

## **Unified Lecture Software for Statics, Dynamics, and Mechanics of Deformable Bodies**

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### Abstract

The history and current budget-driven challenges of teaching the basic engineering mechanics sequence are reviewed. In particular, necessary changes in lecture delivery caused by the reluctant decision to change from small to large sections are described. Newly developed lecture software for statics, dynamics, and mechanics of deformable bodies, designed to be used both in class by the instructor and online by the student, is presented.

### Background

The College of Engineering at Virginia Tech consists of eleven departments with the total number of incoming freshmen engineering students being about 1000. For many decades, the Department of Engineering Science and Mechanics has been responsible for teaching three undergraduate mechanics service courses (statics, dynamics, and mechanics of deformable bodies) to the students in most of these departments. Ten years ago, the philosophy for teaching these courses was to keep the number of students in a section to between 30 and 50 and to have only full-time faculty teach these sections. With enough faculty, which the department was fortunate enough to have at the time, it was possible to teach the service courses in this format, teach departmental courses for the undergraduate mechanics majors, and provide a robust offering of graduate courses, all while maintaining a very reputable funded research program in a number of fields.

Unfortunately, as has been the case in many other parts of the United States over the past ten years or so, funding levels for education in the Commonwealth of Virginia have been reduced considerably. This trend has accelerated over the last several years. As part of the reduced funding, faculty have been offered inducement packages to retire early, the number of positions for graduate teaching assistants, who are normally used to grade homework, have been reduced, and new faculty hiring has been curtailed. In addition, legislators have required that tuition increases be kept to a minimum. The number of students allowed to enroll in the College of Engineering has not been reduced proportionately. Two or three years ago, an examination of the teaching schedule in the department in any particular semester would reveal that about one-

third of the departmental teaching effort was devoted to the undergraduate service courses. This was often to the detriment of being able to offer a full range of graduate courses in order to maintain a strong graduate program and the associated funded research activities. It was very clear that adjustments to the long-standing philosophies regarding the service courses had to be made if the department were to continue a full spectrum of activities. To adjust to the new economic conditions, it was reluctantly decided, after decades of resisting this change, to teach the service courses in the available large classrooms on campus and thereby dramatically reduce the number of sections offered in a given semester.

There are numerous administrative and other challenges associated with this decision to go to large sections. In this paper, we concentrate on only one, and that is the lecture delivery itself. In very large classrooms (capacity of 200-300), writing on the board is not always practical, because the students in the rear, especially in the rear corners of the room, have difficulty seeing even very large writing. Large writing means that not much material can be put on the board at one time. As an alternative, the instructor can use one or two overhead projectors in such rooms, but drawing accurate figures of sufficiently large size on such projectors can be difficult in real time. The overhead material could be prepared in advance, but then we would have multiple instructors individually spending time solving the same problem, whereas one universal presentation would be more time efficient and could adhere to higher presentation standards.

### Description of the Software

To address the above difficulties encountered in large lecture halls, the authors have begun the development of departmental lecture software for the mechanics service courses. The software can be shown in any classroom with a computer-driven projector (typical is one large screen per room), and it can be placed on the internet for student review. A typical module consists of a concise review of the theory and one or more example problems – the latter worked out in ways impossible with chalk or overheads. Permission has been obtained from the publisher of leading statics, dynamics, and mechanics of materials textbooks<sup>1,2</sup> to use the high-quality illustrations therein, so that the students can generally see the same style of illustration as used in their textbooks. The chosen software platform is Macromedia's Flash.

The history of the present software dates back to the early 1980's when student-owned personal computers first became a factor in engineering mechanics education. This effort represents the third generation of mechanics software for the ESM Department. The first in the 1980's was DOS-based<sup>3,4</sup> while the second iteration in the 1990's was based on the Authorware platform<sup>5</sup>. Beginning with the second generation, professional input on design and navigation strategies has been received. The current development is based in good part on careful and continuous contact with colleagues who are using the software in their classes and on feedback from students.

The desired properties of the software include readability in all sizes of classrooms, ease of navigation, ability of the instructor to control the pace of unveiling, absence of long wordy passages, and the use of animation when that feature would be useful. Anything that looks like a button is a button. Red material indicates that a popup expanded explanation is available, while yellow is used for situations in which further information is available, usually in blank areas of

the screen. For example, the governing equation  $\Sigma F_x = 0$  might appear in yellow, indicating that clicking will show the application of that governing equation to the FBD at hand.

## Statics

Figure 1 shows the table of contents page for the statics software. The arrangement of chapters generally follows that of the standard sophomore-level textbooks. Clicking on any of the chapter buttons immediately brings one to the chapter-opening page of that particular chapter. As an example, the opening page for Chapter 2 (Force Systems) is shown in Figure 2. The topics are in yellow, meaning that they may be clicked upon to proceed to that article.

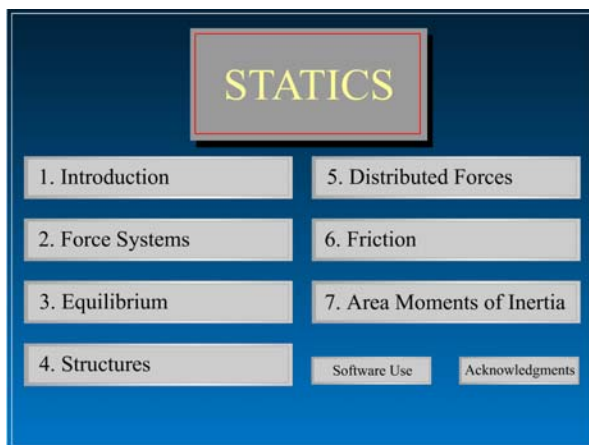


Figure 1 Statics Table of Contents

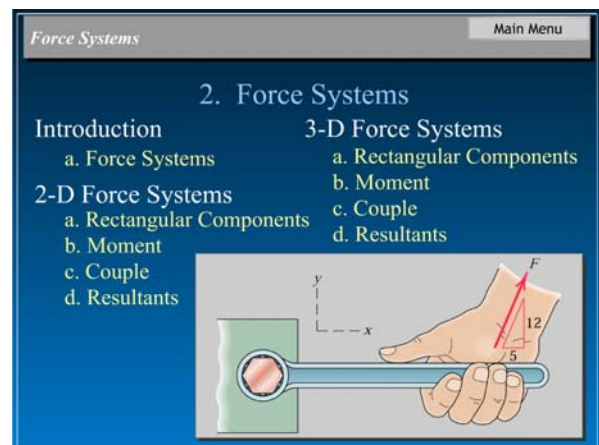


Figure 2 A Typical Chapter-Opening Page

Figure 3 shows the beginning of the article on 2-D moments. As a typical text page, it shows the chapter and article in the upper gray bar, along with buttons to take the user back to the main menu or to the chapter menu. The lower gray bar has a page indicator with forward and backward buttons. Also appearing in the lower gray bar is any unusual information that the user might need in order to operate the software. The theory here is that the upper and lower gray bars belong to the instructor (the operator) in class, while the main blue field belongs to the student.

Figures 4, 5, and 6 show the remaining theory pages in the article on 2-D moments. Figure 7 is the following sample-problem page. This sample problem performs a moment calculation with five different approaches, with the fourth approach shown in Figure 8. Note that animation is involved as the principle of transmissibility is used to slide the force along its line of action.

The above transition from the main menu page to a chapter-opening page to a typical article is used as an example to show the structure of the software. The overall package includes approximately 300 pages which cover the traditional statics course.

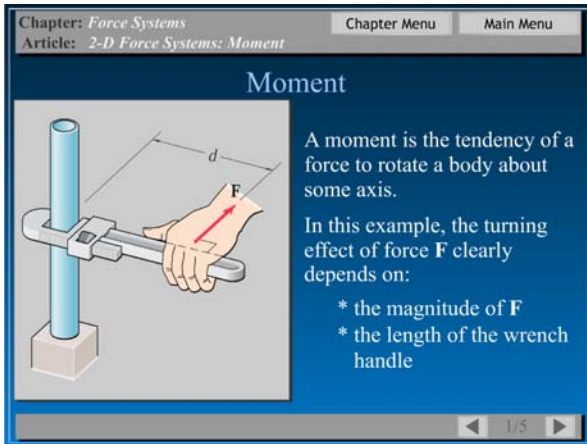


Figure 3 The Opening Page for a Typical Article

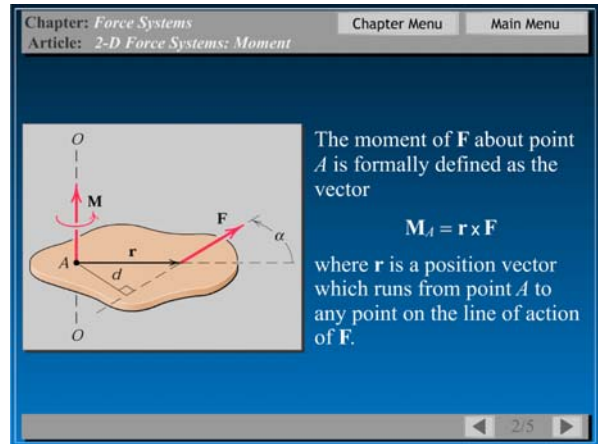


Figure 4 The Second Page of a Typical Article

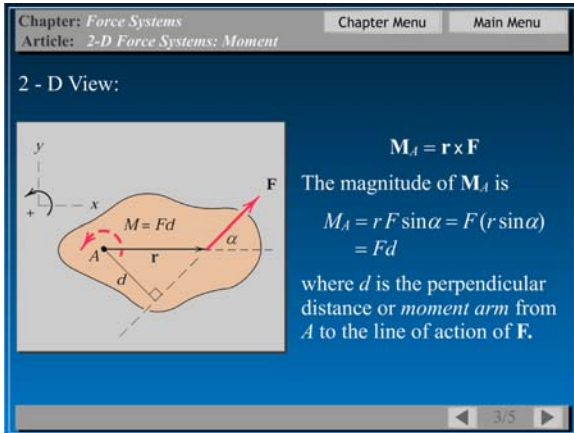


Figure 5 The Third Page of a Typical Article

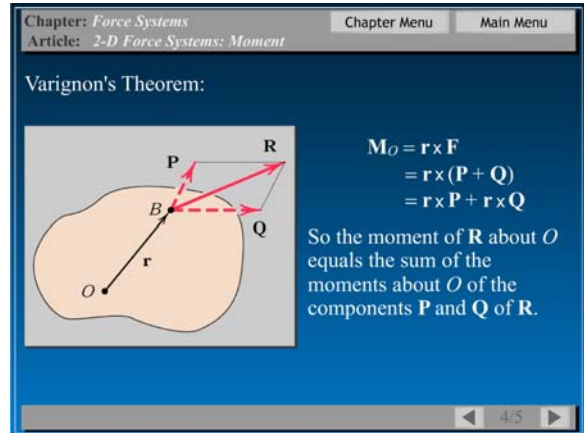


Figure 6 The Fourth Page of a Typical Article

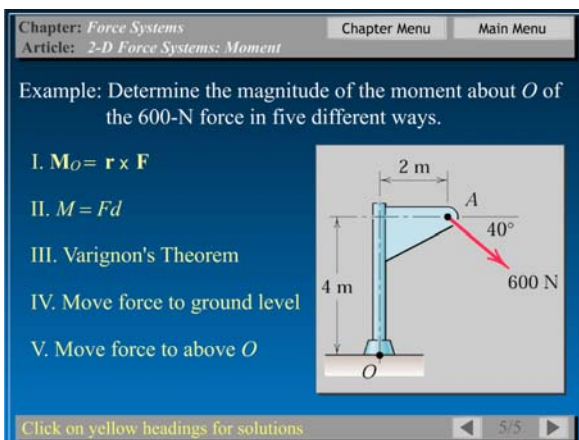


Figure 7 A Typical Example Problem

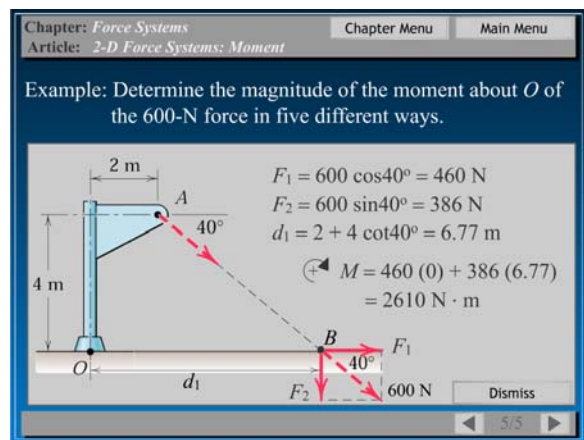


Figure 8 Approach IV of the Example Solution

Figures 9-12 show an area from the method of sections as applied to a simple plane truss. In Figure 9, the user must click on the pin and roller supports to show the external forces (note the

instructions in the lower grey bar). This action results in the FBD shown in Figure 10. The user may now click on any internal member to cut it; one such cut sequence is shown in Figure 11. Then the user can separate the resulting sections as shown in Figure 12. The software logic supports any legal cut.

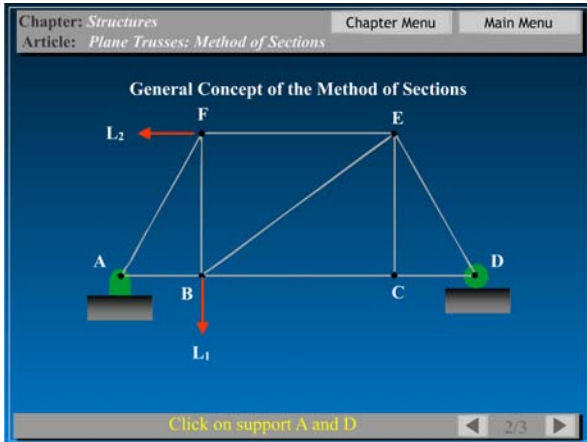


Figure 9 The Method of Sections

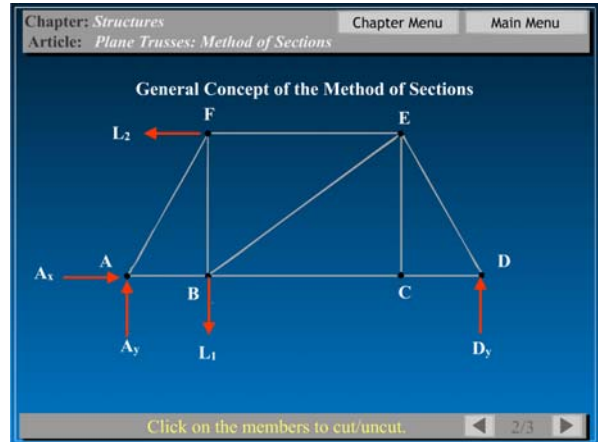


Figure 10 After Clicking on the Supports

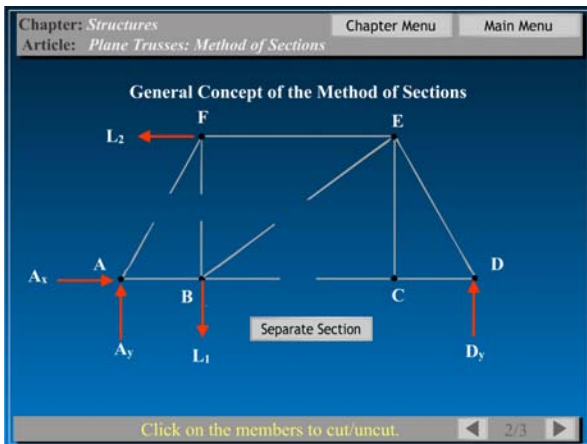


Figure 11 After Making a Cut

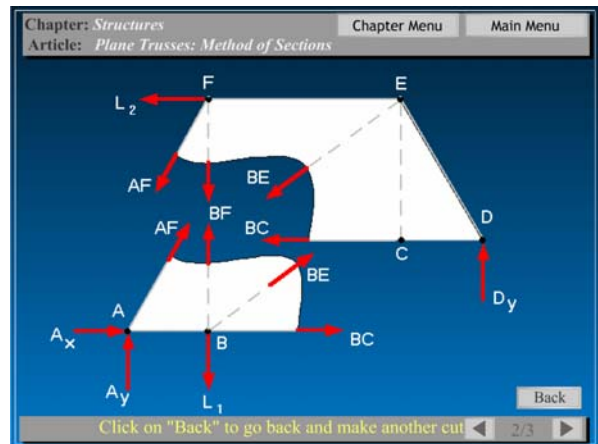


Figure 12 After Separating the Sections

## Dynamics

As Figure 13 suggests, the structure for the dynamics software is identical to that for statics. Thus, once instructors and students are accustomed to the statics software, using the dynamics software should come totally naturally. The main difference in the packages is the fact that many more animations are used in dynamics, both in the theory and in the sample problems. In the sample problems, the user can normally set the given illustration into motion at any point in the solution process. This aid in visualization of the motion is regarded as an important advantage to the use of this type of lecture software. The current approximate page count for dynamics is 450.



**DYNAMICS**

Introduction	Rigid Body Kinematics
Particle Kinematics	Rigid Body Kinetics
Particle Kinetics	Mass Moments of Inertia
Software Use	Acknowledgments

Figure 13 Dynamics Table of Contents

Particle Kinetics Main Menu

Particle Kinetics

Introduction

Force, Mass, and Acceleration

a. Introduction to  $F = ma$       c. Normal - Tangential Coordinates

b. Rectangular Coordinates      d. Polar Coordinates

Energy Methods

a. Work and Kinetic Energy      c. Potential Energy

b. Power

Momentum Methods

a. Linear Impulse and Momentum      c. Impact

b. Angular Impulse and Momentum

Combination Problems

Figure 14 A Typical Chapter-Opening Page

Chapter: Particle Kinetics Chapter Menu    Main Menu

Article: Energy Methods; Potential Energy

The 3-lb slider is released from rest in position  $A$  and slides without friction along the vertical plane guide shown. Determine the maximum deflection  $\delta$  of the spring by the potential energy method.

Animation

Next

◀ 19/19 ▶

Figure 15 A Typical Dynamics Example

Chapter: Particle Kinetics Chapter Menu    Main Menu

Article: Energy Methods; Potential Energy

The 3-lb slider is released from rest in position  $A$  and slides without friction along the vertical plane guide shown. Determine the maximum deflection  $\delta$  of the spring by the potential energy method.

Animation

Next

◀ 19/19 ▶

Figure 16 After Pressing the Motion Button

Figure 14 shows the chapter-opening page from the chapter on particle kinetics. Figures 15-18 show various pages from an example on the use of the potential-energy form of the work-energy equation. Note the yellow animation button in Figure 15; Figure 16 shows the final result of having pressed this button. Figure 18 shows what happens when one clicks on the red word datum in Figure 17.

Chapter: Particle Kinetics Chapter Menu Main Menu  
 Article: Energy Methods: Potential Energy

With state  $F$  defined to be the state of maximum spring deflection, we write

$$T_A + V_A + U_{A,F} = T_F + V_F$$

We define the datum to be at state  $A$ . Thus

$$0 + 0 + 0 = 0 + \frac{1}{2}k\delta^2 - mgh_{A,F}$$

$$\delta = \frac{\sqrt{2mgh_{A,F}}}{k} = \frac{\sqrt{2(3)(10)}}{125(12)}$$

$$= 0.2 \text{ ft.}$$

Back

Figure 17 Solution of the Example Problem

Chapter: Particle Kinetics Chapter Menu Main Menu  
 Article: Energy Methods: Potential Energy

With state  $F$  defined to be the state of maximum spring deflection, we write

$$T_A + V_A + U_{A,F} = T_F + V_F$$

We define the datum to be at state  $A$ . Thus

$$0 + 0 + 0 = 0 + \frac{1}{2}k\delta^2 - mgh_{A,F}$$

$$\delta = \frac{\sqrt{2mgh_{A,F}}}{k} = \frac{\sqrt{2(3)(10)}}{125(12)}$$

$$= 0.2 \text{ ft.}$$

Recall that a datum is defined to be the altitude at which the gravitational potential energy is zero.

Back

Figure 18 Typical Hot Word Explanation

### Mechanics of Deformable Bodies

Figure 19 shows the main menu page<sup>6</sup> for the mechanics of deformable bodies course, while Figure 20 shows a typical chapter-opening page. In Figure 21 the user can apply and remove a shear force and see the resulting deformation of the elastic body being defined. The remaining figures indicate the spirit of our software attempts in this course: to help the student visualize the deformations resulting from a given physical situation. In Figure 22, the user presses on the button to increase the tensile force  $P$ , and the cylindrical member is shown to increase in length and decrease in diameter, as shown in Figure 23. As a prelude to introducing normal stress, Figure 24 depicts a sequence in which the software displays an increasing tensile force applied to three cylindrical members, while simultaneously colored-keyed dots move along the appropriate force-deflection curve.

Mechanics of Deformable Bodies	
Introductory Concepts	Analysis of Stress and Strain
Stress, Strain, and Material Response	Applications of Plane Stress
Axially Loaded Members	Deflection of Beams
Torsion	Statically Indeterminate Beams
Shear Forces and Bending Moments	Columns
Stresses in Beams	Centroids and Moments of Inertia
Acknowledgments Software Use	

Figure 19 Deforms Table of Contents

Introductory Concepts Main Menu

### Introductory Concepts

- Basic Definitions
- Force
- Units
- Accuracy

Figure 20 Deforms Chapter-Opening Page

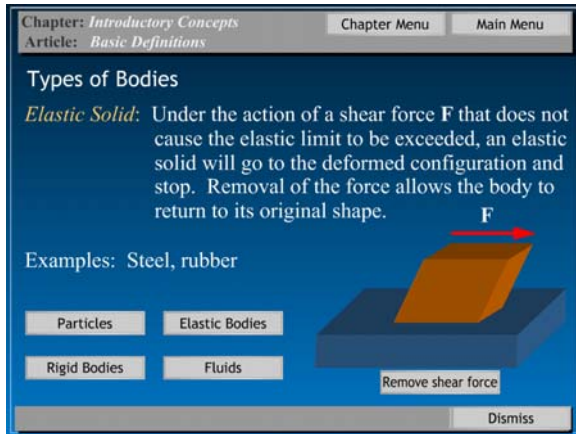


Figure 21 Introductory Concepts Page

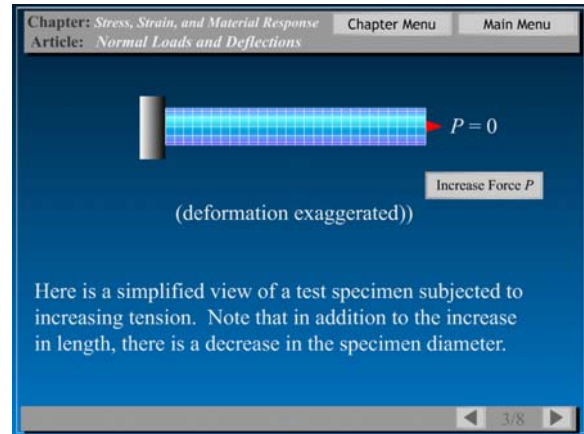


Figure 22 Simplified Tension Specimen

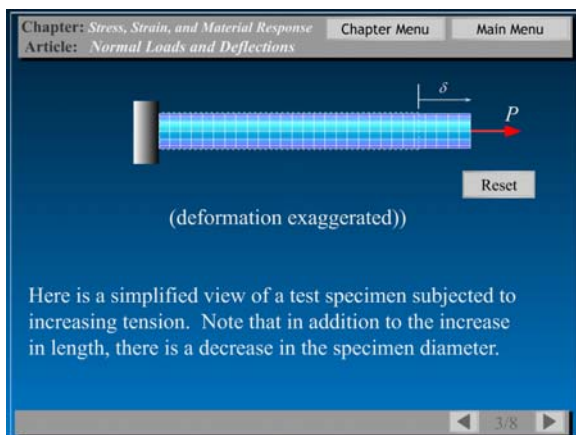


Figure 23 Deformed Tension Specimen

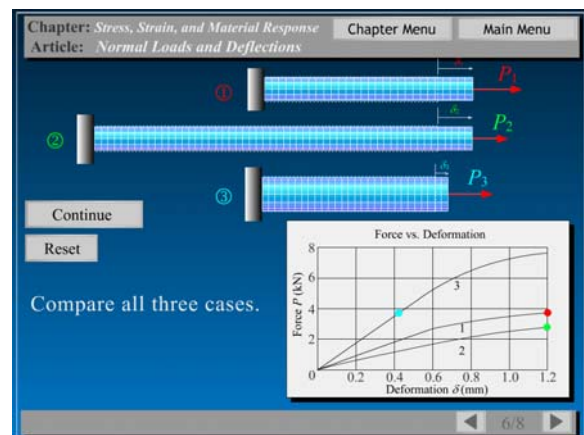


Figure 24 Force-Deformation Curves

### Faculty and Student Reaction

We are early in this process, so reaction is limited. The 2004 fall semester was the first semester during which some of the software was made available to all students. The faculty reaction varies greatly from instructor to instructor, with some faculty members (especially in the large 300-student sections) wildly enthusiastic, while others, especially those assigned small sections, have not yet begun to use this lecture aid. Because the decision was made to make the software available to all students regardless of whether the individual instructor uses it in class, it is not possible to perform any effectiveness studies with a control group that has no access to the software.

A few questionnaire comments from the students of a 2004 fall-semester dynamics class:

"The software was great for test review since it hits on the major point of each section."

"Personally, I found the software to be a very useful tool. It helped me understand concepts and ideas that were difficult to understand from the book. The interactive and multimedia nature of the program is what makes it so effective. The moving animations help you imagine how parts



move under forces considering the constraints, which is very useful when it comes to angular velocities and accelerations."

"My main concern with electronic teaching aids is that it encourages the student to learn by watching and not by trial an error. I understand that the software is intended to be supplemental but I also know that people will make it a primary source for education."

"In all, the dynamics software is fantastic. Having the same class topics presented from a slightly different angle is extremely helpful when trying to learn new and challenging concepts. Also, the animated figures throughout make visualizing movements, forces, and interactions so much easier."

Here is additional student reaction from a 2005 spring-semester statics class taught by a different instructor. These comments are based upon only the early portion of the software.

"The software is the closest thing, next to a living breathing tutor, to giving you step by step information in learning new concepts and understanding how to work problems."

"There should be more example problems." (Note: This observation occurred several times.)

"It helped me understand statics more because of the visual aids."

"Just having very clean drawings /figures to look at is a help."

## Summary

Coupled with the recent decision to teach the basic engineering mechanics courses in large sections, the ESM Department has begun the development of lecture software to aid in-class presentation of the theory and animated example problems. Flash-based software for the standard statics and dynamics courses has been largely completed, and work is currently focused on the deformable-bodies software. Prime features of the software include professionally prepared figures from textbooks, font sizes chosen for use in the largest (up to 300) classrooms, fast navigation, fine user control of progress within a page, a concise review of the theory, numerous sample problems, and good use of animation to help the student to comprehend the action being considered. Plans for distribution of the software are currently being studied.

## Acknowledgements

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