2006-2452: WEB-BASED TOOLS AND COURSE MATERIALS FOR TEACHING CAPSTONE DESIGN INTERNATIONALLY

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Web-based Tools and Course Materials for Teaching Capstone Design Internationally

Abstract

After years of collaboration and discussions[1], the authors found it highly desirable to develop and share a set of web-based course materials and tools for teaching senior capstone design in different countries. Because different countries may have different requirements of the educational objectives for graduating seniors, the course material has a minimum set of topics which will be used by all participating schools. Then, a more extensive part of the course material will be elective topics that cover special needs. These special needs could be different government or ABET requirements, or it could be project specific knowledge that is too specialized to be taught to all students. An example of the common topics is how to use Quality Function Development to generate a set of quantifiable design objectives. An example of the elective topics is the tolerance stack analysis and design, which is necessary knowledge for design projects requiring high precisions assemblies.

Some developed and under-developing web-based teaching tools, which can be also used in real world engineering design, are searchable design case libraries located on different computers at different schools, and optimization tool box that can be executed using web browser from different part of the world. More practically useful tools will be described and presented, such as the computing tool to obtain the preferred fits and tolerance, and the unit conversion tool for converting Imperial units to metric units. A major concern for current and future development of web-based tools is the copyright or intellectual property right issue. Currently, unless these tools are developed by collaborating faculty members or students, commercial software are not shared by participating schools. Some information and software tools are very important to high quality capstone designs, the authors are exploring the possibilities and technical constraints of sharing national standards, material properties specified in different national standards.

From international collaboration and working on capstone education, the authors found many teaching tools and materials developed and used by teaching capstone can be used also for other undergraduate mechanical engineering courses.

Introduction

To teach capstone design in a global environment, and to teach more efficiently and effectively, a set of web-based, globally accessible computer tools has been developed. In this paper, a few developed tools will be described. Also, a base set of common teaching materials, with many practically useful but more specialized special-topic materials, have developed. Base set teaching material will be always used in teaching capstone design, and the extended special-topic materials will be selectively used by different countries, or by special design projects.

Figure 1 showed the front page of the design tools developed and under-development. In this paper, first the developed searchable design case library is presented. The case library is developed using MYSQL and Linux platform. A design case library with a large collection of design projects, including project report, presentation slides and detailed design drawings can be a very useful resource for engineering students and design engineers in practice. According to Ullman[2], a design engineer's experience can be effectively obtained by studying design cases, which do not have to be one's own design cases. Another reason for promoting and using design case library is that new and better design can be generated with less effort and time using available successful old design cases.

Then a computer program that helps selecting the precision grade, type of fits, and computes the upper and lower deviation of tolerances is presented. To produce quality design, fits and tolerance specification is very important. While undergraduate students do not have as much mental blocks to come up with innovation design ideas, more often than not, specifying correct and functional fits and tolerances[3] is a weakness in most senior design projects the authors have observed. Although the preferred cylindrical and one dimensional fits can be looked up from national and ISO standards, a computing tools is developed to compute the tolerance online, after the type of fits is determined. Not every computed fit value is exactly that specified in the standard, but practically it is accurate and useful[4]. By computing the tolerance, the copyright problem of republishing any existing standard is avoided.

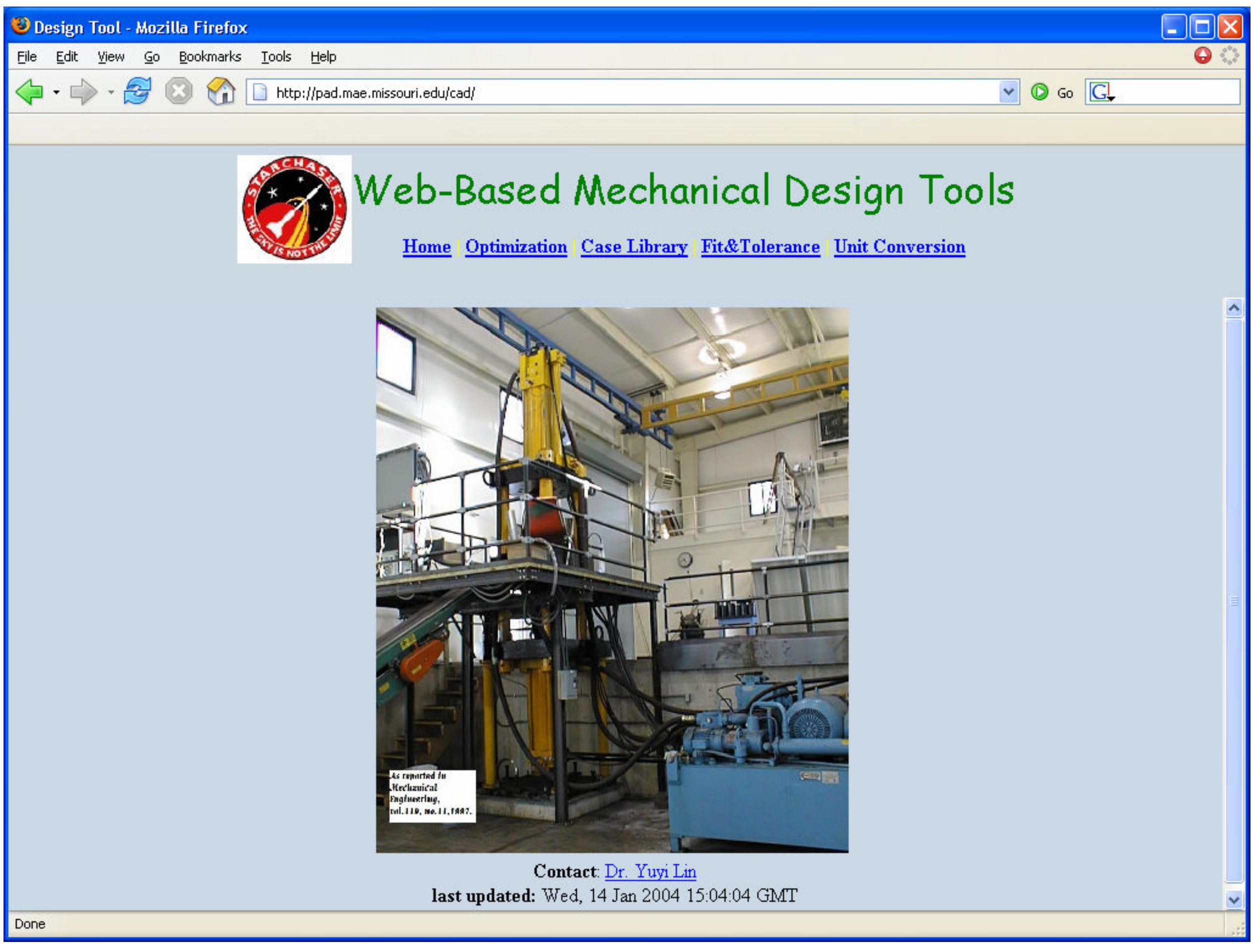


Fig.1 Web site under development for web-based capstone design teaching tools

Then, using a numerical optimization tool as an example, it is demonstrated how to run an executable program on a remote computer using a web browser. To use optimization in any design, the more difficult part is the formulation of the optimization problem. Once the problem is put into standard format, it is relatively easy to select an algorithm, to compile the user problem, and to execute the optimization subroutines. The developed optimization tool solves most linear and nonlinear, constrained and unconstrained design optimization problems. This is very useful, because other optimization tools, such as MATLAB, DOT[5], and IMSL can be expensive to maintain, and cumbersome to use.

The simplest tool presented is a unit conversion tool that converts between commonly used Imperial and metric unites. This tool was originally developed in Javascript, however, the same function can be achieved using a spread sheet. Since this computer program is very short, it can be easily downloaded to any local computer, or executed on remote computer. The purpose of keeping such a tool is that some students are more familiar with Imperial units, and some old drawings are specified in old units, which may have to be converted into metric units for manufacture in a different country. Web-based teaching tools presented in this paper are not conclusive and exhaustive. More useful tools can be developed and shared by international instructors and students. Figure 2 showed the basic structure of web-based tools, and its interface with web browser.

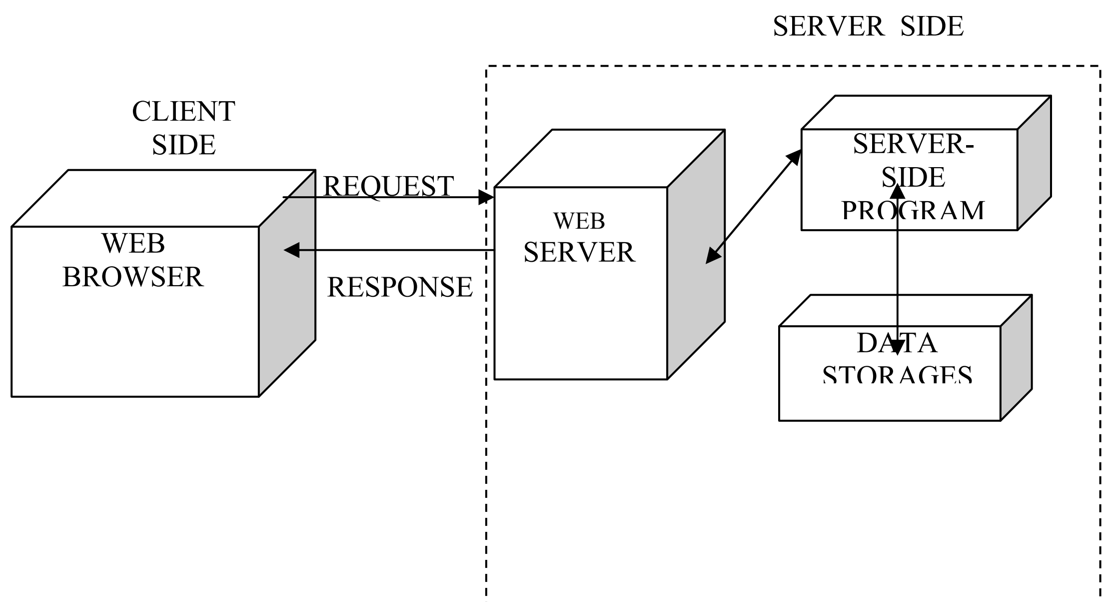


Fig.2. Three-tier web application architecture

Finally, the reasons and explanations for adopting any teaching materials into this internationally taught course are presented. Through thorough discussion among faculty members in different countries, it is decided some subject materials must be covered even they are not taught at some schools currently. Some materials are desirable to be included but time constraint may not allow them to be always used in every capstone design course.

Searchable Design Case Library

Figure 3 shows the block diagram of the internal structure of the design case library. As the first step of database construction, Entity/Relationship (E/R) model is developed as shown below:

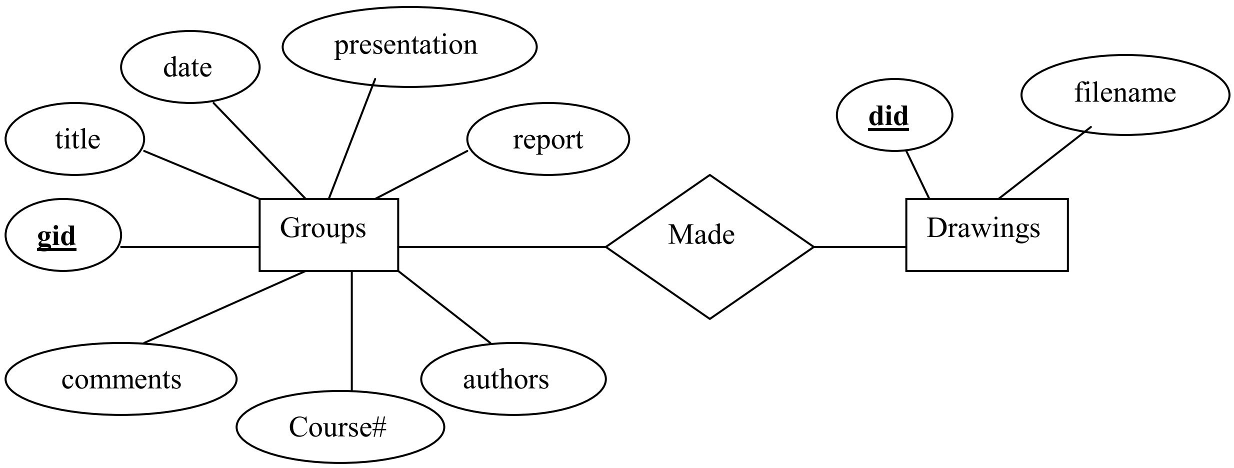


Fig.3 E/R model

It is clear from the database structure, the design case library can be searched by key words in the design report, or in the design presentation slides. Design case can be also searched by instructor's comments, by the design engineer's name, or by date. All design drawings can be retrieved with permission. It is also possible to query all case by exhaustively listing all design titles stored in the design case library.

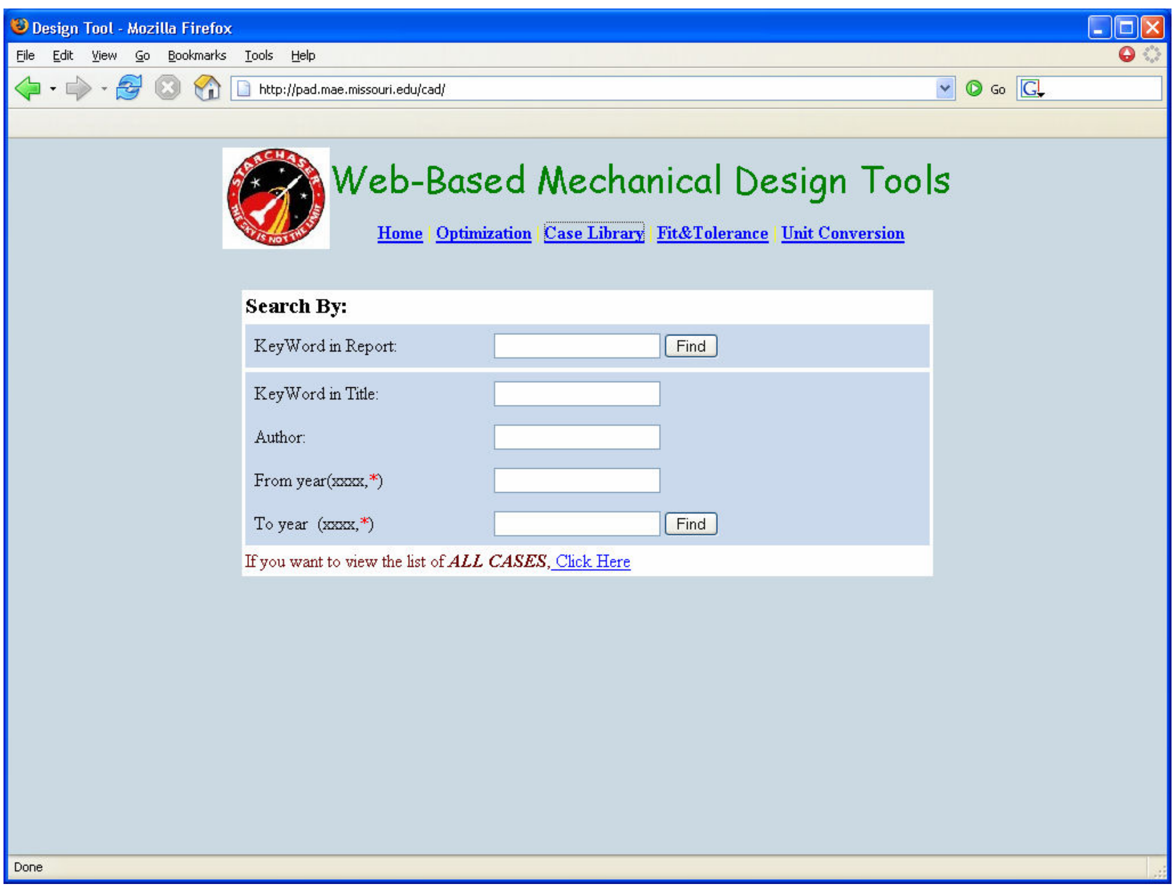


Fig.4 Web interface for the searchable design case library

Figure 4 shows the interface to this design case library. Due to at least one discovered and successful hacking attempt to this web site, sometimes a password is required to access this database. However, all tools described in this paper will be functional and open to public when ASEE 2006 annual conference is in session.

Computing Preferred Fits Online

From the authors' combined experience, very often the student design project fail to function as desired not because of a bad original idea, but because of the failure to do professional quality design specifications. According to reference[4], once the type of fits are determined, upper and lower deviation can be computed with good precision, instead of looking up from standard table. Fig.5 shows the web interface of a upper and lower deviation computing tool.

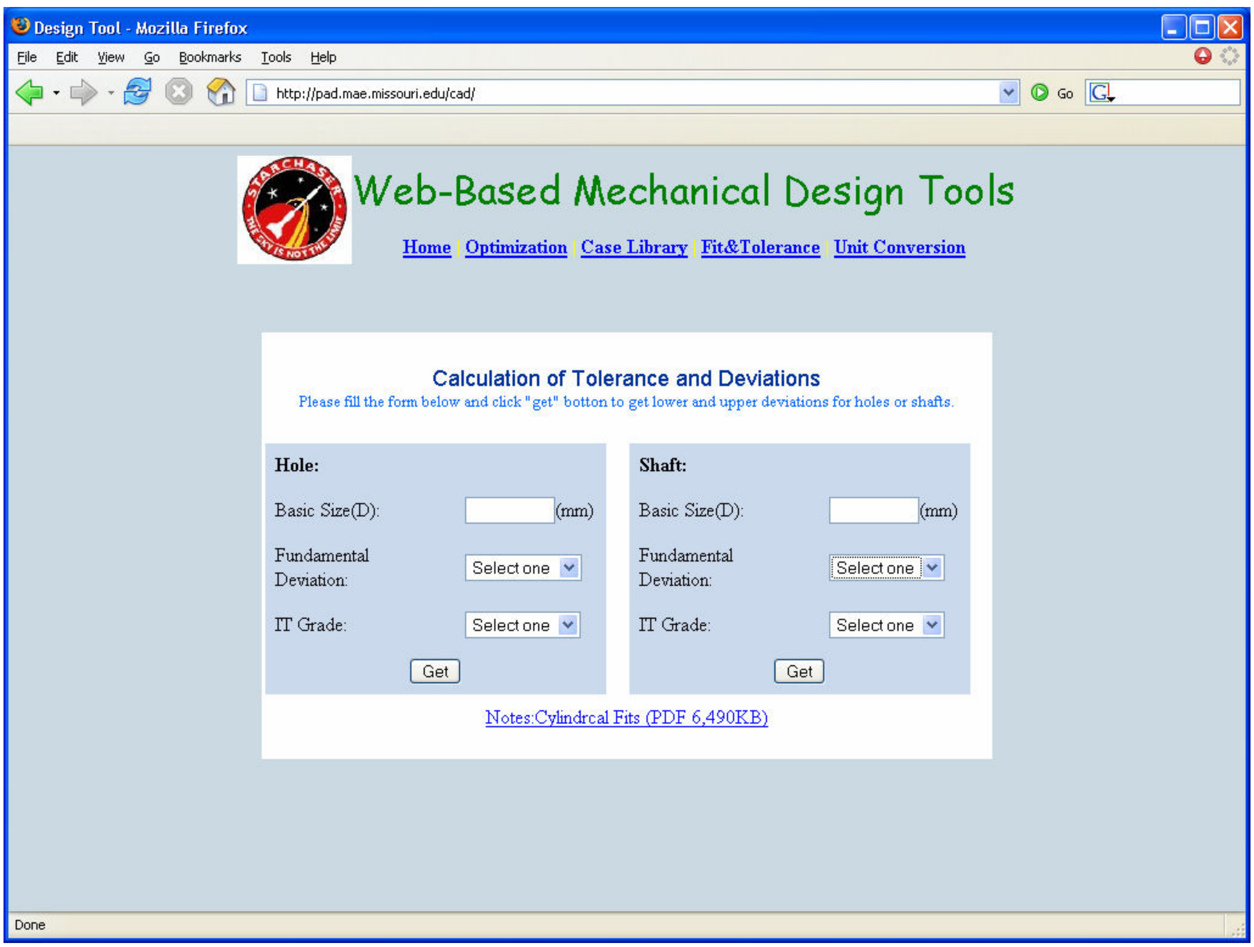


Fig.5 Web interface for a tool that computes upper and lower deviation of different fits

Fig.6 is the assembly drawing of a precision surgical tool. Without careful consideration of tolerance, the first prototype failed to function properly. However, the design concept and idea have no major problem. If correct tolerances are specified, the device can function as desired.

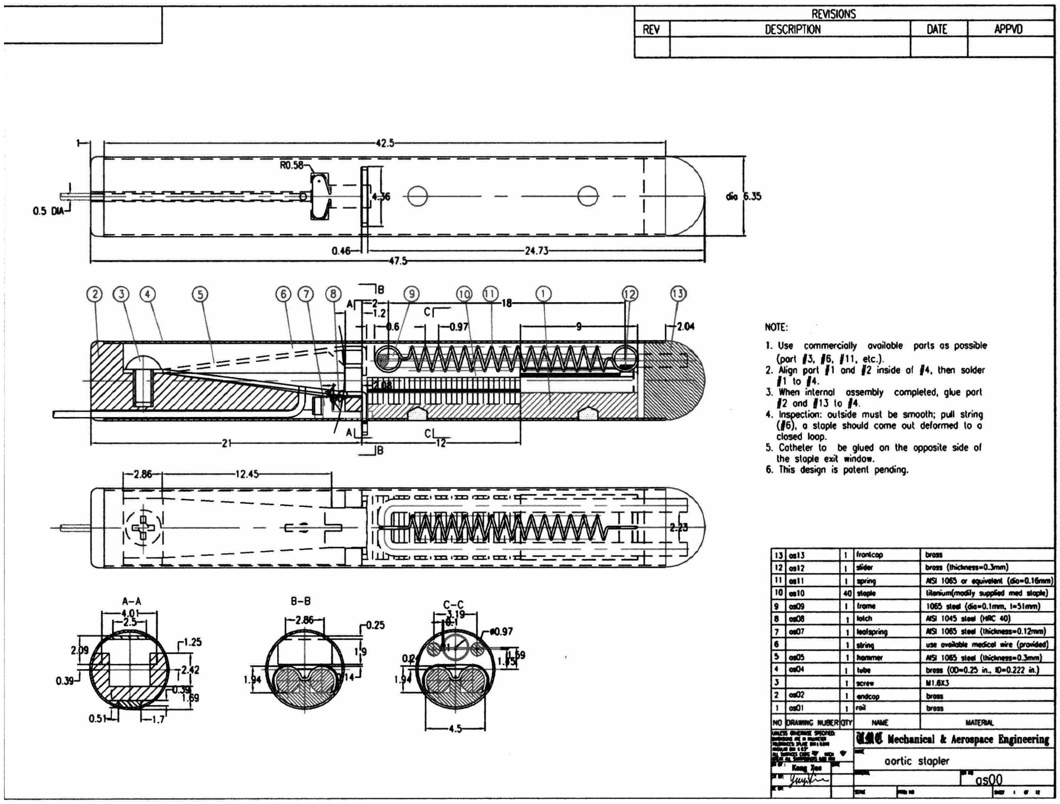
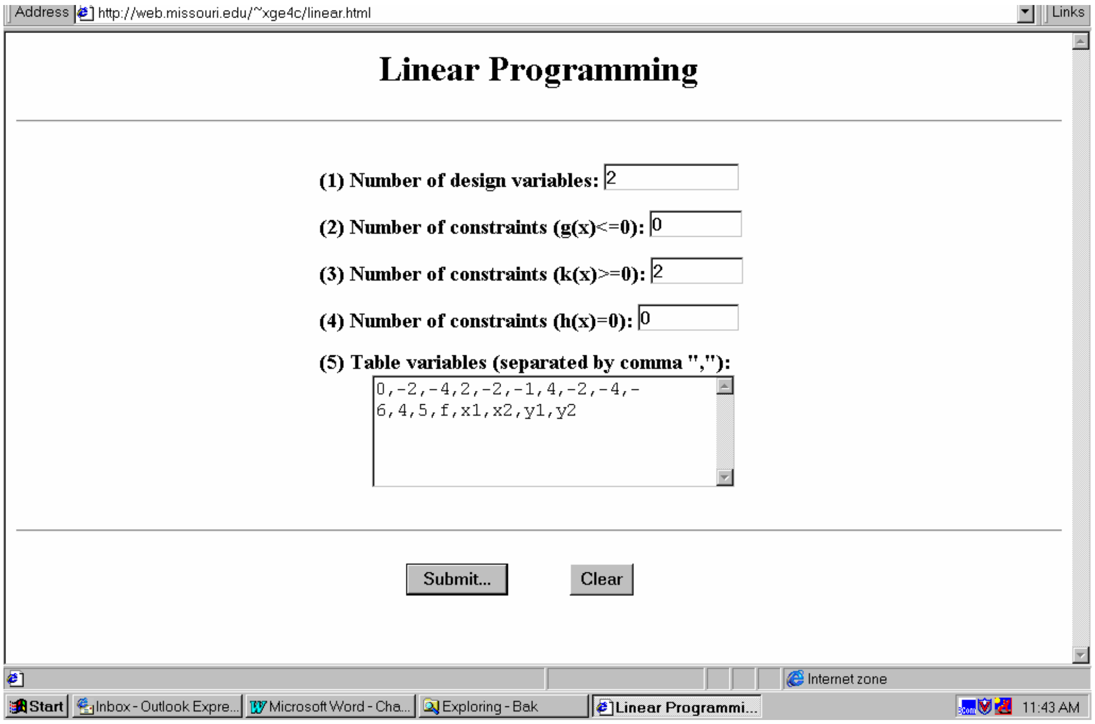


Fig.6 The design of a stapler for non-invasive surgery

Running Optimization Programs Online

Although there is a number of commercial optimization software available, some of them can be expensive to maintain (MATLAB, MATHEMATICA), some of them can be cumbersome to use (IMSL, Numerical Recipes, ADS). Another major problem for our use of these programs internationally is the copyright and loyalty payment problems. Using basic subroutines in the public domain, a general purpose optimization program was developed with two basic modules; one for solving linear programming problem that is based on Simplex Algorithm, and one for solving nonlinear problem that is based on Genetic Algorithm. Online manual and examples were also provided. Figures 7(a) and 7(b) show the web interface. Linear problem is much easier since the solution process does not require recompiling and linking of objective program modules. However, once the online remote compilation problem was solved, similar interface (CGI) can be used to run other program that requires online and remote compilation, such as linking finite element program and optimization program to create design automation tool.



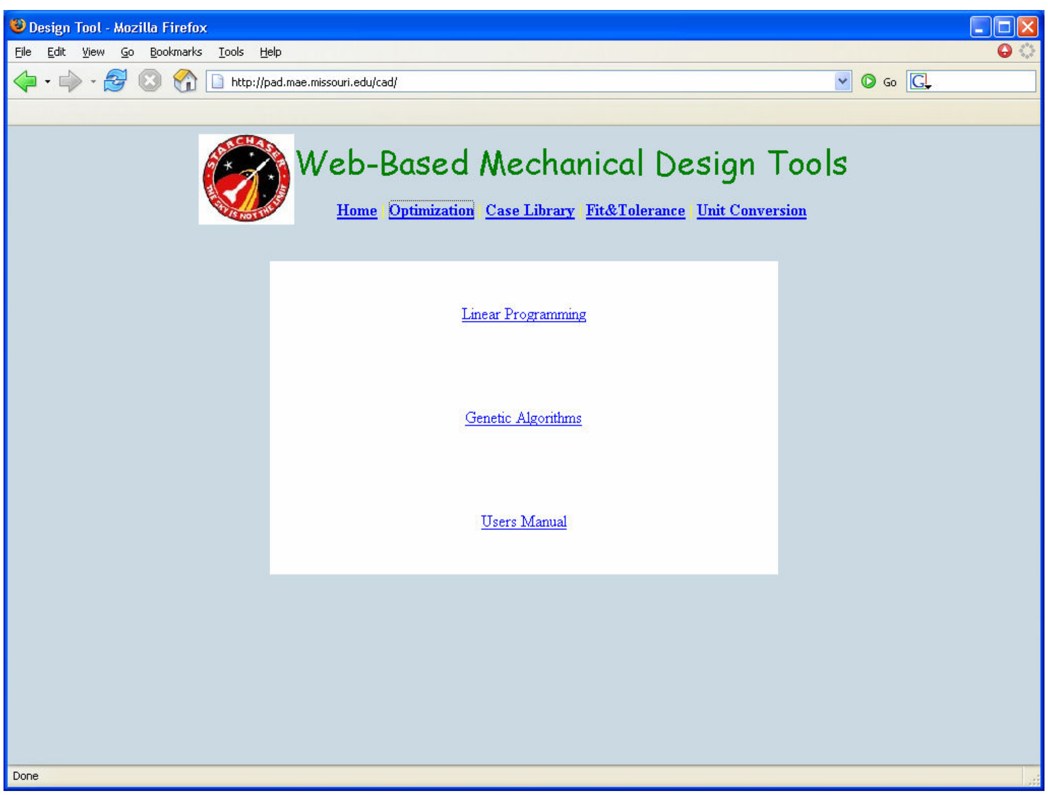


Fig.7 Interface to general purpose optimization tool (a) and (b) example for linear programming problem

The capacity of such simple optimization tool should not be under estimated. Fig.8 showed a well cited test problem and its solution by using genetic algorithm and penalty function method. The problem has 7 design variables and 24 design constraints. The result is better than all previously published result.

$$\min f(X) = 0.7854 x_1 x_2^2 (3.33 x_3^2 + 14.933 x_3 - 43.0934)$$
$$- 1.508 x_1 (x_6^2 + x_7^2) + 7.4777 (x_6^3 + x_7^3) + 0.7854 (x_4 x_6^2 + x_5 x_7^2)$$

$$s.t. \quad 27 x_1^{-1} x_2^{-2} x_3^{-3} - 1 \le 0$$
$$397.5 x_1^{-1} x_2^{-2} x_3^{-2} - 1 \le 0$$
$$1.93 x_2^{-1} x_3^{-1} x_4^3 x_6^{-4} - 1 \le 0$$
$$1.93 x_2^{-1} x_3^{-1} x_5^3 x_7^{-4} - 1 \le 0$$

$$\frac{[(745 x_4 x_2^{-1} x_3^{-1})^2 + 16.91 * 10^6]^{\frac{1}{2}}}{110 . x_6^3} - 1 \le 0$$

$$\frac{[(745 x_5 x_2^{-1} x_3^{-1})^2 + 157.5 * 10^6]^{\frac{1}{2}}}{85 . x_7^3} - 1 \le 0$$

$$x_2 x_3 - 40 \le 0$$

$$5 \le \frac{x_1}{x_2} \le 12$$

$$x_1 - 12 . x_2 \le 0$$

$$(1.5 x_6 + 1.9) x_4^{-1} - 1 \le 0$$

$$(1.1 x_7 + 1.9) x_5^{-1} - 1 \le 0$$

There are also bound constraints as follows:

$$2.6 \le x_1 \le 3.6, \quad 0.7 \le x_2 \le 0.8,$$
$$17 \le x_3 \le 28, \quad 7.3 \le x_4 \le 8.3,$$
$$7.3 \le x_5 \le 8.3, \quad 2.9 \le x_6 \le 3.9 \quad 5.0 \le x_7 \le 5.5.$$

Best Solutions	x_1	x_2	x_3	x_4	x_5	x_6	x_7	f(x)
MAE366Results	3.185	0.708	18.4	8.16	7.81	3.17	5.30	2905.6
Prev. Results	3.5	0.7	17	7.3	7.7156	3.3502	5.2869	2994.5

Fig.8 Sample optimization test problem[7] solved[8]

It has been proven in limited experiments that students with minimum training in optimization theory can use this online tool to solve non-trivial mechanical design optimization problem.

Imperial and Metric Unit Conversion Tools Using JavaScript

Using the wrong unit for engineering calculation and design can caused major problem, an example is the well known lost of 125 million dollar NASA Mars probe in 1999. Due to the inertia of using Imperial system in the US, engineers in other countries doing business with US have to be familiar with Imperial measurement system. There many such conversion tools available on the web, however, most of them are not designed for engineering use, and some of them even have serious error in them. We adopted and modified one that used JavaScript to do the calculation so that the conversion tool is very compact. Since the program file size is small, this tool can reside in any local computer and used through hyperlink, without locating at a heavy duty central computer server. Newer modules are still been added from time to time. For example, when a capstone design project calls for calculation of pressure loss caused by viscosity in different unit systems, this viscosity conversion module was added to the conversion tool. Fig. 9 showed the interface to this unit conversion tool.

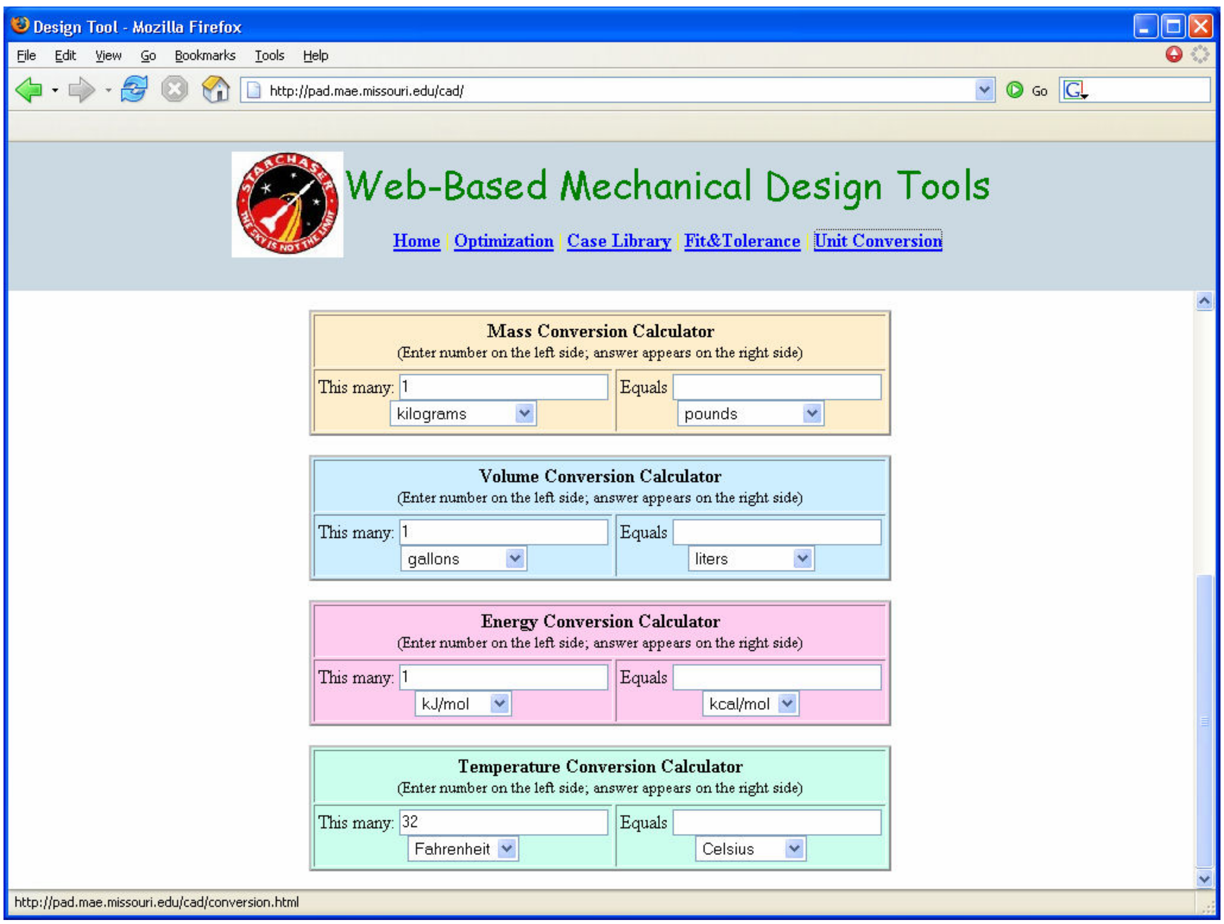


Fig.9 A compact imperial and metric unit conversion tool

Subject Course Materials to Be Included

It is decided that the set of teaching material to be used by the faculty members in different countries will be called the Capstone Design Manual. A tentative table of contents is as follows:

0. Introduction to the Manual: An ASEE 2004 National Conference paper, describing the effort of internationalizing the capstone design course.
*1. Introduction to Capstone Design: This lecture describes the conceptual difference between design *analysis* and *synthesis*, the *process approach* and *system integration approach* to teaching and learning mechanical design, and the expectation and outcome of the course.
2. Design team organization and dynamics: Design team can be organized by personality and temperament, or by random drawing. Team members play different roles in a synergetic way to produce the successful design.
*3. Collecting information for design and protecting intellectual property.
*4. Establishing measurable design specifications using QFD method: Quality Function Deployment method has become more widely used in the industry and in the engineering curriculum. The lecture notes describes how to prepare a QFD with a number of examples. Most important is to practice this technique by preparing a QFD for your capstone design project. Realistic design constraints that are emphasized by ABET, some of these are non-technical, will be considered here together with the technical and economical constraints that are in traditional QFD charts.
*5. Methods and tools for project planning and scheduling.
6. Encouraging creativity and producing conceptual designs.
*7. Preparing professional quality design drawings (Lecture notes with many examples and comments).
8. Review and application of CAD tools--FEA software.
9. Review and application of CAD tools--Optimization software: Unit #9 of the Capstone Design Manual includes the following parts: Lecture Notes, Slides, and a Manual on how to use web-based design optimization tools located at http://pad.mae.missouri.edu/cad.
*10. Cost estimate for design projects: Cost estimations for different types of design project and different scale are described in this lecture, with reference to a number of standard textbooks and reference books.
*11. Writing design project proposal and reports: Writing project proposal and report is a very important training for engineers.
12. Basics of engineering ethics.
*13. Presenting and defending the design.
Additional subjects of materials that have been considered include:
14. Selection of preferred limits and fits [6].
15. Tolerance stake analysis and specification.
16. Application of geometric dimensioning and tolerancing

Topics marked with a "*" will be required parts of the lecture notes. Unmarked parts will be elective, depending on the background of the design team, and the need of the specific design project. The above selection of materials leaves the individual instructor sufficient freedom to choose appropriate materials, and guarantees commonly agreed, critical subject topics will be covered by every school.

Conclusion

Through a multi-year effort and collaboration, the authors in different countries are trying to create a set of teaching materials and tools, for internationalizing capstone education in mechanical engineering. Some commonly agreed subjects of materials have been identified and prepared. Some practically useful web-based tools have been developed. These tools can be improved, and more web accessible tools can be added. The purpose of the endeavor is to combine the strength and overcome the weakness in each individual curriculum, and to train globally adaptable future engineers more effectively and efficiently.

Acknowledgement

The authors thank Department of Mechanical and Aerospace Engineering of University of Missouri-Columbia for providing TA support for web-based teaching tools development. Support from Capstone Education Center of Seoul National University of Technology is also gratefully acknowledged. Graduate students, Xiaoying Sheng, Ying Zhang, Amy Lee, and S.C. Huang have contributed partially to the development of the web-based tools.

References

1. Lin, Yuyi, D. Harby, D. Jang and W. Zhen, 2004, "Teaching Capstone Design in Globalization Environment," *Proceedings of the 2004 ASEE Annual Conference & Exposition,* Salt Lake City, UT.
2. Ullman, D. G., 2003, *Mechanical Design Process*, McGraw-Hill.
3. Preferred Limits and Fits, ANSI/ASME B4.1 and B4.2.
4. Shirgly, J. E. and Mischke C. R., 1986, Standard Handbook of Machine Design, McGraw-Hill.
5. Vanderplaats, G., 1998, Numerical Optimization Techniques for Engineering Design, VR&D Inc., Colorado Springs, CO.
6. ANSI/ASME B4.2, 1984, Preferred Limits and Fits.
7. Floudas, C. A. and Pardalos, P. M., 1990, A Collection of Test Problems for Constraint Global Optimization Algorithms, Springer-Verlag.
8. Babu, S.C., 2002, *Optimization using Genetic Algorithm,* MAE 366 Final Project Report, University of Missouri-Columbia.

Biography

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