

## **Introducing ADAMS, a Mechanical System Simulation Software, to Bioengineering Students**

**Rakié Cham, Brian Moyer**  
**Department of Bioengineering, University of Pittsburgh**

### **ABSTRACT**

Integrating mechanical system simulation software into traditional engineering courses enhances the instruction of basic dynamics principles and improves creative design skills. ADAMS simulation software and its add-on tool, Human Figure Modeler, developed and marketed by Mechanical Dynamics Inc., was, for the first time, introduced to bioengineering students at the University of Pittsburgh to enhance the learning of biomechanical principles. The goal of this paper is to describe the course, report on our instructive experience and students' evaluation of the class and suggest future teaching strategies. Twelve, two-hour weekly sessions were scheduled during the fall 2001 semester to teach this course. Based on our experience, we believe that the integration of ADAMS into existing bioengineering courses can greatly improve students' understanding of biomechanical systems, while simultaneously adding to their engineering skills. However, the efficient use of this software requires training and regular use. We suggest that students be required to take a course similar to the *Introduction to ADAMS for Bioengineers* course discussed in this presentation before they enroll in any other bioengineering class that incorporates ADAMS as an additional educational tool.

### **MOTIVATION**

In regular classroom environments, students sometimes find it difficult to grasp the properties rigid body motion, partly due to the difficulty of using intuition to visualize three-dimensional dynamics. It is our opinion that dynamics including body biomechanics are learned much better in an interactive way. With the use of a mechanical simulation software, students can get beyond the mathematical formalism and use physical reasoning to tackle challenging problems, quickly change the model's parameters and observe the effects of the changes. The Department of Bioengineering at the University of Pittsburgh has recognized the importance of visual learning in the field of biomechanics, acquired ADAMS simulation software from Mechanical Dynamics Inc, and introduced its students to this tool. This paper describes the course, reports on our instructive experience and students' evaluation of the class and suggests future teaching strategies.

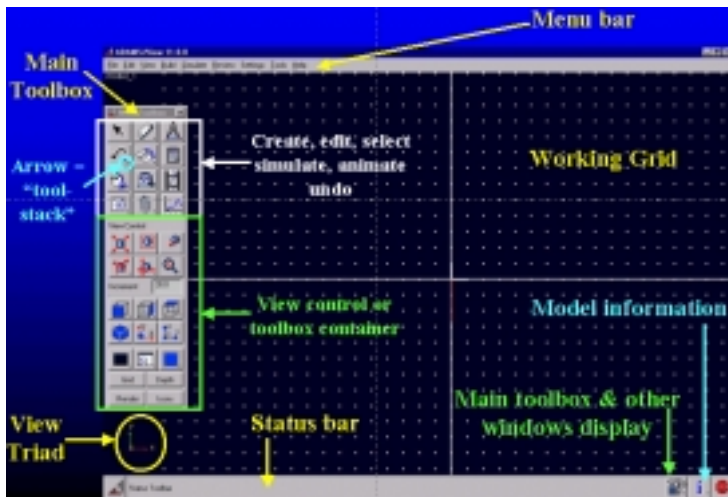
We chose ADAMS based on its utility in industry and its integration in a number of mechanical engineering courses. We focused on two of ADAMS' numerous components: (1) ADAMS/View (A/View), a graphical interface used for building, simulating and animating models, and (2) Human Figure Modeler, an add-on tool that allows modeling of human body biomechanics. Another appealing feature of the software is its numerous potential applications in research, both in mechanical engineering and bioengineering. For example, both instructors of this course use Human Figure Modeler to study the biodynamics of human movement (standing and gait) and postural control mechanisms under various external perturbations.

## **COURSE STRUCTURE**

Our teaching objectives were (1) to introduce students to the basics of A/View and Human Figure Modeler, and (2) guide instructors towards appropriate teaching strategies for future teaching efforts. Twelve, two-hour weekly sessions were scheduled during the fall 2001 semester, each including thirty minutes of lecture and on-screen demonstration covering basic concepts and specific techniques, followed by ninety minutes of hands-on tutorials. Handouts summarizing the material covered in class were handed out at the beginning of each session. The first nine sessions were devoted to A/View, while Human Figure Modeler was covered in sessions 10 and 11. Finally, students were introduced to ADAMS/Controls during the last session. The details of the material covered in each session are described in Table 1. In order to avoid frustration among students while attempting the first tutorials, detailed step-by-step instructions were given. In addition, the problems at the beginning of the course were fairly straightforward and were intended to allow students gain familiarity with the A/View interface (Figure 1). As the course went on, detailed instructions were omitted progressively. Finally, the tutorials for Human Figure Modeler assumed knowledge of the A/View interface.

**Teaching Human Figure Modeler:** A one-hour lecture period was used in week 10 to cover the basic model building paradigm and typical sequence of steps used to build a model in Human Figure, i.e. build segments, build joints, add soft tissues, set initial posture, create environmental contacts and possibly import experimental data to drive the model. Then, the students were asked to build a human model and simulate a passive fall (Table 1). Segment impact forces and accelerations were evaluated both in A/View using measures and in the Postprocessor tool. With their prior knowledge of the A/view interface, students were able to follow instructions and complete the tutorial.

In week 11, the second week of Human Figure Modeler, the basic concepts covered in week 10 were revisited before the students started the hands-on tutorial of the week. The exercise involved modeling a stooping movement (Table 1). This required importing experimental data, performing inverse and forward dynamics simulations and reviewing joint energies and powers results, once again, in A/view and the Postprocessor tool.



(a)



(b)



(c)



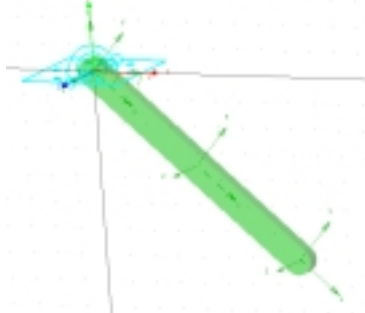

(d)



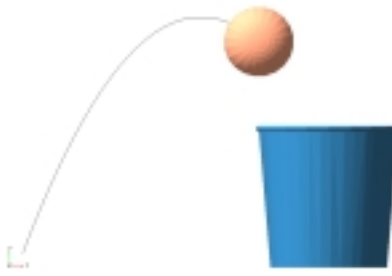
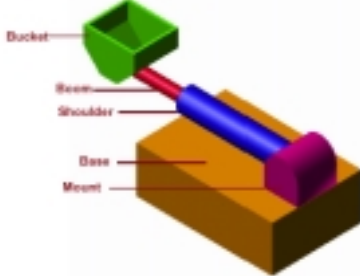
(e)

Figure 1: (a) A/View interface, (b) Main Toolbox, (c) Geometries, (d) Joint, and (e) Force palette

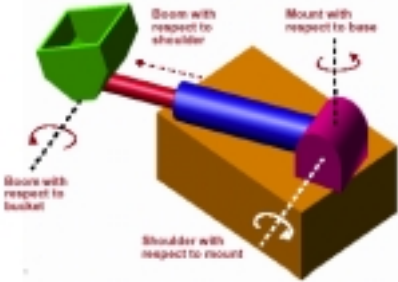
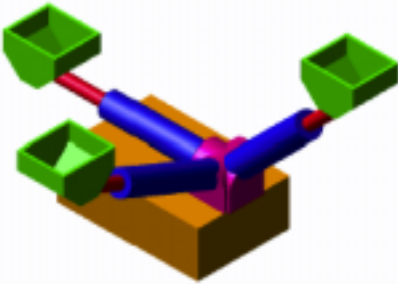
**Table 1: Timetable and material covered**

Week number	Material	Tutorials
1 – 9/18	<p>What is ADAMS?</p> <p>ADAMS-related products</p> <ul style="list-style-type: none"> <li>• Typical modeling process</li> <li>• How to start A/View</li> </ul> <p>How to select a working directory</p> <p>A/View main window and toolbox</p> <p>Overview of the following topics:</p> <ul style="list-style-type: none"> <li>• Geometries, joints and forces palettes</li> <li>• Zoom in/out tools and shortcuts</li> <li>• View tools and shortcuts</li> <li>• Menus available by right-clicking</li> <li>• Simulation and animation</li> <li>• Measures</li> <li>• Post-processor</li> <li>• Motion generators</li> <li>• ADAMS simplified hierarchy</li> <li>• Command and database windows</li> </ul> <p>How to get online help</p> <p>Saving an ADAMS model</p> <p>Resources available on the Web</p>	<p>The instructor illustrated introductory concepts using an on-screen example of a one-DOF pendulum (shown below).</p>  <p>The hands-on tutorials for this session were simple exercises involving a pendulum (shown above) and a mass-spring-damper (shown below) as well as centrifuge motion in a revolute joint.</p> 


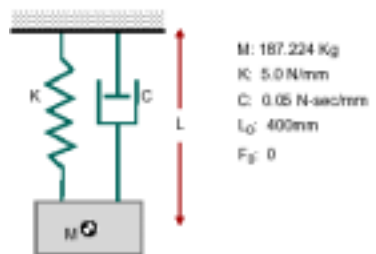
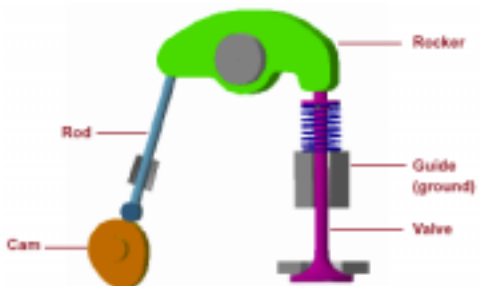
**Table 1, Continued**

<p>2 – 9/ 25</p>	<p>A/View's hierarchy:</p> <ul style="list-style-type: none"> <li>• Database – Model – Part - Geometry, etc</li> </ul> <p>Concept of “ground”</p> <p>More details on types of geometries</p> <p>Edit a geometry/part:</p> <ul style="list-style-type: none"> <li>• How to select</li> <li>• Position: translate, rotate, align, etc...</li> <li>• Coordinate system: LCS/GCS</li> <li>• Properties: mass, material, etc...</li> <li>• Initial conditions</li> <li>• Group</li> <li>• Rename</li> <li>• Merging geometry</li> </ul>	<p>The instructor illustrated concepts using an on-screen example of a falling stone.</p> <p>The hands-on tutorial for this session asked the students to create a virtual basketball rim and net hollow sphere (a basketball), which were then used to illustrate projectile motion via initial conditions (see figure below).</p>  <p>An additional exercise helped the students master more complicated geometry construction by building the lift mechanism shown below.</p> 
------------------	--	--


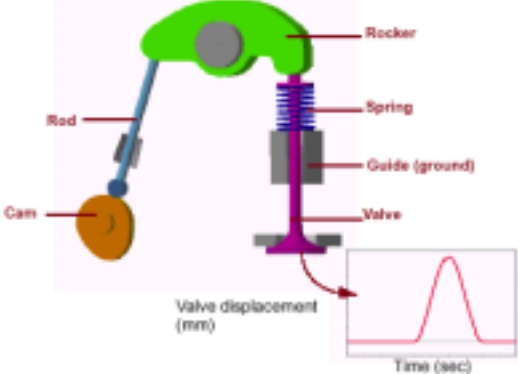

**Table 1, continued**

<p><b>3 – 10/2</b></p>	<p>What is a joint?</p> <p>Anatomy of joints</p> <ul style="list-style-type: none"><li>• I, J markers</li><li>• DOFs, etc ...</li></ul> <p>More details on types of joints, including joint primitives</p> <p>Edit a joint</p> <ul style="list-style-type: none"><li>• Selecting a joint</li><li>• Initial conditions</li><li>• Joint motion</li><li>• Angle measures</li></ul>	<p>The instructor used simple on-screen examples involving idealized joints (e.g. revolute, cylindrical, translational, spherical).</p> <p>The students practiced adding idealized joints to the lift mechanism they built in the previous session (see figure below).</p>  <p>The diagram shows a 3D model of a lift mechanism. A green bucket is attached to a red boom, which is connected to a blue shoulder. The shoulder is mounted on a purple mount, which is fixed to a brown base. Red dashed lines and arrows indicate the degrees of freedom for each joint: 'Boom with respect to shoulder', 'Mount with respect to base', 'Shoulder with respect to mount', and 'Bore with respect to bucket'.</p> <p>In addition, joint primitives were used to restrict the bucket's motion such that it maintained its horizontal orientation (see below).</p>  <p>The diagram shows the same lift mechanism as above, but with two green buckets attached to the boom. The buckets are positioned horizontally, indicating that their motion is restricted to maintain a horizontal orientation.</p>
------------------------	---	---

**Table 1, continued**

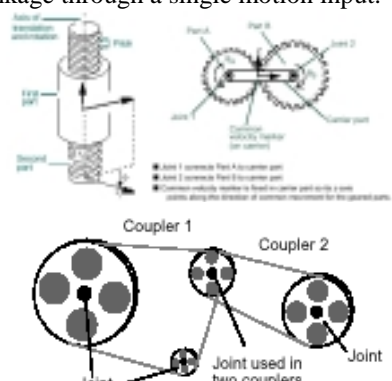
<p><b>4 – 10/ 9</b></p>	<p>More details on types of forces, including flexible connectors (e.g. spring, bushings)</p> <p>Defining forces in ADAMS</p> <ul style="list-style-type: none"> <li>• Parts</li> <li>• Point of application</li> <li>• Magnitude (constant or function)</li> <li>• Direction</li> </ul> <p>Create and edit a force</p> <p>Other: Function builder</p>	<p>The instructor described in details the type of forces described in Figure 1 using on screen examples.</p> <p>Contact forces were illustrated using an on-screen example of a ball bouncing down steps (see below).</p>  <p>Finally, the students did a more advanced (than the first week) mass spring damper tutorial (see below)</p> 
<p><b>5 – 10/ 16</b></p>	<p>Simulation</p> <ul style="list-style-type: none"> <li>• Details of simulation palette</li> <li>• Simulation modes</li> <li>• Saving results, etc ...</li> </ul> <p>Measures</p> <p>Animation Palette</p> <p>PostProcessor</p> <ul style="list-style-type: none"> <li>• PostProcessor interface</li> <li>• Plotting / animation modes</li> <li>• Overlay and modify plots</li> <li>• Add and modify animation graphics</li> <li>• Create avi files</li> </ul>	<p>The tutorial for this session, a cam-rocker mechanism (shown below), required applying a number of previously learned concepts such as adding revolute and translational joints, applying and modifying a spring force, and performing simulations.</p> 

**Table 1, continued**

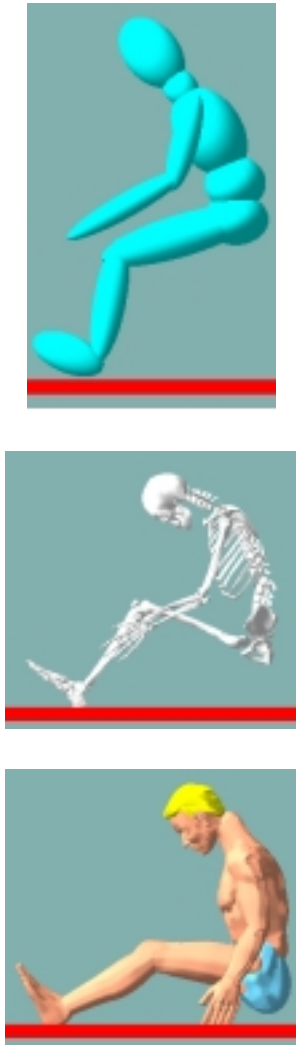
<p><b>6 – 10/23</b></p>	<p>Types of motion generators</p> <ul style="list-style-type: none"> <li>• Joint motion</li> <li>• Point motion</li> </ul> <p>Defining motions in ADAMS</p> <p>Other</p> <ul style="list-style-type: none"> <li>• Function builder</li> </ul>	<p>The inverted pendulum on screen example and box sliding on a plane tutorial (shown below) helped to illustrate the concepts discussed in the lecture.</p> 
<p><b>7 – 10/30</b></p>	<p>More advanced concepts</p> <ul style="list-style-type: none"> <li>• Splines</li> <li>• Curves</li> <li>• Cams</li> <li>• Point traces and contacts</li> </ul>	<p>The cam-rocker example was revisited with more spline-related applications added.</p> 
<p><b>8– 11/13</b></p>	<p>Refining model designs - Overview</p> <ul style="list-style-type: none"> <li>• Parameterization methods</li> <li>• Parametric analyses tools</li> </ul> <p>Parameterization methods</p> <ul style="list-style-type: none"> <li>• Overview</li> <li>• Design variables</li> </ul> <p>Parametric analyses</p> <ul style="list-style-type: none"> <li>• Design study</li> <li>• Design of experiments</li> <li>• Optimization</li> </ul>	<p>In the example shown below, the students used parameterization methods and analyses to find the correct launch spring stiffness allowing a marble to hit a target.</p> 



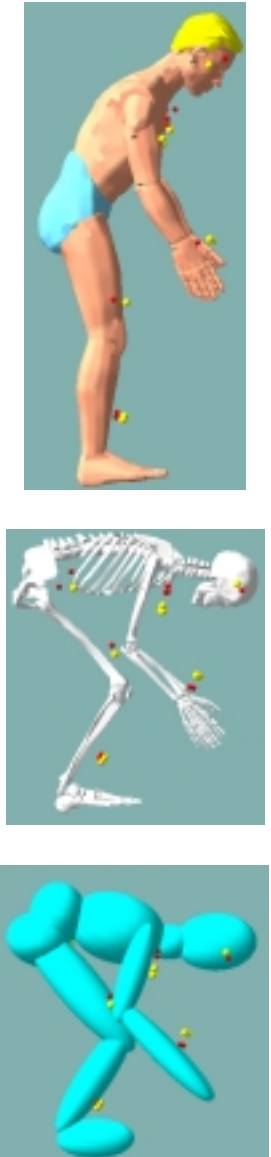
**Table 1, continued**

<p>9 – 11/20</p>	<p>Complex constraints</p> <ul style="list-style-type: none"> <li>• Screw joint</li> <li>• Gears</li> <li>• Couplers</li> </ul>	<p>Students worked to duplicate an on-screen example illustrating a multi-body linkage utilizing all three complex constraints to drive the linkage through a single motion input.</p>  <p>The diagrams illustrate three types of complex constraints:</p> <ul style="list-style-type: none"> <li><b>Screw Joint:</b> A 3D assembly showing a screw, a nut, and a shaft. Labels include 'Screw', 'Nut', 'Shaft', 'Screw Head', 'Screw Tail', 'Screw Thread', 'Screw Head Washer', and 'Screw Tail Washer'. A legend indicates: 'Joint 1 connects Part A to Part B', 'Joint 2 connects Part A to Part B', and 'Constraint: Part A is fixed to Part B and only a screw motion along the direction of the screw thread is allowed for the screw part'.</li> <li><b>Gear Linkage:</b> A 2D diagram showing two gears, Gear 1 and Gear 2, meshing with a central coupler. Labels include 'Gear 1', 'Gear 2', 'Coupler', 'Screw Joint', 'Screw Head Washer', and 'Screw Tail Washer'.</li> <li><b>Coupler Linkage:</b> A 2D diagram showing two couplers, Coupler 1 and Coupler 2, connected by a joint. Labels include 'Coupler 1', 'Coupler 2', 'Joint', and 'Joint used in two couplers'.</li> </ul>
------------------	---	---

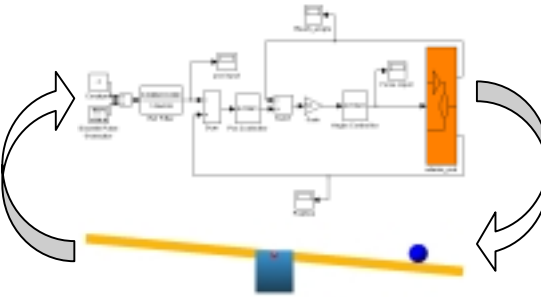
**Table 1, continued**

<p><b>10 – 11/27</b></p>	<p>Human Figure Modeler I- Overview</p> <p>What is Human Figure Modeler?</p> <p>Basic model building paradigm</p> <p>Basic model building process</p> <ul style="list-style-type: none"><li>• Building segments</li><li>• Add joints</li><li>• Adding soft tissues</li><li>• Setting initial posture</li><li>• Creating environmental contacts</li><li>• Importing experimental data</li><li>• Imposing motions – Inverse dynamics</li></ul>	<p>Students were asked to build a 50<sup>th</sup> percentile male human model, create contacts between the body segments and the environment, and allow the model to fall from a specified height onto a flat surface</p> 
--------------------------	--	--

**Table 1, continued**

<p>11 – 12/4</p>	<p>Human Figure Modeler II-</p> <p>Revisited important aspects of lecture on 11/27</p>	<p>The exercise for this week illustrated the active simulation of a deep knee bend and served to demonstrate the general principals for inverse-dynamics and direct-dynamics simulation in Human Figure. Students were asked to build a human model, drive it using imported experimental motion data, and conduct an inverse dynamics simulation. The displacements captured during this simulation were used for a direct dynamics simulation, where the model was driven exclusively with joint torques.</p> 
------------------	--	---

**Table 1, continued**

<p><b>12 – 12/11</b></p>	<p>Introduction to ADAMS/Controls:</p> <ul style="list-style-type: none"><li>• Plant inputs and outputs</li><li>• Integrators</li><li>• Continuous versus discrete simulation</li><li>• Mechanics for connecting the two software packages</li></ul>	<p>Students connected previously developed (by Mechanical Dynamics, Inc.) A/View models, a ball balancing on a pivoting beam and a more complicated moving dish antenna, to Simulink (from MathSoft) through the A/Controls toolkit to demonstrate how control systems can interact with dynamic models.</p> 
--------------------------	--	---

## STUDENTS' EVALUATION OF THE COURSE

At the end of the course, students were asked to provide feedback on the course by filling out a questionnaire and suggesting teaching recommendations for the future (Figure 2). On average, students who provided feedback attended 10 out of the 12 lectures and have taken a dynamics class previously. All students replied “YES” to the question whether they were able to follow the lectures and tutorials. In general, students thought that a class such as A/View and Human Figure Modeler would add to their understanding of classical dynamics and biomechanics of human (an average rating of 4.2). However, students also suggested that A/View and Human Figure Modeler training would be needed prior to incorporating those tools in regular bioengineering classes. In general, a class format of 2 to 4 hours per week with regular homework was proposed. Students selected an average rating of 3.8 on the question “compared to your other classes how much did you learn?” Students were also asked whether they thought A/View and Figure would be useful to their engineering training. The answer was an average rating of 4.2. Finally, general opinions and typical teaching recommendations are listed below:

- “I thought the class was very useful. I now feel that I can develop models on my own and how to analyze the results and alter the model accordingly. A/View is a fantastic tool and the applications for it are infinite.”
- “I believe that a useful tool would be for the students to develop a project at the beginning of the semester. Then, as they progress through the class, they can create different parts of the model and by the end of the semester they can refine their model and have a finished product.”
- “I know A/View has many options and can be used in many ways. I think we attempted to cover too much material for two hours/week”



## CONCLUSIONS

We believe that by introducing ADAMS and Human Figure Modeler in the class, students will gain the sense of involvement produced by a genuine understanding of the principles of the biodynamics of Human Movement. In general, the power and numerous applications of this software appealed to the students. Based on our experience and the students' feedback, we believe that the integration of ADAMS into existing bioengineering courses can greatly improve students' understanding of biomechanical systems, while simultaneously adding to their engineering skills. However, the efficient use of this software requires rigorous training and regular use. We suggest that students be required to take a course similar to the *Introduction to ADAMS for Bioengineers* course discussed in this paper before they enroll in any other bioengineering class that incorporates ADAMS as an additional educational tool. Furthermore, we suggest that such course be taken for credit, with regular homework and a final project.

## ACKNOWLEDGEMENTS

Mechanical Dynamics Inc provided a number of examples used in the class. We would like to thank in particular John Janevic and Shawn McGuan for facilitating the use of those examples in educational settings.

### RAKIÉ CHAM

Rakié Cham is a Research Assistant Professor. Her research includes the biomechanical analysis of human movement and occupational tasks towards the prevention of injuries. She is particularly interested in the biomechanics of falls and uses gait studies and computer modeling to investigate such incidents. She taught ergonomics, biomechanics, bioinstrumentation, and more recently, computer modeling and bio-thermodynamics.

### BRIAN MOYER

Brian E. Moyer is currently pursuing his Ph.D. in Bioengineering at the University of Pittsburgh. His research, conducted in the Human Movement and Balance Laboratory, focuses on modeling, simulation and control of virtual human body motion to gain insight into injury biomechanics.