part with Federal funds from the U.S. Department of Education under Contract No. ED-99-CO-0013, titled *Trends and Issues Alert: Tech Prep,* by Susan Imel, by 1993 almost half of all school districts in the United States, that included more than 60% of all secondary students, were involved in technical preparation programs. However, only a small percentage of students took courses in this area.

In the areas of engineering and technology, many equivalent courses are articulated and offered at both high school (through Regional Occupational Programs or ROP) and community college systems in Southern California; they include basic engineering drafting with AutoCAD, wood and metal machine shop operations, and electronics. Technical and vocational courses offered at community colleges can be "articulated" by determination of their equivalency to similar courses offered at high schools, in terms of course content and numbers of unit hours required. According to Los Angeles Community College District website, articulation of courses offers the following benefits:

- Minimizes needless course duplication, thus reducing the costs for students, their parents and the institution;

- Allows students to receive college credit through hard work and achievement at the high school level;

- Provides incentive for students to continue their education, particularly at the articulated community college, which is a valuable recruitment tool;

- Encourages enrollment in articulated high school curricula, increasing career vocational and technical career exploration for high school students;

- Increases self-confidence and self-efficacy in students when they complete college-level courses;

- Prepares students for higher education via high academic standards, vocational skills integration and work-based learning opportunities in the articulated courses;

- Provides an opportunity for high school and community college faculty to interact and improve cooperation and curriculum integration;

- Helps to insure high school and community college curricula is relevant, topical and meeting the needs of the institutions, the students and industry.

Articulation of equivalent courses between two-year community colleges and four-year universities can offer the following benefits:

- Minimizes needless course duplication, thus reducing the costs for students, their parents and the institution;

- Allows students to receive four-year university credit through hard work and achievement at two-year community colleges;

- Reduces crowdedness at four-year universities by allowing students to complete their lower division courses at smaller-sized classroom at local institutions of learning, offering greater opportunity for higher education. Los Angeles City College, Pasadena City College and many others have “2 Plus 2” articulation agreements with California State University at Los Angeles and others to complete the entire lower division engineering programs (including both major and general education) at community college level. Interestingly enough, due to the fact that classes offered at community colleges usually have smaller number of enrolled students (generally about 20-30), compared to those offered at undergraduate courses at four-year State universities (usually about 30-50, students have more opportunity to know each other and to interact with the teachers if enrolled at community colleges;

- Offers financial benefits to low-income people with lower registration fee for individual student (for example: after several increases, registration fee per semester unit at community colleges across the State of California is less than $30, compared to more than $100 for California State University System;

- Offers faster and easier process to apply for admission or to register for classes for every potential student (application and registration can be completed the same day the student shows up at the admissions office, or even within 30 minutes if the student goes on-line to complete the process through the internet, at most if not all community colleges in Southern California, with opportunity to be admitted virtually guaranteed. In four-year universities, admission process usually takes weeks to complete, and there is no guarantee for opportunity to be admitted);

- Provides incentive for life-long education (students can complete a certificate program in a technical area, such as engineering drafting and machine shop operations, go to work for a few years to make money and get real world experience, then continue their four-year Bachelor of Science in Mechanical Engineering program at four-year universities).

A comparison of strength and benefits of two-year community colleges and four-year universities:

Two-year community colleges are more skill-oriented than four-year universities; and they respond quicker to the needs of local community and small to medium-sized companies. Compared to four-year universities, two-year community colleges are more locally controlled in the design of curriculum and the administration of programs, and can usually respond faster to community and industry needs with vocational and technical courses teaching particular industry skills with more accommodating schedules and learning curve to students, with day, evening and weekend sessions. Community colleges in Southern California such as Los Angeles Trade Technical College, Cerritos College, Glendale College and Santa Ana College offer many unique courses in architecture, engineering drafting, machine shop operations, electronics and computer-aided manufacturing that are either not offered at all at four-year universities or are offered at more “compressed” format as illustrated in Table 1 below:

Table 1: Comparison of CAD Course Offering at CSULA and Some Community Colleges in Southern California

CAD Program	**Related Courses**	
	Community College Engineering Department	**College of Engineering, Computer Science & Technology, California State University Los Angeles**
SolidWorks	**Manufacturing Technology (MT) at Santa Ana College:** MT 103 - SolidWorks Basic Solid Modeling (3.0 units) MT104 - SolidWorks Intermediate Solid Modeling (3.0 units) MT 105 - SolidWorks Advance Solid Modeling (3.0 units) MT 106 - SolidWorks Drawing (1.5 units)	Technology 454L-3D Solid Modeling: SolidWorks (3.0 units)
CATIA	**The Technology Department (Computer Aided Design/Drafting, or CADD); and Machine Tool Technology or MTT) at El Camino College:** CADD 31abcd - Orientation to CATIA (2.0 units) CADD 32abcd - Solid Modeling with CATIA (2.0 units) CADD 31abcd - Advanced CATIA Functions (2.0 units) All CADD courses repeatable four times regardless of grade received. MTT 10G – Numerical Control Graphics Programming with CATIA (3.0 units)	Technology 454L-Advanced 3D Solid Modeling (3 units)

In addition, many course teaching low-end to mid-range CAD programs such as Autodesk AutoCAD, Mechanical Desktop and Inventor that are used by small business firms and local government agencies are offered extensively at community colleges with full-blown certificates or Associates of Science degrees. Four-year universities usually offer courses on more high-end CAD systems used in large corporations or higher-up government agencies. In recent years, the best of local community colleges such as Pasadena City College, Cerritos College, Santa Ana College, El Camino College and Rio Hondo College have actively fought for and succeeded in bringing their engineering and machine technology computer lab up-to-date with new technology used in industry, in terms of software and hardware, as well as implementation of internet-driven new technique, such as on-line or on-line and classroom hybrid teaching and learning (also called "distance education"). Most of these community colleges have computer labs that rival those operated by four-year universities. Community colleges are focused on serving the needs of local students.

Community colleges also offer more flexibility in creating short-term certificate programs for particular industry needs. For example, to meet the need of industry for better presentation of engineering design through photo-realistic video animation, Long Beach City College offers two certificates based on Autodesk AutoCAD and Discreet 3D Studio MAX:

- AutoCAD III, Visualization, Rendering, Animation (108 Hours) with a 4-unit course (Draft 204-3D Visualization/Animation);

- CAD Professional (324 Hours) with Draft 202 – AutoCAD I, Fundamentals (4 units); AutoCAD II-Advanced Concepts (4 units); and Daft 204 - (Draft 204 – 3D Visualization/Animation).

Pasadena City College offers a 13-unit Certificate of Completion – Computer Aided Technical Modeling and Animation based on AutoCAD, SolidEdge, Autodesk VIZ, etc, with the following four courses:

- Drftg 8A-Engineering Drafting Technology (3 units);

- Drftg 17-Computer Aided Drafting (3 units);

- Drftg 118-Three Dimensional CAD (3 units);

- Drftg 8A 229-Photo-realistic Rendering and Animation (4 units).

These short-term certificate programs are good for preparation beginning CAD job seekers and for training experienced engineers with a new presentation skill. As a matter of fact, community colleges, with flexible curriculum design and modification, lower fees, more accommodating evening and weekends schedules, and open admission, offers a great opportunity for life-long education for people of all ages.

Four-year universities are more geared towards teaching “academic” subject mater, and conducting research projects. In addition, they better serve the needs of larger corporations and higher-up government agencies. For example, California State University at Los Angeles is well connected to industrial giants such as Northrope Grumman, Boeing and NASA. Four-year universities attract students all over the world. Four-year universities are generators of new technology in partnership with resourceful multinational corporations and government agencies; and usually receive more corporate funding. Four-year universities also offer opportunity for life-long learning through “open university” or “extension” programs for lower and upper division undergraduate courses, currently at a tuition fee of $150 per semester or quarter unit in CSU system.

Integration of academic subject matter and hands-on vocational skills in engineering, manufacturing and technology programs at community colleges in Southern California

Students benefit from integration of academic subject matters and hands-on skills, in terms of less abstract concepts, more connection to real-world problem-solving; increased academic achievement through portfolio preparation, etc.. Community colleges are able to recruit more diverse groups of students (new students seeking degrees, and returning students learning new skills). For example, El Camino College’s CATIA courses attract many engineers with Bachelor of Science degrees and experience from nearby corporations, who come to El Camino to learn new skills.

Engineering departments at community colleges are committed to broadening course content through integration of subject theory with real-world practice (for example, Engineering 100-Introduction to Engineering at Santa Ana College and others includes guest speakers, field trips, seminars, reading and Internet search to expose students to the real world of design, construction and manufacturing; and students are encouraged to become members of Engineering Club and to participate in design competitions). Another example of building bridges with industry is found at the Engineering and Manufacturing Departments at Glendale Community College, in Los Angeles County. Local companies donate CNC machining equipment to the machine shop at Glendale Community College’s Manufacturing Department; and a cooperative educational program allows students to work on custom-machined components for the donors, using the donor-supplied materials. This creative financing scheme allows the school to obtain needed tools, students to learn real world skills, and industry to save labor training costs.

Many formats are employed in the integration of academic subjects with vocational skills. According to Gary (1999), “there are at least four different forms of integration"; and my personal research into the administration of curriculum offered at local community colleges in the Greater Los Angeles or Orange County Areas indicate that the general principles of three of these "four different forms of integration" are reflected in CAD/CAM- and technology-related vocational and technical programs:

- **Course-level integration** (adding more academic content to existing vocational courses, and more work-related applications to academic courses). Engineering drafting courses at most community colleges teach not only drafting theory (orthographic, isometric, oblique and sometimes, perspective projection, history of the evolution of drafting techniques, calculation of tolerance, units and measurements, etc.), but also hands-on skills with free-hand lettering and sketching, plus CAD techniques with AutoCAD, SolidEdge, etc.. There are also courses that teach the application of an academic subject like mathematics to a particular industry, such as MTT 40 – Machine Shop Calculation at El Camino College, MT 053 – Technical Mathematics at Santa Ana College, and EL 10 & 12 - Mathematics of Electronics I & II at Los Angeles City College.

- **Cross-curriculum integration** (more opportunities for academic and vocational teachers to coordinate as a team and connect academic and vocational courses). Many community colleges offered technical certificates that integrate academic courses with technical ones. For example, the Associate Degree in Engineering (0202) at the Engineering Department, Santa Ana College is designed for students planning to transfer to four-year college or university engineering programs or to seek employment as designer, technician, or engineering assistant in both private industry and city, county and state agencies, and includes 3- to 4-unit academic courses (Mathematics 180 - Analytic Geometry and Calculus, Mathematics 185 - Analytic Geometry and Calculus, Physics 217 - Engineering Physics, Physics 227 - Engineering Physics or Physics 237 - Engineering Physics, Chemistry 219 - General Chemistry, and Engineering 148 - Introduction to Engineering), as well as 3-unit hands-on drafting skill courses (Engineering 122 Engineering Drawing (3.0 units) or Engineering 125 Engineering Graphics, Engineering 183 - AutoCAD I-Computer Aided Drafting).

- **Programmatic integration** (well-planned and coordinated changes to curriculums to meet new industry challenges). New courses teaching skills with popular, industry standard CAD/CAM programs such as AutoCAD Mechanical Desktop, Inventor and Mastercam, design presentation programs such as AutodeskVIZ, and electronic design and simulation programs such as Electronics Workbench MultiSIM and UltiBOARD, have been added to well-established engineering drafting and design, CNC manufacturing, and electronics technology programs at Los Angeles Trade

Technical College, El Camino College, Cerritos College, and Santa Ana College in recent years, so as to meet the evolving needs of industry due to changing market conditions of the software programs.

- **School-wide integration** (creation of academies or special high schools to meet the needs of a major an industry or of a career area). Due to budget cut in public financing for education and the trend towards the shrinking down of institutions and bureaucracies, unless wealthy large corporations are willing to pay, creation of academies or special high schools for a particular industry or career area is no longer a viable option. Besides this fiscal reality, most of technology and engineering programs are already well-established in their administrative structure across Southern California, preempting any further need for new administrative bodies. What is really needed now is consolidation and modernization of existing programs and institutions so as to attract more government and corporate support. This is what far-sighted leaders of engineering, manufacturing and technology departments are fighting for in recent years. The unfortunate truth is, if a program is disconnected from industry or out-of-date with new technology, then it will eventually die. For example, in a conversation with a professor at Cerritos College, I am informed that out of seven electronics departments/programs in Southern California, only two still exist. This is due to many reasons. One of the reasons is globalization (more and more electronic components are now imported from foreign companies, either foreign- or American-owned, resulting in a shrinking manufacturing job market). Another reason is lack of industry support (if a program is out-of-date with new technology, or disconnected from industry; or in other words, if the leaders of the program do not maintain close relationship with corporations and constantly fight for updating of hardware and software, but instead depends on government funding and keep existing programs unchanged for years, then it will gradually lose support).

Although integration of academic subject matters and hands-on skills is generally beneficial, it is by no means suitable for all courses offered at community colleges. Some courses such as those teaching AutoCAD skills should be based on hands-on skills although drafting theory can be included to a certain degree, not as a main topic to be discussed, but rather as a supporting subject; while other courses, such as engineering physics, statics etc., should be based on teaching of theory and learning of formulas used in the solutions of problem, both of these two items are considered as “academic.” This is due to the constraints of schedule (teachers involved in these courses need to cover a lot of topics within a 3-4 unit schedule). Hands-on courses on these academic subjects are difficult in the physical world; however, they might to possible through the use of digital Finite Element Analysis software program in the future (this, however, depends also on availability of budget to pay for teacher salary and purchase of software and/or hardware). Another restriction on integration is faculty and administrative resistance. Some community college teachers are still used to the old concept of teaching the same "traditional" knowledge for ten years; some administrators are over-burdened with implementation of existing educational programs in their current formats, and have no energy for or interests in initiating changes. Financial resource is another important issue. Implementation of new technology needs money for the purchase of new software and hardware, as well as for teacher training; and this is especially critical under the current situation of budget cut in California. And finally, even with the solution of all of the above problems, promotion of new courses is an important issue. For example, with enthusiastic support from Mrs. Hilda Roberts Dean of Business Division and Ms. Susan Sherod, Chair of Engineering Department, I designed and opened the 3-unit Engineering 189-Parametric 3D Modeling with Autodesk Mechanical desktop and Inventor for Fall 2004 at Santa Ana College; the school advertised it in the Fall Schedule, but due to lack of personal promotion, only 3 students registered for the course, and the course has been cancelled.

In this age of digital revolution, technological advances are driven by upgrades of CAD/CAM programs at a faster pace than ever before. The good old days when instructors can repeat the same subjects and use the same tools in teaching for ten years is over. In order to better serve the ever-changing needs of industry and therefore, enhance the potential of employment or further education at four-year universities of the large community college student constituent, substantial reforms to existing curricula in the direction of further integration of course topics and teaching technique with industry and technology needs to be initiated.

Part Two
CAD/CAM, Their Application in Industry and Available Educational Programs at Community Colleges in Southern California

The objective of this part of the report is to investigate the computer aided design, analysis/simulation and manufacturing software programs used in industry, especially in the field of mechanical and electronic design and manufacturing.

Application of CAD/CAM programs in modern manufacturing process and education

According to an article titled *Manufacturing Engineering document: PART II. Manufacturing. Software Applications* available in a United States Government database at http://www.mel.nist.gov/msidlibrary/doc/sima-study/bakstud2.htm, "The modern manufacturing process can be divided into three stages: mechanical and electronic engineering design, manufacturing engineering, and production. The output of the design engineering stage is a detailed 2D CAD drawings and 3D digital CAD models of the part to be manufactured (this stage might include parts and assembly analyses and simulation). This becomes the input to the manufacturing engineering stage, which results in a detailed specification of how the part is to be manufactured. This specification in turn becomes the input to the production stage, which determines when and where the part will be made, and then proceeds to manufacture it."

Mechanical CAD/CAM systems use computers to aid in generating product models of mechanical parts, including specifications such as materials, features, tolerances, surface conditions, etc., in an electronic format. General CAD/CAM capabilities are:

Model creation, editing, and viewing; component and subsystem layout; 3-D part and assembly modeling (in solids, wireframes, or surfacing), including 3D scanning for the creation of digital geometry from hand-made objects in the process of industrial consumer product design, or from existing mass produced products found in the market place in the "reverse engineering" process; generation of stereo-lithography (STL) files for rapid prototyping systems; and mechanisms for linking to engineering analysis packages (e.g., finite element, tolerance, dynamic, and kinematics analyses).

According to the above-quoted United States Government website, "More than 1,000 CAD products are available on the market, sold by more than 200 vendors. The price of the software ranges from under $1,000 to over $75,000. Systems at the lower end of that range have more limited capability and generally run on personal computers. Higher-end systems have integrated modules for design, analysis, and NC machining capability, and run on state-of-the-art computer workstations. Major users of mechanical CAD systems are the aerospace, automotive, capital machinery, electronic and consumer goods, and tool and die industries."

"The technology of computer-aided design and computer aided manufacturing (CAD/CAM) has progressed significantly from the two-dimensional wireframe drafting systems of the 1970's to the parametric and feature-based solid modelers of the 1990's."

CAD/CAM and associated engineering analysis programs help to create new experimentation environments called VEDAM (Virtual Environment for Design and Manufacture) and VADE (Virtual Assembly Design Environment); and their application in industry can "significantly reduce the time to market and increase the competitiveness of a company" (Lyons and Angster, 1997).

Although the skills of traditional board drafting is still taught at community colleges in Southern California such as Santa Ana College, Pasadena City College, El Camino College with limited schedule allocation (for example, at engineering department at Santa Ana College and Pasadena City College, manual board drafting are covered in the first several weeks of beginning engineering drafting courses; while at other schools, the number of courses entirely dedicated to board drafting have been decreased), CAD/CAM programs including those based on the new technology of parametric 3D modeling have replaced traditional board drafting as the primary means of design communication. It is important to notice that the purpose of learning traditional board drafting skills nowadays is the mastery of free-hand lettering and sketching skills used to quickly record design concepts with a “professional” look, during the initial, “informal” stage of product R&D such as a “brainstorming” session, in notebooks to be shared with colleagues, before a “formal” CAD-based design process start, rather than the preparation for a manual drafting career. These lettering and sketching skills will be always needed because CAD programs, with all of their strict rules and settings, will unlikely eliminate the need for quick recording of informal, free-flow creative ideas.

The market for CAD/CAM programs has been growing steadily in recent decades due to the following factors:

- **More affordable, user-friendly and powerful CAD** - the continuous evolution of CAD/CAD programs themselves in terms of better graphical user interface (GUI), improvement of existing or addition of new tools, features, options and settings, which steadily increases their efficiency in the product R&D process, as well as changes in pricing structure that makes CAD systems more affordable to users;

- **Better CAD education** - Increased availability of educational resources such as low-price educational versions of CAD programs for students and teachers, more courses offered at public and private schools, and publication of more textbooks and digital courseware materials; all of them serve to promote the CAD programs in the market place;

- **Increased market needs**- the competitive pressure on mechanical product manufacturers for faster product turnout cycle, for saving on design time and labor cost, as well as for increasing profits;

- **More powerful but much cheaper CAD-related hardware** - drastic technological breakthrough in hardware (workstation-class computer with increased CPU clock and bus speed, and peripheral equipment such as modems, printers, etc.), coupled with drop in the price (for example, a Dell Pentium 2 900-MHz workstation was around $3,000 around 2000; the much faster Dell Dimension 3000 with Pentium 4 2.80-GHZ CPU non-workstation general purpose PC is now for sale at around $499; a many times much faster Dell Precision 370 Single Processor Workstation with Pentium 4 3-GHz CPU (88MHz Front Side Bus) and much larger and better hard drives (40GB) as well as much faster 64MB PCI express x 16NVIDIA Quadro NVS 280(VGA/Dual Monitor) Graphics Card, can be purchased now at $1,299, as advertised on the September 2004 Dell Catalog).

Classification of CAD/CAM programs and their application in industry - design-centric and process-centric:

There are two categories of CAD/CAM programs used in modern manufacturing process:

- **Design-centric:** Design-centric CAD programs have tools and features related to 2D and 3D design and drafting, and in most cases today, some Finite Element Analysis (FEA) and assembly kinematics simulation capabilities. They are usually low-end or mid-range packages. Examples include: AutoCAD, Mechanical Desktop, Inventor, SolidWorks, and SolidEdge. AutoCAD, AutoCAD Mechanical, Inventor, and SolidWorks are the most used in mechanical design. For electronics engineering, Electronic Workbench family products (MultiCAP, MultiSIM, UltiBOARD, UltiROUTE and CommSIM) as well as Circuit Maker are widely used. 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. SolidEdge is the most powerful. SolidWorks uses a core technology called "Parasolid Kernel" that is developed by Unigraphics, the maker of SolidEdge. These programs are used in the above-mentioned "first stage" (mechanical and electronic engineering design). Files created in any of these programs can be placed in finite element analysis (FEA) or kinematics simulation software such as MSC.Nastran/Patran, COSMOSWorks, COSMOSDesignStar, and ANSYS for engineering evaluation; and after the evaluation, they are imported into computer aided manufacturing (CAM) and/or Computer Numerical Control (CNC) programs such as Mastercam or GibbsCAM and reworked if needed for final manufacturing of the real physical product. Occasionally, CAM or CNC programs can be used as 3D engineering design modeling tools as well. Some mechanical CAD programs such as SolidEdge, also include mold-making interface that can automatically generate the design of mass production molds, with all real world features as well as correct material shrinkage tolerance and other parameters, from existing 3D part geometry.

- **Process-centric:** 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, manufacturing, cost estimation, planning, 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/ProMechanica, CATIA, I-Deas and Unigraphics. These programs can perform the entire modern manufacturing process throughout all of the above-mentioned "three stages." 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.

Traditional CAD design standard: AutoCAD

Before 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 are based on 2D drawing geometry, and products are represented with separate 2D orthographic (top, front, right, auxiliary) and isometric views. 3D wireframe models are 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 wireframe 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 wireframe 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 wireframe 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.

Parametric 3D Modeling - the new CAD design standard with SolidWorks, SolidEdge, Autodesk Inventor and others

Great changes have occurred in CAD industry in the last decade with the birth of a new technology called “parametric modeling”, which is based on a new generation of 3D geometry coding system such as the Parasolid Kernel owned by Unigraphics, a maker of high-end CAD/CAM program. As In parametric modeling technology, creation and editing of either solid or surface 3D models are performed through the application of parametric values (sizes or dimensions) on a 2D sketch, and/or on a 3D feature that is created on top of the 2D sketch. Parametric 3D modeling CAD programs allow easy, interactive and intuitive creation and modification of 3D parts and assembly models. Typically, the whole process of parametric design is described in the following paragraphs.

First of all, in several “part” files, a 2D sketch is created and constrained first with dimensioning tools; then a 3D “sketched feature” (3D solid such as extrusion, cut, revolution, loft, sweep, etc.) is created based on the constrained 2D sketch; then a “placed feature” (fillets, chamfers, holes, etc.) is added on top of the 3D “sketched feature.” The original 2D sketch, the “sketched feature” and the “placed feature” are all stored in a design history recorder interface called “Browser” in Mechanical Desktop, “Feature Manager” in SolidWorks, or “Specification Tree” in CATIA for future editing. When editing is needed, the designer can double-click in the design history recorder either the sketch or the feature to open an editing dialog box and change the parametric values (sketch or feature dimensions); and the 3D model will update.

Next, “assembly” or “presentation” files are created to import and assemble the parts from several part files created so far with geometric constraints; to perform kinematics simulation; to check for tolerance, and to create animated presentation movies.

Next, 2D orthographic multi-view working drawings or isometric presentation drawings are created based on 3D model files.

Thanks to an inter-file 3D data transmission functionality called “associativity,” any changes made in the original 3D part files created in the first step will be updated in the assembly and drawing files. In addition, part name, number and other “property” information entered in the part files can be compiled into a BOM (Bill of Materials) in the 2D drawings.

Another outstanding feature of parametric modeling packages is the inter-part size-accommodation functionality called “adaptivity,” which allows changes made to a strategic size of a part in an assembly to trickle corresponding changes to the size of another part that is set to an “adaptive” mode with the first part.

In parametric modeling, the relationship between parts and assemblies can be either "bottom-up" or "top-down." In a "bottom-up" relationship, individual parts are created first in separate files; then an assembly file is created to bring in and put together all separate parts with appropriate constraints. In "top-down" relationship, an assembly file is created first; individual parts are created separately but within the same assembly file with appropriate constraints; then individual parts are saved as separate part files along with the assembly file, preferably in the same folder in the computer's storage system.

Parametric CAD programs such as Autodesk Inventor include tolerance allocation features that assist in the evaluation of the relationship between mating parts in the assembly, under real world conditions, but in a virtual digital space.

In real world practice, due to the fact that the modern manufacturing process is complicated and involves the collaboration of professionals from related field in a team-work environment, the above-mentioned three stages of the in most cases overlap and interact in most manufacturing organizations. "It is now generally accepted that the deliberate planning of such interaction - leading to what is known as *concurrent engineering* - is beneficial in improving product quality and reducing the time from design to production" (US Government, 2000).

Thanks to their separate but well integrated or "associated" working environment (such as Inventor's division of the whole design, drafting and presentation into Standard.ipt for parts, Standard.iam for assembly, Standard.idw for drawing), parametric modeling technology provides a great convenience for cooperation in teamwork and concurrent engineering. The recent versions of Autodesk Inventor also contain the Design Notebook, another feature that allows engineers to attach notes to 3D part features and helps engineers and engineering department supervisors to communicate ideas for changes.

Another strength of parametric modeling technology is its ability to create a series of components with different sizes but all based on a master component with same features, all within the same part files, through the use of an internal database or a linked external database file from a third party program such as Microsoft Excel. This is very handy for manufacturers of stock items, such as screws and fasteners, beams, channels, and others. All parametric programs come with libraries of standard parts and design features (holes, notches, cutouts, and many others) that can be easily incorporated and edited into the design process, saving engineers and designers tremendous amount of time, allowing them to spend more energy on overall strategic creative thinking and product planning rather than on some technical routine details that can now be automatically generated by a computer. Due to the fact that the key to parametric modeling and editing is the changes in 2D sketch or 3D feature dimensional parameters, parametric modeling is also called "constraint-based modeling" or "feature-based modeling."

Mechanical Desktop, Inventor, SolidWorks, SolidEdge, ProEngineer, CATIA, and Unigraphics are all parametric programs. Due to the fact that the parametric programs need to store the design history data, both the programs and the files demand more storage space than non-parametric products such as AutoCAD. However, the convenience gained in the design and modification process well justifies the increased demand for digital storage space.

Engineering evaluation - stress, strength or finite element analysis (FEA), kinematics simulation and others…

In the "good old days" of traditional mechanical engineering design, engineers worked hard to complete design projects; then proceeded to analysis of their design using engineering physics formulas (often calculus-based) as well as theoretical reasoning; then they need to build full size or scaled physical prototypes to test if the system they invented could actually work. This process of computation and prototyping might be repeated several times until a relatively perfect solution was found and the design was then ready for mass production. The whole process was very time-consuming and costly. With the introduction of finite element analysis and kinematics simulation programs, the whole testing process, including the analysis of stress, strength, structural, thermal analysis of individual parts, as well as the checking of clearance and interference between different part in subassemblies and assembly, and of kinematics, vibration, static, dynamics of the system, and other needed evaluation such as thermal analysis and flow analysis, can all be done in software programs, through the pre-programmed large set of linear (or sometimes non-linear) equations describing the physics of the situation to be analyzed, with amazingly accurate prediction of the actual functional behavior of the system, way before the actual physical prototypes are built as a final proof for the quality of the design.

Computer aided virtual engineering analysis tools aid designers by calculating information about functional behavior, production cost and other matters related to design optimization, and by verifying the compliance of their design with functional or environmental requirements through the digital simulation of its behavior under operational conditions. For these reasons, they help corporations to save time and money, increase productivity and profit.

In terms of logistics, FEA programs use a full rainbow color spectrum to describe the conditions of the part under investigation in all its finite segments (usually divided into tiny triangles or meshes); and kinematics simulation programs display "danger" flags or other indicator symbols in troubled spots in an assembly.

Although these programs can make automatic calculations and analysis, it is up to the engineers and designers involved in the virtual testing to correctly interpret the results, based on their mastery of the subject matters. Therefore, contrary to whatever exaggerated claims that might be made by some makers of FEA packages, the digital analysis and simulation technology is by no means, and will never be an alternative to learning the related subject matter in traditional college classrooms.

There is currently no agreed-on industry standard in FEA programs. Engineering evaluation programs are usually used in medium to large-sized companies involved with complex mechanical, electronic, and civil projects. They are expensive ($6,000 to $11, 000 for COSMOS products, the cheapest one with good features). Small companies generally deal with components with less complexity that built-in FEA functions included in low-end to midrange CAD programs (such as Autodesk Mechanical Desktop and SolidWorks) can take care of, neither have a need to purchase dedicated FEA programs nor can afford them.

Application of CAD/CAM/FEA programs in industry and recommendation for students:

The following is a list of the most popular software programs used in different fields of engineering:

- **Mechanical engineering:** AutoCAD, Mechanical Desktop, Inventor, SolidWorks, and SolidEdge, ProEngineer, CATIA, and Unigraphics, Autodesk VIZ, 3ds MAX;

- **Electrical and electronics:** Electronic Workbench MultiSIM, AutoCAD;

- **Architecture:** AutoCAD, Architectural Desktop, Revit, Autodesk VIZ, 3ds MAX.

- **Civil:** AutoCAD, AutoCAD Map and Civil Design, Microstation, ArcGIS, etc.;

- **Manufacturing (CAM):** MasterCAM, GibbsCAM, CNC Workshop, etc.;

- **Finite Element Analysis:** MSC.Nastran/Patran, COSMOSWorks and COSMOSDesignStar, ANSYS, etc.

Potential engineers should learn at least 2 programs in their chosen field of study, namely, AutoCAD plus a mid-range or high-end program, depending on the company or institution they intend to work for:

- **For mechanical engineering:** AutoCAD, plus one of the following: Mechanical Desktop, Inventor, SolidWorks, SolidEdge, or CATIA.

- **For electrical and electronics:** AutoCAD and Electronics Workbench MultiSIM.

- **For architecture:** AutoCAD, Architectural Desktop or Revit, Autodesk VIZ.
- **Civil:** AutoCAD, and Microstation.
- **Manufacturing (CAM):** Mastercam, or GibbsCAM.

CAD/CAM-based engineering and manufacturing technology programs at Santa Ana College, and other local community colleges in Souther California, a case study

At Santa Ana College

The Engineering Department at Santa Ana College is currently offering five Certificate Programs: Associate Degree in Engineering (0202), Associate Degree (0258) and Certificate (0794) in Engineering Civil Technology, Associate Degree (1054) and Certificate in Engineering Computer-Aided Drafting and Design (1093), Associate Degree and Certificate in Engineering Drafting and Design (Option I-Engineering Drafting and Design (0254), Associate Degree and Certificate in Engineering Drafting and Design (Option II-Architecture/Civil Engineering/Construction Drafting and Design (0284). The software programs taught at the above courses include Autodesk AutoCAD, Mechanical Desktop, Architectural Desktop, SolidWorks, and Bentley Microstation. Compared to other community colleges, Santa Ana offered the best and most comprehensive training in AutoCAD, with a total of 5 courses entirely dedicated to AutoCAD hands-on drafting skills, and 5 courses integrating AutoCAD skills with design and drafting theory and practice in Fall 2004, in the fields of mechanical, civil engineering and architecture. These courses are:

AutoCAD skill courses:

- Engineering 183-AutoCAD I-Computer Aided Drafting (3 units) and Engineering 184-AutoCAD II-Computer Aided Drafting (3 units), for AutoCAD 2D tools, settings, and options;
- Engineering 185-AutoCAD III-Computer Aided Drafting (3 units), for customization of AutoCAD program;
- Engineering 186-AutoCAD 3-Dimensional Drawing (3 units) and Engineering 187-Advanced 3D AutoCAD (3 units), for AutoCAD 3D modeling and rendering.

Hybrid courses teaching both engineering field theory and integration of AutoCAD tools for drafting:

- Engineering 051-Basic Technical Drawing (3 units), Engineering 122-Engineering drawing (3 units), Engineering 125-Engineering Graphics (3 units), Engineering 288-Descriptive Geometry (3 units), Engineering 142-Architectural/Civil Engineering/Construction Drafting Standards (3 units).

Santa Ana College also sports the best and most comprehensive training program for SolidWorks, as explained before in the previous section of the report, with 4 courses; and for MicroStation with 2 courses (Engineering 191-Intergraph MicroStation I, 3 units, for 2D tools and options; and Engineering 193- MicroStation 3D, 3 units). The solidWorks courses are offered at Manufacturing Technology Department but classified under both Manufacturing Technology and Engineering. The Microstation courses are offered at Engineering Department.
The Manufacturing Technology Department offers a total of 8 CNC courses based on or integrated with Mastercam, the industry-standard CAM software, including two courses totally dedicated to Mastercam software tools:

- Manufacturing Technology 073-Mastercam 2D Geometry, 2D Toolpaths (3 units);

- Manufacturing Technology 075-Mastercam 3D Geometry, 3D Toolpaths (3 units).

In the future, when budgetary and other issues are solved, courses related to professional engineering and architectural presentation software such as Revit and Autodesk VIZ, and to electronic design and analysis such as Electronics Workbench MultiSIM and UltiBOARD might be proposed for consideration.

At other community colleges

Over all, **Pasadena City College** and **Glendale Community College** might have the best integration of CAD/CAM programs from 2D, 3D design and drafting, to 3D digital presentation, to 3D prototyping with CNC machine and/or 3D printer (rapid prototyping with polymer and other “soft” foam or plastic materials). Both are well connected to industry. Engineering faculty at Pasadena City College is connected to Jet Propulsion Laboratory. The Engineering and Manufacturing programs at Glendale Community College enjoy a lot of support from local industry; and have received many honors from United States Congress as well as local and state-level business associations. Pasadena City College also offers the best drafting courses in Southern California, integrating AutoCAD, SolidEdge and other mid-range presentation programs with real world-like learning of design and drafting theory. These courses are:

- Drftg 8A-Engineering Drawing Technology (3 units);

- Drftg 8B-Engineering Modeling and Working Drawing (3 units);

- Drftg 8C-Engineering Product Development (3 units); and
- Engr 2-Descriptive Geometry (3 units).

El Camino College at Torrance offers the best CATIA program among community colleges in Southern California with 4 courses.

Cerritos College offers good and well-integrated programs, stretching from drafting to mechanical engineering design, to electronics technology, to plastics manufacturing, to CNC-based manufacturing. The Cerritos College programs receive support from private corporations (such as Boeing), through internships and scholarships (such as several $750 Boeing Technology Scholarships in the Spring Semester, 2004).

In electronics programs, both **Cerritos College** and **Los Angeles Trade Technical College** offer courses that teach Electronics Workbench software, the industry standard used by large and small corporations.

Rio Hondo College at Whittier offers great programs in architecture, environmental design and geographic information system (GIS), with a comprehensive set of CAD programs that include AutoCAD, Architectural Desktop, Revit, Microstation, Triforma, ArcGIS, ArcMAP, 3D Studio Max. Students are taught the skill of traditional sketches, renderings, handmade models and detailed drawings, and the technique to create and present their design in a photo-realistic “virtual walkthrough” in computer programs. The school offers special programs to train employees from private corporations; and is active with many professional clubs, such as American Society of Engineers and Architects (ASEA), SKILLS USA/VICA and Rotaract (sponsored by Rotary Club). The facilities at Rio Hondo College’s Visual Technology Department feature the latest in modern computers, printing reproduction equipment, drafting, and rapid prototyping. They include 4 computer labs with 25 workstations each. Most open lab workstations range between 1.9 GHz and 2.8 GHz based systems with as much as 1GB of RAM. The network is anchored by several multi-processor severs offering about 700GB of centralized storage. Several CD-Writers and DVD-Writers are available in each lab to allow for easy data backup and portability. Optical mice offer the latest in reliable control and accuracy.

Other community colleges in Southern California also teach CAD/CAM software and have their own lab facilities; but the above-mentioned colleges are among the best organized, best supported and best equipped in their engineering, architectural, manufacturing and technology programs.

Across community colleges I have reviewed, some courses teaching basic hands-on skills such as AutoCAD drafting, machine shop operations, are articulated between high school or ROP programs (such as those offered at West Valley Occupational Center in Woodland Hills) and community colleges; others that involve the use of more expensive software and equipment such as SolidWorks and CNC machining, are usually the exclusive domain of community colleges and four-year universities. Most of hybrid theory and hands-on skill courses such as engineering drafting, descriptive geometry, electronic circuit design, as well as “academic” courses teaching engineering physics and static offered at two-year community colleges are articulated with their counterparts in four-year universities through inter-institutional agreements such as “2 Plus 2” transfer plans.

Part Three
Conclusions

From data and analysis presented in this report, we can draw the following conclusions:

- Some of engineering, architectural, manufacturing and technology programs offered at selected community colleges in Southern California reflect the idea of articulation of equivalent courses among high schools, two-year community colleges and four-year universities, which is good for students of all ages and career plans;

- Most of engineering, architectural, manufacturing and technology programs offered at selected community colleges in Southern California reflect the idea of integration of academic subject matters and hands-on skills, in terms of teaching theory through practice, especially with CAD/CAM software. Some of the community colleges mentioned in this report are very well integrated with the most current technology (software and hardware), and are supported, besides government funding, by private business institutions, through internship, scholarship and equipment donation. Building bridge between community colleges and business is mutually beneficial for industry and schools.

- The good old days when teachers could repeat the same subjects to students with same techniques for five to ten years is over. In this age of “digital revolution” with continuous change in both hardware and software, teachers should be always working at adopting new technology;

- In terms of financing for the implementation of new technology, corporate grants and donations should be actively pursued at a supplement to government funding;

- An understanding that community colleges exist primarily to serve the changing needs of community and business is very important in the improvement of the quality of technical education.

Reference

Hoachlander, Gary. (1999). *Integrating Academic and Vocational Curriculum - Why Is Theory So Hard to Practice?* Retrieved July1, 2004 from http://ncrve.berkeley.edu/CenterPoint/CP7/CP7.html

Imel, Susan. (1996). *Trends and Issues Alert: Tech Prep.* Retrieved July 1, 2004 from http://www.cete.org/acve/docgen.asp?tbl=tia&ID=103

Los Angeles Community College District. (2004). *Articulation.* Retrieved July1, 2004 from http://www.laccd.edu/workforce_dev/tech-prep/articulation.htm

Lyons, Keven, & Angster, Scott, & Jayaram, Sankar. (1997). *Environments for Design and Manufacture, Concurrent Engineering - The Agenda for Success.* Res Studies Press Ltd. Retrieved July 1, 2004 from http://www.mel.nist.gov/msidlibrary/publications.html.

Rio Hondo College. (2004). *Architecture and Engineering Design Drafting - CAD and GIS: "Visual Technology".* Retrieved July 1, 2004 from http://www.riohondo.edu/tech/cad/index.htm

US Government. (2000) *Manufacturing Engineering document: PART II. Manufacturing, Software Applications.* United States Government Database. Retrieved July 1, 2004 from http://www.mel.nist.gov/msidlibrary/doc/sima-study/bakstud2.htm

APPENDIX E

Post-Study Survey Forms and Lists

Part A
List of Local Community Colleges and University Engineering & Drafting Departments in California for Potential Post-Study Survey & Survey Forms

Part A-1a Sample cover letter requesting for Educational Survey

From: Name of Future Graduate Student
Address
Phone No.
Email

To: Chair of Engineering Department
Any local community college/university

RE: Survey on CAD program used in engineering drafting and descriptive geometry courses

Date: Any date

Dear Sir/Madam,

My name is X and I am sending this email to you to request your assistance. I am a graduate student pursuing a Master of X degree in X major at the X Department, X College, at X University. I am currently continuing to write a college-level textbook on engineering descriptive geometry using AutoCAD 2D and 3D tools, as well as popular parametric 3D modelers, such as Inventor, SolidEdge, SolidWorks and CATIA. In addition, I am writing research paper on the use of CAD/CAM programs at local community colleges and universities.

I am hereby requesting your assistance in responding to a short survey on engineering graphics and descriptive geometry courses offered at your school, which shall provide great help to me in completing my graduate project. Your input to this survey will be kept in strict confidentiality. I hereby attach the Educational Survey form in Microsolft Word format with this email. Please down load the attached file, open it, keep the multiple choices that apply and delete those that do not, and email me back. Thank you for your assistance. I shall look be looking forward to hearing from you soon.

Sincerely Yours,

X student

Part A-1b Educational Survey: CAD Programs in Engineering Courses

Objective: To investigate the application of CAD programs in engineering courses offered at local community colleges and four-year universities in California.

Survey Questions:
1. The CAD/CAM software my department currently teaches or plans to teach in engineering programs include (Please keep all that apply and delete the ones that do not):

Mechanical engineering design, drafting, modeling and presentation
❒ AutoCAD ❒ Mechanical Desktop ❒ Inventor ☐CATIA ❒ SolidWorks
❒ SolidEdge ❒ MicroStation ❒ ProEngineer ❒ Autodesk VIZ ❒ 3D Studio MAX
❒ Others:___________________________
The most important programs in this category that my department uses are (Please specify):_____________

Mechanical simulation, computation and analysis:
❒ COSMOExpress ❒ ANSYS ❒ I-Deas ❒ ProMechanica
❒ Mathematica ❒ MathCAD ❒ MatLab
❒ Others:____
The most important programs in this category that my department uses are (Please specify):_____________

CNC manufacturing:
❒ MasterCAM ❒ CNS Workshop ❒ GibbsCAM ❒ ProManufacturing ❒ Others:________
The most important programs in this category that my department uses are (Please specify):_____________

Electrical and electronic engineering design, simulation, and presentation:
❒ P-Spice ❒ ElectronicsWorkbench ❒ SolidEdge ☐CATIA ❒
Others:____________________
The most important programs in this category that my department uses are (Please specify):_____________

Civil engineering, GIS (geographical information system), surveying, and architectural design:
❒ Architectural Desktop ❒ AutoCAD MAP 3D ❒ FormZ ❒ Rivet ❒ ArcView
❒ Others:________
The most important programs in this category that my department uses are (Please specify):_____________

2. Regarding the subject of engineering descriptive geometry, we
❒ Offer it as a separate course in the past but currently teach it as a part of regular engineering graphic course.
❒ Currently offer it as a separate course (Please specify the frequency: ❒ Every semester/quarter
❒ Once every________).
❒ Currently do not offer it as a separate course, but plan to do so in the future.
❒ We teach manual drafting and AutoCAD in our descriptive geometry course.
❒ We use a 3D parametric CAD program to teach this subject (Please specify the program (s):_________).
❒ We would like to have a textbook on solving descriptive geometry problems in the following 3D parametric CAD program (s):____).

2. For engineering graphics courses, we currently use or plan to use the following textbook (s):
Author__________________Title____
Author__________________Title____

5B. For descriptive geometry course, we currently use or plan to use the following textbook(s):
Author__________________Title____
Author__________________Title____

School Name/Contact Person/Phone Number/Email (Optional):____

Part A-2a   Sample cover letter requesting for Student Survey

From: Name of Future Graduate Student
Address
Phone No.
Email

To: Students of X Course, X Semester, X Year, at X College

Subject: Survey on the usage *Descriptive Geometry with Autodesk AutoCAD, A Collection of Step-by-Step Learning Modules for Engineering Students,* and *Descriptive Geometry with Autodesk Inventor, A Collection of Step-by-Step Learning Modules for Mechanical Engineering Students*, by Edward Locke

Date: Monday, December 12, 2005

Instruction:
Please complete the following anonymous survey on the learning modules you have used in the descriptive geometry part of your course.

Part A-2b Classroom Survey: Instructor-supplied Learning Modules

Objective: To collect student feedback on the learning modules supplied by the instructor.

Survey Questions:

1. Over all, the learning modules are (Please check one):

❒ Very good ❒ Fairly good ❒ Generally good ❒ So so ❒ Poorly written

2A. The best written AutoCAD Modules are (Please check the best two):

❒ AutoCAD Module 1A: The Basic Concepts and Application of Descriptive Geometry
❒ AutoCAD Module 1B: Points, Lines, & Planes in the Three-Dimensional Space
❒ AutoCAD Module 1C: Solving For Shortest Distances Between Points, Lines and Planes
❒ AutoCAD Module 1D: Solving For Angles & Diehedral Angles
❒ AutoCAD Module 2: The Development of The Five Plutonic Solids
❒ AutoCAD Module 3A: The Parallel-Line Development of Cylinders
❒ AutoCAD Module 3B: The Parallel-Line Development of Prism
❒ AutoCAD Module 4: The Parallel-Line Development of Prism
❒ AutoCAD Module 5: Solving Descriptive Geometry Problems in AutoCAD 3D Environment

2B. The best written Inventor Modules are (Please check the best five):

❒ The Autodesk Inventor Program and The Solution of Mechanical Engineering Descriptive Geometry Problems
❒ Inventor Module 1A: Parallel-Line Sheet-Metal 3D Folded Part Modeling and 2D Pattern Development-Truncated Right Cylinder
❒ Inventor Module Inventor Module 1B: Parallel-Line Flat Pattern Development of Sheet-Metal Folded Model Wrapping The 3D Space of A Truncated Right Prism
❒ Inventor Module 1F: Creating A Circle-Based Cylindrical Sheet-metal Part With Locking Seams on The Lateral Edges
❒ Inventor Module 1G: Creating A Circle-Based Cylindrical Sheet-metal Lateral Piece with An Overlaying Lateral Edge Seam And Dove-Tail Seams on The Top Edge
❒ Inventor Module 1H: Creating An Ellipse-Based Cylindrical Sheet-metal Lateral Piece
❒ Inventor Module 2: Radial-Line Sheet-Metal 3D Modeling and 2D Pattern Development: Right Cone (Regular, Frustum, and Truncated)
❒ Inventor Module 3A: Intersection and Development of Sheet Metal Parts in Inventor
❒ Inventor Module 4A: Creating The 3D Model of Right and Oblique Pyramids
❒ Inventor Module 4B: Creating Sheet Metal Parts Enclosing The 3D Space of Right And Oblique Pyramids With The Work Surface of Derived Parts
❒ Inventor Module 5: Creating Sheet Metal Transition Piece Between A Square Tube And A Rectangular Tube With Triangulation
❒ Inventor Module 6A: Creating Poly-Cylindrical (Gore) Sheet Metal Pieces For A Spherical Space
❒ Inventor Module 6B: Creating Poly-Conic Sheet Metal Pieces For Spherical Space
❒ Inventor Module 6C: Intersection and Development of Cylindrical and Spherical Sheet-Metal Parts
❒ Inventor Module 7: Creating Oblique Surfaces On A 3D Model Through A Multi-Facetted Tube Connector Project
❒ Inventor Module 8: Creating A Sheet Metal Part & Flat Pattern Wrapping The 3D Space of A Polyhedron
❒ Inventor Module 9: Creating 2D Working Drawings of The Flat Patterns of Sheet Metal Parts

3. For the improvement of the learning modules, please email your comments to Edward Locke, the authors, at edwardnlocke@yahoo.com

Part A-3a List of Local Community College Engineering & Drafting Departments

The following website contains an alphabetical listing of all two-year community colleges in the State of California, with links to the Home Pages of individual colleges:

http://www.cccco.edu/find/alphabetical.htm

A list of local community college engineering & drafting departments can be composed from information available at these website Home Pages.

Part A-3b List of University of California Engineering & Drafting Departments

The following website contains a listing of all campuses of the California State University system, with links to the Home Pages of individual campus:

http://www.calstate.edu/search_find/campus.shtml

A list of engineering & drafting departments can be composed from information available at these website Home Pages.

Part A-3c List of University of California Engineering & Drafting Departments

The following website contains a listing of all campuses of the University of California system, with links to the Home Pages of individual campus:

http://www.universityofcalifornia.edu/

A list of engineering & drafting departments can be composed from information available at these website Home Pages.

Part B
List of Local Sheet-metal Fabricators in Southern California for Potential Post-Study Survey & Survey Form

Part B-1a Sample cover letter requesting for Business Survey

From: Name of Future Graduate Student
Address
Phone No.
Email

To: Manager/Engineer at any sheet metal company in Southern California

Subject: Survey on CAD program used in sheet metal design

Date: Any date

Dear Sir/Madam,

My name is X and I am sending this email to you to request your assistance. I am a graduate student pursuing a Master of X degree in X major at the X Department, X College, at X University. I am currently continuing to write a college-level textbook on engineering descriptive geometry using AutoCAD 2D and 3D tools, as well as popular parametric 3D modelers, such as Inventor, SolidEdge, SolidWorks and CATIA; and a large portion of this textbook is devoted to the development of sheet-metal flat pattern. In addition, I am writing research paper on the use of CAD/CAM programs at local manufacturing and fabrication business, for the purpose of improving CAD/CAM education at local community colleges.

I am hereby requesting your assistance in responding to a short survey on the application of CAD software at your company, which shall provide great help to me in completing my graduate project, and in better integrating my teaching of CAD courses with the practical needs of local business. Your input to this survey will be kept in strict confidentiality. I hereby attach the Business Survey form in Microsolft Word format with this email. Please down load the attached file, open it, keep the multiple choices that apply and delete those that do not, and email me back. Thank you for your assistance. I shall look be looking forward to hearing from you soon.

Sincerely Yours,

X student

Part B-1b Business Survey: Application of CAD Programs in Sheet-Metal Design and Fabrication

Objective: To investigate the application of CAD programs in sheet-metal design and fabrication in Southern California.

Survey Questions:

1. The CAD/CAM software my company currently uses or plans to use in sheet-metal design and fabrication include (Please keep all that apply and delete the ones that do not):

Sheet-metal design and fabrication:

❒ AutoCAD ❒ Mechanical Desktop ❒ Inventor ❒ CATIA ❒ SolidWorks
❒ SolidEdge ❒ ProEngineer ❒ Metalix CAD/CAM cncKad
❒ Striker Systems FAB Professional ❒ data M Software GmbH ❒ FCC Software AB
❒ Radan Sheet-Metal Modules ❒ SPI GmbH
❒ Others:___________________________
The most important software in this category that my company uses are (Please specify):_____________

Other software used in engineering and manufacturing at my company:

❒ COSMOExpress ❒ ANSYS ❒ I-Deas ❒ ProMechanica
❒ Mathematica ❒ MathCAD ❒ MatLab
❒ MasterCAM ❒ CNS Workshop ❒ GibbsCAM ❒ ProManufacturing
❒ P-Spice ❒ ElectronicsWorkbench ❒ SolidEdge ❒ CATIA
❒ Others:____
The most important software in this category that my company uses are (Please specify):_____________

2. Regarding the knowledge of engineering descriptive geometry and drafting skills, as applied to sheet-metal design and to fabrication (Please keep all that apply and delete the ones that do not):

❒ I believe that using traditional manual pattern drafting techniques is good enough for sheet-metal layout design.
❒ I believe that using CAD software for sheet-metal pattern design increases efficiency by __________%
(Please give an estimate).
❒ I would like to see a textbook on sheet-metal flat pattern design with AutoCAD.
❒ I would like to see a textbook on sheet-metal flat pattern design with a 3D parametric program such as Inventor, SolidWorks, SolidEdge, etc. (Please specify:_______________________).
❒ I would like to see engineering drafting students at local community colleges master the following skills
(Please specify:_______________________________________).
❒ For a sheet-metal course at local community college, I recommend the following textbook (s):
Author__________________Title____ISBN:______________
Author__________________Title____ ISBN:______________
❒ My Company is willing to send representative to attend your school's annual advisory meeting, to offer advice on the uses of CAD/CAM software in industry.
❒ My Company cannot send representative to attend your school's annual advisory meeting; but is willing to offer advice on the uses of CAD/CAM software in industry through email contact.

Company Name/Contact Person/Phone Number/Email
(Optional):____

Part B-2b List of Local Sheet-metal Fabricators in Southern California

ThomasNet®, the website of ThomasRegister®, a popular registry for companies, provides a great search engine for different categories of companies located in different states in the United States. The website address is

http://www.thomasnet.com/nsearch.html?cov=CS&which=prod&what=Sheet+Metal+Fabrication&heading=74351008&pos=2&next=25

The website contains contact information of individual companies, including name, address, telephone and fax numbers, website and e-mail addresses, etc., as shown in the following figure:

Search for: Sheet Metal F California - Southern Search Search Tips

Product / Service Category: **Sheet Metal Fabrication**
Serving: California - Southern
View companies located in California
Displaying: 126 to 150 out of 606 results

Alco Metal Fab Contact
3400 W. Castor St.
Santa Ana, CA 92704
Phone: 714-556-6060
Fax: 714-979-2532

Integral Engineering & Fabrication, Inc. Contact
222 S. 9th Ave.
City Of Industry, CA 91746
Phone: 626-369-0958
Fax: 561-258-8203
http://www.integral-ef.com
Contact us at:
TEL: (626) 369-0958 FAX: (626) 968-7905
E-mail: info@integral-ef.com

info@integral-ef.com
sales@integral-ef.com
engineering@integral-ef.com

APPENDIX F

List of Websites on Sheet-metal Design and Fabrication

The following websites contains useful information on sheet-metal design and fabrication, including information on sheet-metal products of some fabricators, on the application of CAD programs on sheet-metal design, as well general information on sheet-metal trade:

http://www.ugs.com/products/nx/design/sheet_metal.shtml
This website contains information on sheet metal design, including the aerospace field, with Unigraphics software products.

http://www.ptc.com/products/cadds/datasheets/sheet_metal.htm and
http://www.ptc.com/appserver/wcms/datasheet/main.jsp?&im_dbkey=30218&icg_dbkey=841
These websites contains information on sheet metal design with ProEngineer software.

http://biz.yahoo.com/iw/050711/090517.html
This website contains a press release: Alibre and Amada Form Strategic Partnership to Bring 3D to the Sheet Metal Fabrication Industry (Alibre's 3D Parametric Modeling Solution to Be Integrated With Amada's Production Sheet Metal Fabrication Processes and Machine Tools)

http://www.amazon.com/gp/product/customer-reviews/0827302959/ref=cm_cr_dp_pt/103-3639568-7737450?%5Fencoding=UTF8&n=283155&s=books
This website contains information on a textbook titled Mathematics for Sheet Metal Fabrications, by Arthur F. Ahr

http://copper-by-design.com/fs/
This website contains information on a sheet metal fabricator specialized on custom copper sheet metal chimney caps and related sheet-metal products.

http://www.solidworks.com/swexpress/pages/nov05/TT_Sheetmetal_Tips.html
This website contains information on a sheet metal design with SolidWorks.

http://www.lehisheetmetal.com
This company website contains information on precision sheet-metal design and fabrication, with many useful sheet-metal design parameter and standard charts.