Graphical Applications: Analysis and Manufacturing

William E. Cole
Northeastern University

ABSTRACT
Graphics is the universal language of the engineering profession. Within the EDGD curriculum, students need to learn the fundamentals of the graphical language and how to use graphics to communicate. This paper focuses upon extending the basic EDGD curriculum to include application tools. These tools include mass properties analysis, Finite Element Analysis, Kinetic Analysis, and Rapid Prototyping. Should students learn how to use these graphical applications within the EDGD curriculum? Should a graphical thread be established in modern engineering and technology curricula to incorporate these tools within the fundamental courses? Alternatively, should these tools be learned on the job? Discussed in this paper are these basic tools, alternative approaches to teach their use, and potential changes to the EDGD curriculum.

Introduction

Graphics is the primary method of communications within the engineering profession. Engineers draw new ideas as sketches to focus concepts in their mind and show them to others. After preliminary work, details are added to these sketches and they are formalized into drawings. These drawings are continually revised as analyses are performed and tests conducted to improve the design and create the final product. Historically, the actual drawing of a product was performed independently from the analysis. The advent of the computer has changed this design process. It is now possible to construct the initial sketch as a three dimensional solid model in the computer. Design analyses can then be performed directly on this solid model to determine its properties and reaction to applied loads. Thus the steps of drawing have been closely linked to the analysis. Analysis by sophisticated tools on a computer model has replaced analysis by hand with simplified geometry for many applications (Waterman, 1997; McIlvaine, 1997).

This trend has generated many acronyms for the processes involved: Computer-Aided Design (CAD), Computer-Aided Design Drafting (CADD), Computer-Integrated Manufacturing (CIM), or Concurrent Engineering. These acronyms all refer to the close integration of drafting, analysis, and manufacturing into the design process as shown in *Figure 1*. These concepts incorporate:

- Finite Element Analysis: determining force, stress, and thermal properties from a computer model;
- Property Analysis: determining physical properties directly from a graphic computer model;
- Rapid Prototyping: fabricating prototypes directly from a graphic computer model; and,
- Kinetic Analysis: determining the dynamic forces directly from a graphic computer model.

Graphical Analysis Tools

Finite Element Analysis (FEA) is incorporated in few engineering technology programs (Roth, 1995). This is because the complexity of FEA analysis forces most

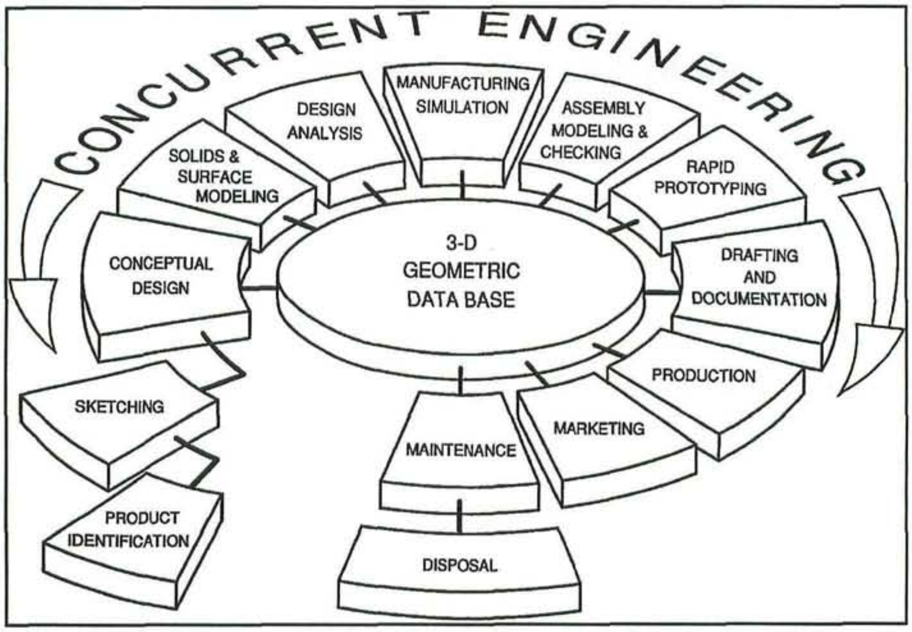

Figure 1 *- Concurrent Engineering Approach (Barr, 1995).*

courses to focus on the theoretical aspects of generating FEA models rather than application of FEA to solve practical engineering problems. However, FEA techniques are becoming less daunting and can now be introduced into freshman EDGD courses (Boronokay, 1997). Thus students can be introduced to this tool which is becoming increasingly common in the workplace. There are still problems, however, in introducing FEA techniques into a traditional EDGD course. These problems focus around how to use this difficult software with very specific data entry requirements (Dally, 1994). At the University of California, this was overcome for engineering students by devoting six hours of class time and "substantial" student efforts outside the classroom (Lieu, 1993). In another case, a GUI front end was created for a FEA program to overcome these difficulties at the expense of generalization capability of the software (Dally, 1994).

Solid modeling overcomes this difficulty of complex software with very specific data entry requirements. Once the solid model is created, there are several programs available that can generate the mesh patterns and perform the FEA analysis on the solid model transparently. Thus FEA can be introduced quickly and easily into an EDGD course. This approach has been used in Engineering at the Northern Arizona University (Howell, 1993). Using a combination of Cosmos Designer and AutoCad, they reported very favorable results in a freshman design/ graphics course.

This Solid Modeling approach to FEA was also used at Northeastern University in a Solid Modeling course. Design Space from ANSYS was used for the FEA. This program appears as a menu item within AutoCad. Once the solid model is created, the student selects the object, adds loads and supports, and then Design Space calculates the stresses. The program is automatic and can be explained in a one hour class. A module was developed in the solid modeling course to teach finite element analysis. Within a two hour lecture, students were introduced to FEA and how to use Design Space. The students were then given a

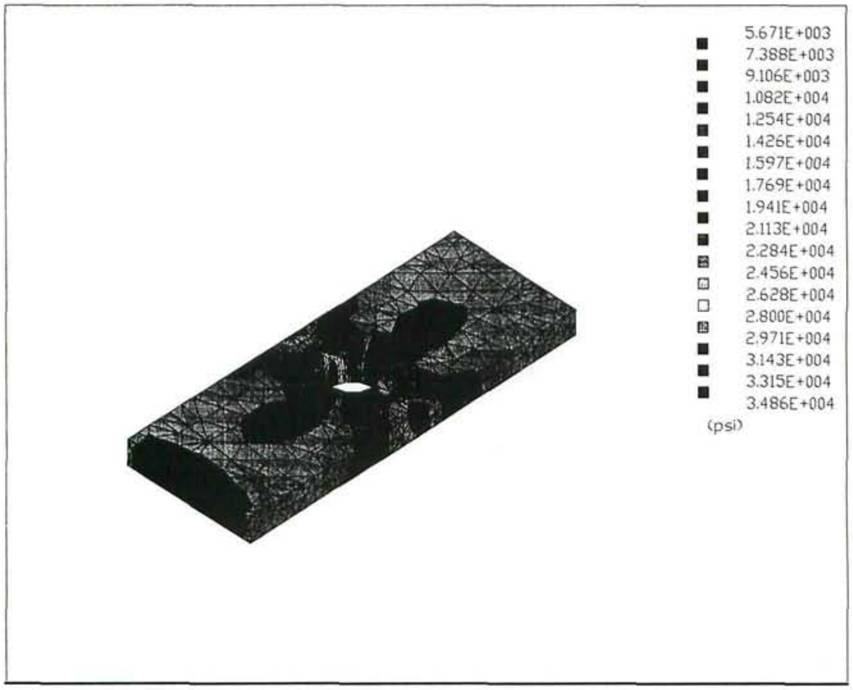

***Figure 2** - FEA analysis of a stress concentration problem.*

homework assignment to do with a partner. An example student assignment is shown in *Figure 2* where the colors on this figure represent the stress on the object when loaded in tension with 5000 pounds.

Rapid Prototyping is a concept that has received widespread attention recently. With rapid prototyping the solid model can be physically fabricated directly -- No intervention by a skilled prototype builder is necessary. A good overview of the many processes and available equipment is presented by Barr (1995).

The original rapid prototyping process uses a laser system to solidify plastic resin in successive layers. These machines are not appropriate for use in undergraduate classes because the models are expensive and they take too long to build (about six hours). This point was reinforced by the experience of the GMI Engineering and Management Institute where 8 hours of SLA time are budgeted for each student (Sullivan, 1996). Thus, for a class of 100 students, a project that each student completes in a couple of weeks is not feasible.

A new low cost process to create models from the STL file is now available from Schroff Development Corporation. Their JP-5 system replaces the printer on a personal computer with a cutter that cuts paper outlines for each of the layers. These layers can then be pressed together to create the object. This system is shown in *Figure 3*.

One of these rapid prototyping systems was used at Northeastern University in a Solid Modeling Class. Example student generated models are shown in *Figure 4*. This rapid prototyping system allowed the students to actually build the object they drew and hold it in their hand. With this system, it appears feasible to give a project to a large number of students. Unfortunately, not too many model assignments can be made because of the time it takes each student to make the model. Hence a more productive system is

Figure 3 *- JP-5 Rapid Prototyping System.*

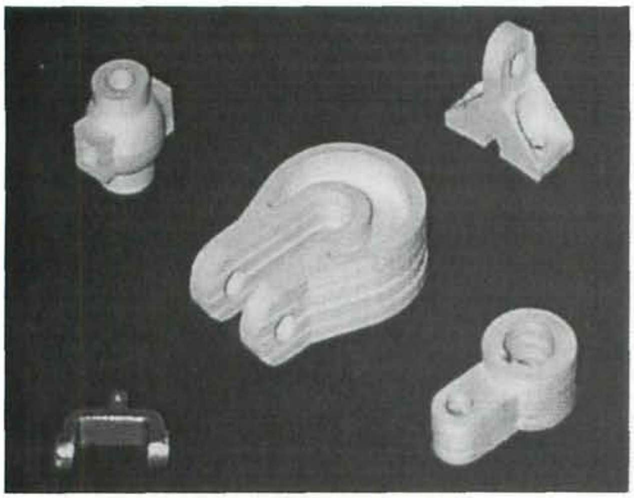

Figure 4 *- Models created by students on the JP-5 system.*

required if rapid prototyping technology is used frequently in the curriculum.

A third approach to rapid prototyping, with higher productivity, is to use numerically controlled machining (Schmidt, 1997). This approach has been largely overlooked in the literature. Software to generate the tool paths has been developed and is commercially available. However, all of these programs require that the user have considerable knowledge of the tools available, material being machined, and appropriate speeds to select (Schmidt, 1997). Freshman students obviously have not learned this material. However, the thrust of new CAM software development is to provide the capability of creating objects on numerically controlled machines directly from the solid model without detailed knowledge of the machining process. This capability will allow students to create solid models in the computer and then use the translator program to generate the tool paths. They can then take this code to the model shop, load it into the CNC machine, and have their object machined. By machining in wax, plastic, or aluminum, machining time should be very short-a matter of minutes.

Kinematic Analysis is another area where new advanced analysis tools are being used to help solve problems. Advanced modeling tools, such as Working Model, now work within AutoCad to provide motion analysis of solid models. These advanced modeling tools allow the objects to be modeled both in geometry, rotational points, and forces. The programs can show the resulting motion of the object, thus visualizing the motion. These tools are used in industry to help design mechanisms and also in the classroom to help teach kinematics. This capability has been used successfully in a number of universities (Grammoll, 1994; Iannelli, 1994).

Teaching Graphical Analysis Tools

These modern graphical analysis tools are currently used in industry. Hence, industry is asking universities to teach students how to use these basic tools. This has been reflected in comments from the Industrial Advisory Committee at Northeastern University (Soyster, 1997) and also from results of a recent survey of the NU alumni (Cole, 1998a). This survey showed that use of graphical analysis tools was one of the most important technical skills new graduates needed.

Several alternative approaches can be envisioned to introduce engineering and technology students to these graphical analysis tools. The first is to introduce them directly into the EDGD curriculum. This approach has been utilized to introduce FEA into the freshman curriculum (Boronkay, 1997; Barr, 1995). The concerns with this approach are the limited time within the traditional EDGD curriculum and the limited background knowledge of freshman students. They do not yet have the background fundamental knowledge to understand what FEA analysis does (or how it works) or to understand the forces and motion produced by a kinetic analysis program. Rapid Prototyping, on the other hand, may fit into the freshman EDGD curriculum if it helps teach basic visualization skills - especially if the manufacturing process is fast, easy to learn, and inexpensive. The differing requirements of two and four year schools probably will result in a different approach and solution for each.

A second approach to introduce these graphical analysis tools is to create a graphical thread throughout the engineering curriculum (Cole, 1998b). This concept is illustrated in *Figure 5*. Students would learn to create solid models within the introductory graphics course in the freshman year. Then, with this knowledge base understood by all the students, the application tools could be introduced in the fundamental upper level course. These tools could be introduced not only as advanced analysis tools but also used to teach the material. For example, FEA could be used to help teach strength of materials. Thus abstract concepts, such as stress concentration, could be taught with this tool and advanced problems, too complex for hand analysis, could be analyzed in these courses. Similarly, Kinetic analysis could be

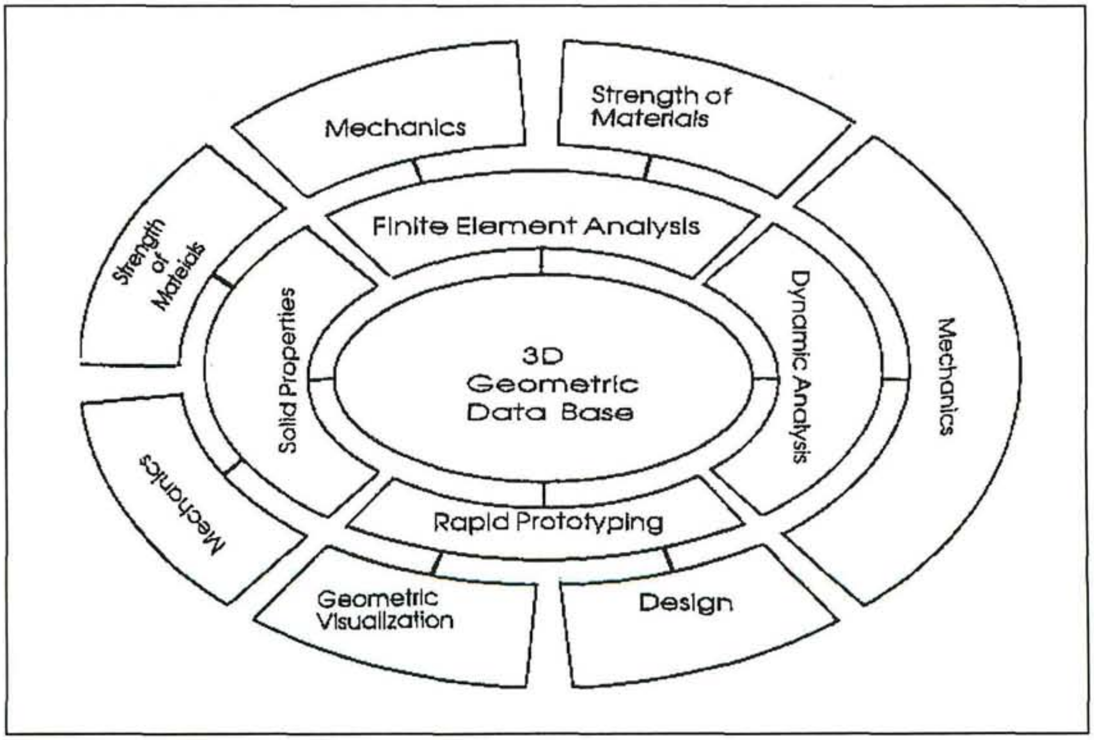

***Figure 5** - Teaching engineering analysis from the geometric model.*

introduced to teach mechanics and Rapid Prototyping used as a design tool. Thus the students would not only learn how to use these tools, they would use the tools to help learn the new advanced material. This would create a graphical thread within the curriculum.

A third approach is to leave teaching of these tools to industry. The rational for this approach is that these tools represent training rather than fundamental education. As such, they may belong in a two year program but not in a Bachelors Degree program.

Questions for Further Analysis

The question then becomes is teaching these analysis tools appropriate in the curriculum? Should these tools be introduced into the basic EDGD courses? Should these tools be introduced as a graphical thread throughout the curriculum? Or should teaching these tools be left to industry? Recommendations are expected to differ for different school missions as well as for different disciplines. For example, the recommendations for a Bachelors Degree program are expected to be different than those for an Associate Degree program. Similarly, recommendations for a Mechanical Engineering Program would be expected to be different than those for an Electrical Engineering Technology Program. The charge, however, is clear: develop a clear definitive approach on how to utilize these new tools within the EDGD curriculum for each of these categories.

References

Barr, Ronald, et al. (1995). Extending engineering design graphics laboratories to have a CAD/CAM component Part III: Prototype manufacturing,. *Proceedings of the 50th EDGD Midyear Meeting*, Ames, Iowa, 83.

Boronkay, Thomas G. (1997). Introduction of finite element methods in the lower division mechanical engineering technology curriculum. *Proceeding of the 1997 ASEE Annual Conference*, Milwaukee, Wi.

Cole, William E. (1998a). MET graduate survey results. *Proceedings of the 1998 ASEE Annual Conference.* Seattle, Wa.

Cole, William E. (1998b). Using CAD analysis tools to teach mechanical engineering technology. *Proceedings of the 1998 ASEE Annual Conference.* Seattle, Wa.

Dally, James W. et al. (1994). Experiences in introducing finite elements in mechanics of materials. *Proceedings 1994 ASEE Annual Conference*, 385.

Gramoll, K. (1994). Using working model to introduce design to a freshman engineering course. *Proceedings of the ASEE 1994 Annual Meeting.* Edmonton, Alberta, Canada.

Howell, Steven K. (1993). Finite element analysis in a freshman graphics course. *The Engineering Design Graphics Journal*, Winter, 29.

Iannelli, J. (1994). Mechanics in action: On the development of interactive computer laboratories for engaging engineering mechanics education. *Proceedings of the TBEED 1994 Annual Conference*, Gatlinburg, Tn.

Lieu, D. K. & Talbot, N. H. (1993). Introducing graphical finite-element structural analysis to an undergraduate curriculum. *The Engineering Design Graphics Journal*, Winter, 33.

McIlvaine, Bill, (1997). CAD makes a difference in time to market. *Managing Automation*, May, 18.

Roth, David E., & Johnson, David H. (1995). Finite element analysis in engineering technology. *Journal of Engineering Technology,* Fall, 8.

Schmidt, Joseph (1997). CNC machining keeps pace with new technologies. *Automotive Engineering*, July, 97.

Soyster, Allen (1997). The engineering workplace in the 21st century. Responses to the COE Industrial Advisory Committee Meeting.

Sullivan, Laura, Erevelles, Winston, & Lai, Gwan (1996). Implementing concurrent engineering through rapid prototyping and manufacturing - An NSF funded project." *Proceedings of the 1996 ASEE Annual Meeting*.

Waterman, Pamela (1997) In search of FEA and CFD. *Design Engineering*, October, 40.