2006-2658: AN APPROACH TO TEACHING COMPUTER AIDED ENGINEERING TO A DIVERSE STUDENT POPULATION

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An Approach to Teaching Computer Aided Engineering to a Diverse Student Population

Abstract

This paper chronicles experiences in teaching a graduate course on Computer Aided Engineering (CAE) to a very diverse student sample. An aspect of the diversity was the undergraduate degrees that the students had which included: mechanical engineering, electronics engineering technology, industrial technology, chemical engineering, business administration, and psychology. These degrees were earned from US, China, and Japan. The age group was from 26 to 48. Four were fulltime graduate students and two were full time employees in the local industry. Their industrial experience varied from zero to 20 years. Four of them had used Mechanical Desktop for 3D modeling. One used AutoCAD for 2D drawings. One did not use any CAD software. Most students had little background in mechanics of materials and design. The challenge that this rich diversity presented also afforded a good learning experience. The topics covered included: 3D modeling using Pro/Engineer, finite element analysis using ANSYS, and rapid prototyping using the Helsisys and Stratasys machines. The pedagogical approach adopted was to use a term long project as a vehicle for applying CAE knowledge in contrast to focusing on theoretical concepts.

A multidisciplinary team based approach was used for the project completion. The motivation behind the project was to get overall idea of product development cycle starting from the conceptual idea to manufacturing a prototype. The selected product was 'banana hanger'. This product had simplicity regarding design, modeling, analyzing, and prototyping. Each student was directed to bring his/her own natural ideas based on their educational and industrial background. This paper explains the different stages of the product development project during entire semester.

Background

The course TECH 5311 -Computer Aided Engineering was offered as graduate level elective for technology major students. No specific prerequisite courses were assigned. Traditionally graduate students in technology have bachelor's degrees in industrial technology and engineering technology. With the consent of the instructor the course is also available for other majors. Other majors (particularly those from programs in Science, Computer Science and Business) take this course because many students work in the high-technology dominated industries in the central Texas region. Consequently, the non-technology/engineering employee also has to deal with issues from the realm of computer aided engineering; at least in a tangential manner as they interact with their technical counterparts in a multidisciplinary team oriented work place. This semester six students who had undergraduate degrees in mechanical engineering, electronics engineering technology, industrial technology, chemical engineering, business administration, and psychology enrolled. The diverse background of students provided the impetus to tailor the course so as to dissipate the direct and applied knowledge related to product development process from 'Computer Aided Engineering' point of view. Both authors have taught traditional courses in CAD and CAE where students had strong background in mechanical engineering. In the case of engineering majors, foundational material in variational calculus, the mathematics of computer graphics, constitutive equations, compatibility equations, element and global stiffness matrix derivations etc. were emphasized. The approach detailed in this paper was to simplify the theoretical and mathematical portion and to use the commercial software such as Pro/Engineer and ANSYS to solve real life problem on product design. The traditional topics in CAE such as those mentioned earlier were not emphasized. Secondly, the topics selected for lecture parts of this course revolved around the project. It was decided to take fullest advantage of resources available in the department including rapid prototyping capabilities. The broad topics were decided as follows:

- Fundamental Concepts: Engineering Materials, Strength of Materials and Design of Machine Elements
- 3D Modeling using Pro/Engineer wildfire 2.0
- Finite Element Analysis using ANSYS 10.0
- Rapid Prototyping using the Helsisys and Stratasys machines

It was realized that to teach abovementioned topics to the diverse audience a term long project would be great learning experience as it afforded opportunities for multiple applications. The product selected was 'banana hanger' considering its simplicity (since practically everyone is familiar with this household product) regarding design, modeling, analyzing, and prototyping. Two teams were formed based on students' background. The teams exhibited good mix of different attributes as displayed in Table 1.

Table 1. Attributes of the two design teams

Attribute	Team A	Team B
Undergraduate Degrees	Mechanical Engineering Psychology Businesses Administration	Chemical Engineering Electronics Engineering Technology Industrial Technology
Country of Graduation	China, USA, USA	Japan, USA, USA
Occupation	Fulltime student Fulltime student Fulltime job	Fulltime student Fulltime student Fulltime job
CAD/CAE Knowledge	MDT*, MDT*, MDT*	---, AutoCAD, MDT*
Sex	Male, Male, Male	Female, Male, Male
Age	28 to 32	26 to 48

MDT- Mechanical Desktop

Teaching Schedule:

This course was taught once a week for about three hours. The total class duration was divided into two parts. Two hours were devoted to instruction in fundamental concepts related to engineering materials, strength of materials, and design of machine elements, finite element analysis, and rapid prototyping. One hour was reserved for learning Pro/Engineer wildfire 2.0 and ANSYS version 10.0. Typically, students spent one-hour in-class and two-hours out-of-class time on learning Pro/Engineer and ANSYS software. It was observed that learning curve for both these softwares were pretty steep. The assigned textbook for Pro/Engineer systematically explained the process of geometric modeling by the medium of click-by-click tutorials[1]. ANSYS tutorials were chosen from University of Alberta website[2]. These tutorials were also explained in a click-by-click manner. The class instruction was correlated to the different stages in product development process. The following section explains the different stages in teaching and product development activities.

Teaching and Product Development Activities

Stage I [1 week]

Teaching Activities

Different terms related to 'Computer Aided Engineering' were explained. These were CAD; CADD; CAM; CAE; Rapid Prototyping; common file formats such as *.iges and *.stl and their historical background; and important stages in design and product development process. The important stages explained were conceive, design, develop, manufacture, and validate as shown in [3]Figure 1. The role of CAE in context of 3D modeling and FE analysis was clearly explained (Figure 2). Students were encouraged to use Internet resources such as Wikipedia free online encyclopedia[3]. Sample analysis and simulations were showed to explain the current applications and importance of CAE[2,4]. Dynamic simulations using LS-DYNA attracted student's attention.

Product Development Activities

Students were required to collect background information about the banana hanger. This information included: product need, available products on market, material of construction, manufacturing processes, price, aesthetics, utility value, number of bananas to be hanged, and shape-size-weight of bananas.

Stage II [3 weeks]

Teaching Activities

Next topics related to 'Engineering materials' were taught in the class. The sub-topics included: Engineering materials- properties, applications, and selection; ductile and brittle materials- difference, examples, fracture; Concept of specific strength and specific stiffness in context of aluminum and composite materials; Factor of safety- selection, fail safe and safe life approaches; Stress-strain curves for ductile, brittle materials, plastics, and elastomers[5,6]. Students were exposed to non-traditional materials such as plastics and composites at the appropriate level of detail.

Product Development Activities

With the background knowledge about materials students were asked to select material, factor of safety, and manufacturing process for banana hanger. Each team documented the proper reasoning for material and manufacturing process. It is observed that students preferred metals rather than plastics. This is because they didn't have sufficient knowledge about plastics and composites. The need for such courses was strongly felt. Students were encouraged to locate the values of strength, Poisson's ratio, and other mechanical properties using open literature available on net such as Matweb[7].

Stage III [3 weeks]

Teaching Activities
The teaching activities were continued as mentioned in stage II and stage IV.

Product Development Activities
This was the innovative step and students were asked to brainstorm and output as many ideas as possible through rough sketches. They were encouraged to think laterally. In the next step students finalized one idea considering simplicity, utility, aesthetics, and price. They were asked to decide the curves and height of the banana hanger with proper reasoning, and document uniqueness of their design compared to ones available on market. In the next step students were asked to present their design using 3D models prepared using any software. Both the teams preferred using AutoCAD.

Stage IV [3 weeks]

Teaching Activities
Next fundamental topics related to strength of materials and design of machine elements was taught. These topic include stress; strain; axial and strain; Poisson's ratio; modulus of elasticity and rigidity; types of stresses-tensile, compressive, shear; bending of beams; torsion of shafts; column buckling; factor of safety- fail safe and safe life approach, selection; concept of optimum design to utilize material to its fullest capacity; stress concentration factor; principal stresses in 2D; theories of failure for brittle and ductile materials- Maximum Principal Stress, maximum Shear Stress, and Distortion Energy. The derivations in above topics were omitted and only applied treatment was emphasized. Few sample problems were demonstrated in each of the category[6,8].

Product Development Activities
After teaching these topics students were able to recognize the types of stresses experienced by a specific part. To clarify their ideas different examples such as fishing rod, airplane cabin, and chair were explained. The combined direct and bending stresses example was elaborated in detail so that students could use it in their banana hanger design project. At this stage students were asked to provide their hand calculations. They simplified the curved design in such a way that they could perform calculations.

Stage V [3 weeks]

Teaching Activities
At this stage the importance of finite element analysis was explained. The complex nature of stresses in banana hanger was highlighted and difficulties in hand calculations were demonstrated. The topics covered in finite element were definition; steps in FE analysis-preprocessor, solution, and post processor; different software available on market for the different steps in FE analysis such as Pro/Engineer, HyperMesh, ANSYS; 1D-2D-3D elements such as link, quadrilateral, triangular, hexahedral or, brick, tetrahedron; concept of degrees of freedom; analysis time for complex problems; boundary condition; different solvers available in

ANSYS; and different files created by ANSYS such as *.db and *.log; and importing *.iges and *.prt files from pro/Engineer[3,9,10]. Five tutorials were selected from University of Alberta website and were modified for ANSYS version 10.0. These tutorials were on two-dimensional truss, bicycle space frame, plane stress bracket, solid modeling, and buckling[2]. The main purpose of these tutorials was to familiarize the FE process and different ways to present the results viz. listing, plotting, and animation.

It is worth mentioning the homework activity for the FE analysis. The homework problem required to the computation of stress concentration factors for standard geometry using ANSYS and comparing the same with values obtainable from standard graphs by J. E. Peterson[6]. The homework problem involved modeling and applying boundary conditions repetitively. There were two students interested in using APDL (ANSYS Parametric Design Language). They were encouraged to see *.log file every time they used any command using GUI. This was the direct approach to teaching APDL rather than teaching command by command. Soon students realized the equivalent ANSYS commands to be used at command line. Both the students prepared APDL program and used the same in solving this tutorial. They took only 1/4th time than their counterparts who used GUI. The productivity in design process was explained with this example.

Product Development Activities

This time students were required to develop the 3D model of the banana hanger using Pro/Engineer. The advantage of Pro/Engineer's feature based, parametric, and associative nature was emphasized. This 3D model was saved in three different formats *.prt which is Pro/E's part drawing format, *.iges (Initial Graphics Exchange Specification) which is a common data format used for transfer of CAD data, and *.stl which is common format used on Rapid Prototyping machines. All these file formats were explained in brief. The *.prt models were imported in ANSYS environment. Team A had many problems while importing the model. The problems were identified and fixed in Pro/E.

Stage V [1 week]

Teaching Activities

The concept and applications of rapid prototyping to the product design and development processes were covered. The different manufacturing techniques such as fused deposition modeling-FDM (Stratasys, Inc.), sterolithography, selective laser sintering, and laminated object manufacturing-LOM (Helsisys, Inc.) were discussed briefly. The department of engineering and technology has Stratasys and Helsisys machines. The detailed demonstration was performed on these machines and many different products manufactured on these machined were showcased.

Students were instructed on how to create .stl versions of their designs from the .prt version of the same. The pros and cons of increasing/decreasing the facet density of the stl files were presented. At this stage, students were explained historical background of STL and IGES file formats. STL is the native file format of the SLA (slective laser sintering) CAD software created by 3D Systems of Valencia, CA, USA[3]. The Initial Graphics Exchange Specification (IGES) defines a neutral data format that allows the digital exchange of information among CAD systems. The IGES project was started in 1979 by a group of CAD users and vendors, including Boeing, General Electric, Computervision and Applicon, with the support of the National Bureau of Standards[3]. Students were encouraged to visit websites of RP machine manufacturers including 3D Systems, Inc., Stratasys, Inc., and Helisys, Inc.

Product Development Activities
At this point students were taken to the rapid prototyping facility and some of their stl files were uploaded into the FDM machine. They were walked through the procedures for homing and calibrating the machines. Next they were guided through the process of setting the build parameters on the machines. Both the teams saved their Pro/Engineer models as *.stl file which is standard file format for rapid prototyping machine. This *.stl file was used on RP machine (the Stratasys) to produce product using ABS as construction of material. Upon completion of the builds the process of finishing a prototype was demonstrated. The advantage of using the LOM and FDM machine consisted in the fact that the students were exposed to an additive and substractive rapid prototyping process.

Each team was asked to prepare PowerPoint presentation containing information: product need, available designs on market and their pros and cons, final design as 3D model, reasoning for selection of particular shape and dimensions, reasoning for selecting particular material of construction, method of mass manufacturing, design calculations, ANSYS outputs for deformation and von-Mises stresses, and conclusions. Each team was also asked to write detailed project report including the points mentioned in the presentation[11,12]. Each team was allocated 15 minutes for their presentation and 5 minutes were reserved for question and answer. One of colleagues was invited as external examiner. The performance was evaluated on the basis of basic understanding of design and analysis, presentation skills, and technical skills. This last activity of writing report and presentation improved students' communication skills.

Product Highlights

Team A
Team A systematically evaluated pros and cons of banana hangers available on market. They felt the necessity of foldable banana hanger to save countertop space and its multi-functionality to store other fruits in the bowl (Figure 3). The product consisted of three parts that required assembly. The material finalized for construction was aluminum using pressure die-casting. The design was bulky and underutilized the material. This point was elaborated to students by explaining the values of von-Mises stresses and deflection of the banana hanger at point of application of load (Figure 4).

Team B
Team B's idea was traditional but the selected shape and curves were sleek (Figure 5). The product was one-piece which would cut down the cost of manufacturing. This team also utilized material of construction as aluminum using pressure die-casting. Industrial technology student in this team not only provided detail reasoning of selecting aluminum die casting as manufacturing process but also provided sketches for dies. He insisted one-piece construction, which would cut down manufacturing cost. The material was utilized to its fullest capacity, which is clear from von-Mises stresses (Figure 6).

Both the teams provided hand calculations for their design considering direct and bending stresses and buckling of vertical column; modeled the product using Pro/Engineer, imported Pro/Engineer's *.prt file in ANSYS; performed the analysis in ANSYS; and produced rapid prototype model on Stratasys machine using ABS (Acrylonitrile Butadiene Styrene) as material of construction.

Observations

- Asian students showed more interest in analysis, namely design, stress analysis, and finite element analysis.
- American students were interested in creative and commercial aspects such as putting forth new ideas and getting the same patented.
- The Psychology student in Team A strongly led the team to push his idea of foldable banana hanger.
- Team A's design was innovative and masculine but bulky. The material was not used to its fullest capacity. Team B's design was sleek and feminine in nature. The material was used to its optimum capacity. The Japanese lady was instrumental in deciding curve and shape of Team B's design.
- Two students showed great interest in learning advanced topics such as APDL. They were convinced about APDL's utility in saving analysis time.

Conclusions

- Fundamental topics related to engineering materials, strength of materials, design of machine elements, 3D modeling, finite element analysis, and rapid prototyping were effectively conveyed to technology students through simple semester long project. Student reactions were very positive. In particular they enjoyed completing the project.
- The direct and applied approach rather that derivations and complex formulae is more useful for technology and majors from the College of Science and Business whose background in engineering analysis is minimal. Thus all majors got a good feel for the area of CAE.
- With this introductory course students would work as efficient team member in product development team.
- The learning curve for both Pro/Engineer and ANSYS was steep. Both teams preferred exhibiting their initial ideas either by hand sketches or, using AutoCAD.
- Though there is wide variety of materials used for current banana hangers, both teams preferred using aluminum. Both teams also preferred pressure die casting as manufacturing method because of possibility of high degree of automation. The reasons given were: lightweight nature of aluminum and smooth surface finish obtained by pressure die-casting.
- It is observed that students preferred metals rather than plastics. This is because they didn't have sufficient knowledge about plastics and composites. The need for such courses was strongly felt.

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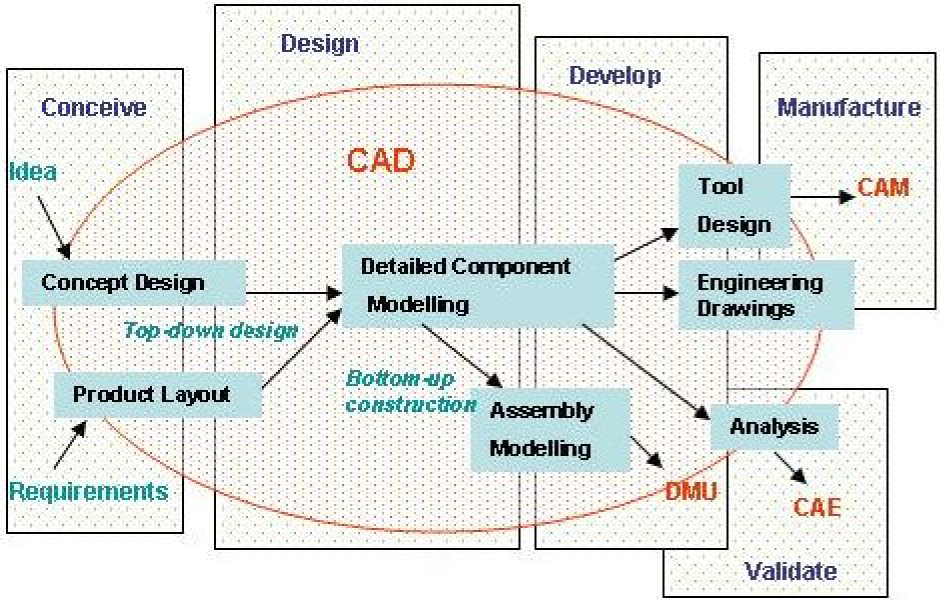

Figure 1. Product Development Steps: Role of CAD and CAE[3]

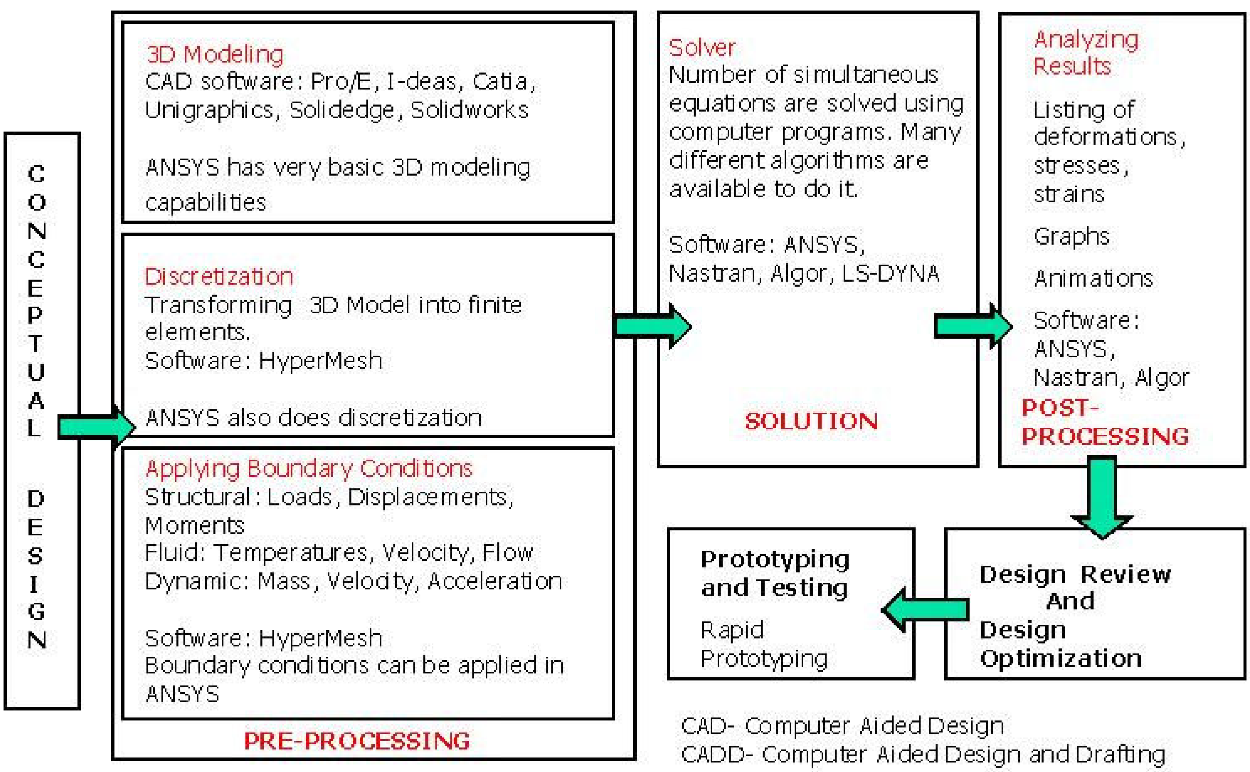

Figure 2. Stages in Computer Aided Engineering with Reference to Software

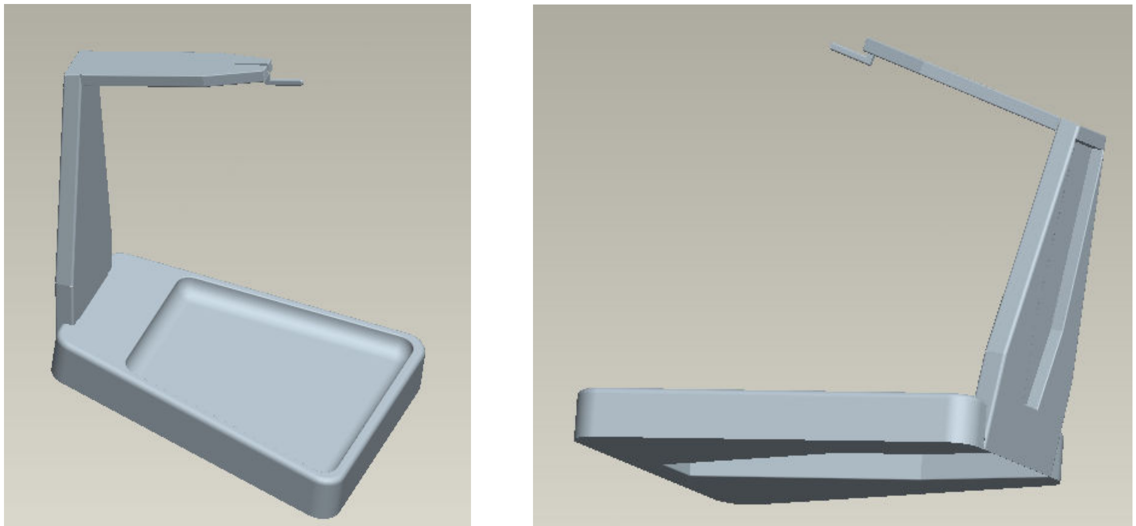

Figure 3. Team A's 'Better Banana Hanger': 3D Model in Pro/Engineer

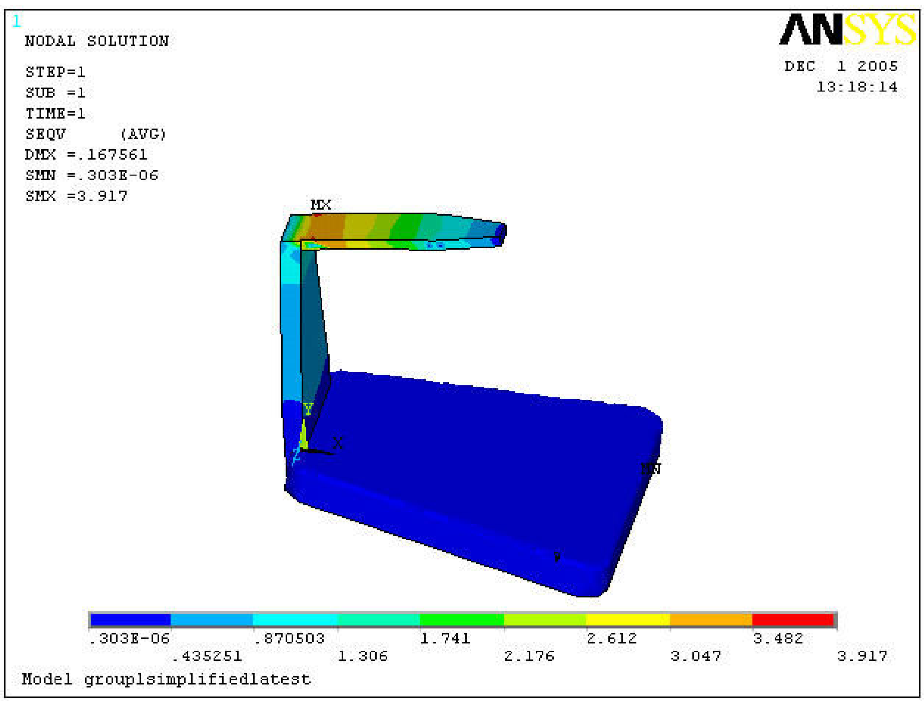

Figure 4. Team A's Simplified Banana Hanger: von Mises Stresses

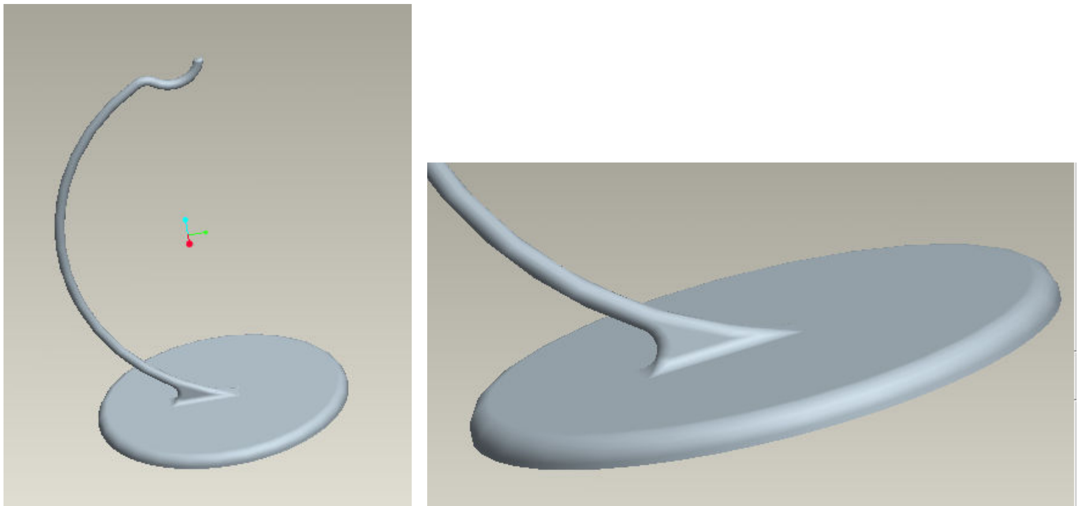

Figure 5. Team B's 'Banana Peg': 3D Model in Pro/Engineer

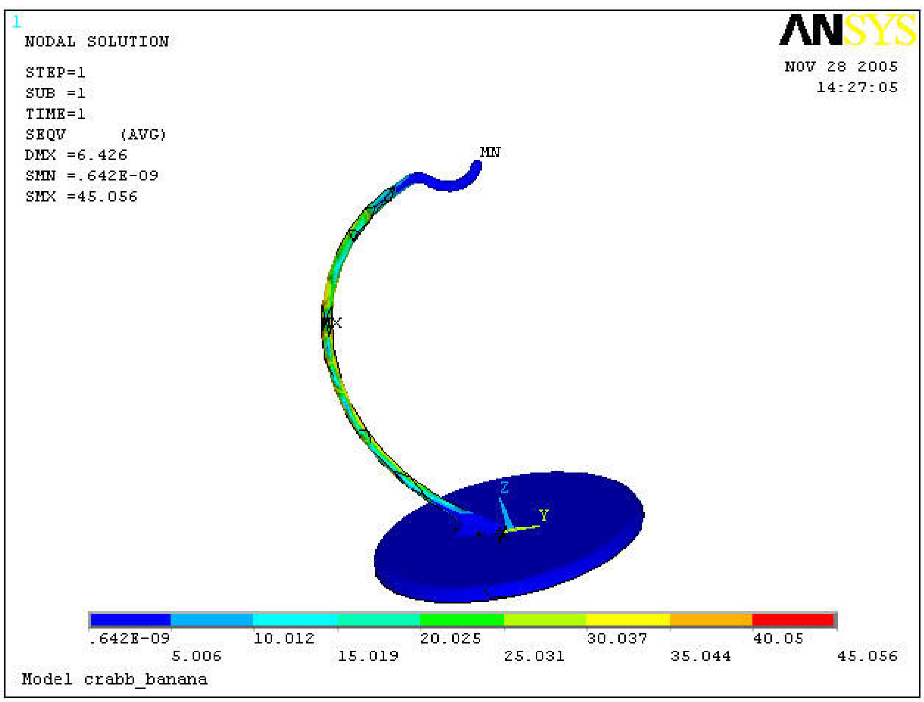

Figure 6. Team B Banana Hanger: von Mises Stresses