Integrating Simulation Software into an Undergraduate Dynamics Course: a Web – based Approach

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Abstract

The goals of this paper are to discuss some issues involved in integrating simulation software into an undergraduate dynamics course, and to suggest an approach to this task. The software package in question is MSC – ADAMS®, a package that is currently used worldwide in industry for advanced mechanical simulation. The course is MECH – 310 (Mechanics III) and is currently being taught at Kettering University by the author.

There is a real need in industry for mechanical engineers with CAE experience and the author finds that introducing computational tools into this course is an excellent way of initiating students into mechanical simulation. Also, through simulation of textbook examples, students can observe problem solutions for full intervals of time, in contrast to traditional methods, which in general allow only for "snap-shot" type solutions (i.e. restricted to an instant in time). This can lead to an improved understanding of the subjects being taught.

The choice for a high-end simulation package is based on the principle of teaching a tool that can be used during the students' senior design courses and in their professional careers as well.

Carrying out the integration of the software into the course can pose some challenging issues. For example, integrating software teaching and assignments into an already full course schedule. Here the author suggests a Web-based approach. Student feedback on the integration is included and an example assignment is also given in the paper.

Introduction

Many universities currently teach kinematics and dynamics of mechanical systems in a traditional fashion. The subjects are presented through lectures, usually following a textbook, and students are asked to solve problems using techniques explained during the lectures. Sometimes a project involving some of the concepts presented during the course is assigned to the students, as a part of their grading, but, most of the time, students are asked to complete exams and homeworks based on textbook examples in order to fulfill the course requirements.

During these courses the goal is to teach students basic concepts, such as kinematics and dynamics of particles and rigid bodies. Simple examples of mechanical systems are used to illustrate the concepts and to test their knowledge of the material. These simple systems (a simple pendulum, a bar on springs, etc.) can readily be solved by using traditional methods and students can obtain problem parameters (such as velocities, accelerations, forces, etc.) at a specific instant in time. If time is allowed to vary the problem must be solved again to lead to the new values of the variables sought. Therefore a solution during an interval of time is usually not obtained and students are not confronted by the behavior of the mechanism while it is moving, for example, throughout a cycle. Also, as students progress to more complex mechanisms, it becomes difficult to fully visualize and understand these systems when a laboratory prototype or a simulation is not given.

In order to allow students to observe and understand mechanism operation, compare hand-obtained solutions to computer derived ones and the ability to see problem variable behavior with varying time, the author suggests introducing simulation software into the basic courses mentioned above.

Course and simulation software

In the present text the introduction of simulation software is discussed for an undergraduate course in dynamics. The course is MECH-310, which is a junior level four-credit course with four hours of contact (two separate blocks of two hours). Pre-requisites for the course require that students complete basic statics and calculus courses. The course is divided in two major parts: (i) kinematics and dynamics of particles, (ii) kinematics and dynamics of rigid bodies. The course material is covered during a period of about ten weeks. (See Appendix A for course content.) The author utilizes the hours of contact to present the material and to periodically evaluate student learning (for instance, via quizzes solved by groups of students).

Introducing simulation software into the course presents the challenge of teaching students the software environment itself as well as creating and running models inside this environment. Several textbooks on the subject of undergraduate dynamics already incorporate some sort of simulation software or an interactive environment where the student can run examples and observe mechanism behavior. One common example is MSC – Working Model®. The current textbook [1] used by the author in this course incorporates examples and exercises that can be solved by using this software. Demonstration versions (limited by number of elements in the model) of this software are readily available for students. Although not difficult to learn, students interested in creating models must follow tutorials and work their way through some examples before being able to handle simple dynamics problems. The software can also be used for demonstrations purposes, i.e., showing a mechanism's cycle and its time-dependent variables during a lecture.

The distinct feature suggested in this text is the introduction of a high-end simulation package into the course. With the advent of the PACE (Partners for the Advancement of CAD/CAM/CAE Education) program [2] several high-end software packages were made available to universities. Software companies grant licenses to universities that are part of the program usually at low or no cost. As a consequence, Kettering University can provide students with software that is currently used in industry for CAD, FEM and simulation. Some examples are: EDS – I-DEAS®, EDS – UNIGRAPHICS®, MSC – NASTRAN® and MSC – ADAMS®.

The high-end package chosen for this course is MSC – ADAMS®. This is a worldwide used package for mechanical simulation. Its availability at Kettering University allows students the opportunity of learning software that can be used in their senior-level courses and in their professional careers as well (in contrast to software designed to be used as a teaching aid). By introducing basic software use into MECH–310, students will learn how to handle simple mechanical models in ADAMS® and will also be able to simulate and visualize their textbook's examples and exercises.

An approach to answer the question of how to teach the software package in a full course schedule is discussed in the following.

Web approach

In order to introduce any software package into a course it is necessary to provide means for the students to learn the package. The following approach is suggested here. During the third week into the course, the author gives a one-hour lecture that teaches students the basics of the software environment. This includes launching the package and working basic software functions. MSC – ADAMS® runs in both Windows and UNIX platforms but currently at Kettering University only UNIX versions are available. (For all practical purposes no differences can be noticed between versions other than platform issues; for instance in a UNIX machine a command is typed in a window to launch the software, while in a PC one can click an icon to accomplish the same.) The author covers these basic issues with the students in a computer laboratory to warrant that at the end of the lecture all students are able to run the software. This is the only time spent teaching the software during actual contact hours. (Office hours can be used for software questions.)

After this first introduction to the package students are given a list of ADAMS® assignments for the entire course. Currently there are four assignments, which cover kinematics and dynamics of particles and rigid bodies. For example, the second assignment, which can be completed after the third week into the course, concerns the motion of a projectile. The exercise asks for the range attained by the projectile when it is launched at a certain angle with a specific initial speed. Here students can solve the problem by hand and compare their solution to the one obtained by using ADAMS®. The software allows students to visualize the motion of the projectile and to observe, for instance, the variation of its velocity and acceleration.

In order to help students with the assignments, tutorials for the problems are included in the author's web site [3]. In an agreement with MSC – Software, the author utilizes some of their teaching material for their basic ADAMS® course. The tutorials include step-by-step instructions on how to build the mechanical models needed to complete the assignments but grow in complexity as lessons advance. (So it is usually necessary to complete the assignments in a specific order.) Some condensed instructions on the software environment, which are discussed in details during the one-hour lecture, can also be found in the site. Also, questions can be sent to the author through the site and a link to the ADAMS® Web site [4] (which includes lots of resources to help solving software questions) is given. The purpose here is to allow students the ability to complete the ADAMS® assignments relying heavily on the Web. Generally, complete assignments require students to present a report including hand calculations, an ADAMS® computer file (with the model) and ADAMS® results (for example: plots for the variables of the problem).

Another important point in this process is that the ADAMS® assignments are given for extra grade in the class. Students can improve their final course grade by completing these assignments. Since learning the software is not a requirement of the course, the author finds that the extra credit idea gives students an incentive to try and learn the program. This is confirmed by student feedback (see below) and can be seen in Figure 1, which shows that almost 100% of the students that took the course since the software introduction completed all ADAMS® assignments.

Student feedback

In order to evaluate the student response to this approach to introducing simulation software into their first dynamics course, they were asked a couple of questions by the end of the term. Below some of their comments are reproduced and a plot with their response to the introduction is given in Figure 1. These data were collected during the last two terms the course was taught (about 100 students). Here comments were edited for clarity and grammar only.

a. Please comment on the use of the WEB tutorials for completing the ADAMS® assignments.[1]

"The tutorials were very helpful. There were a few omitted steps that I wish would have been mentioned."

"Fairly easy. Sometimes they were a little difficult because some of the commands were omitted."

"It was easy to complete the assignments using the tutorials, except for the last one (number 4)"

b. Do you think the ADAMS® assignments helped you understand dynamics better?

[1] Tutorials become more complex as the student progresses to more advanced topics. Steps explained in previous assignments, when needed to complete a more advanced one, are usually not given in details.

"It helped visualize the problems."

"Yes, it made things a little clearer;"

"Yes, it also shows how some of these problems are solved in industry."

"I do not think they did, but I appreciated being able to solve problems using the software."

"It did not really help me understand dynamics better, but I understood how to solve problems using the software."

"The assignments were more beneficial in demonstrating how through a piece of software we can model and simulate dynamics problems."

c. Do you have any suggestions that could improve the use of ADAMS® in the course?

"I would like to see more integration between the lectures and ADAMS®."

"More integration between homeworks and ADAMS®."

"One idea might be giving an ADAMS® assignment based on a homework problem."

"I would like to see more integration between the course and ADAMS® since this is the software I use over my work term."

d. Please comment on the idea of using ADAMS® assignments for extra credit.

"I liked the idea. I would not have used the program otherwise, but now I am glad I did."

"The extra credit was a great idea. It benefits the students through extra learning (software) and through a grade boost."

"I liked it. It was an incentive to use some of the material learned during the lectures and to use the software to visualize motion in the computer."

"I liked the software. The ability to get extra credit while learning it was a bonus."

"It was a good incentive to learn engineering software that is used in the real world."

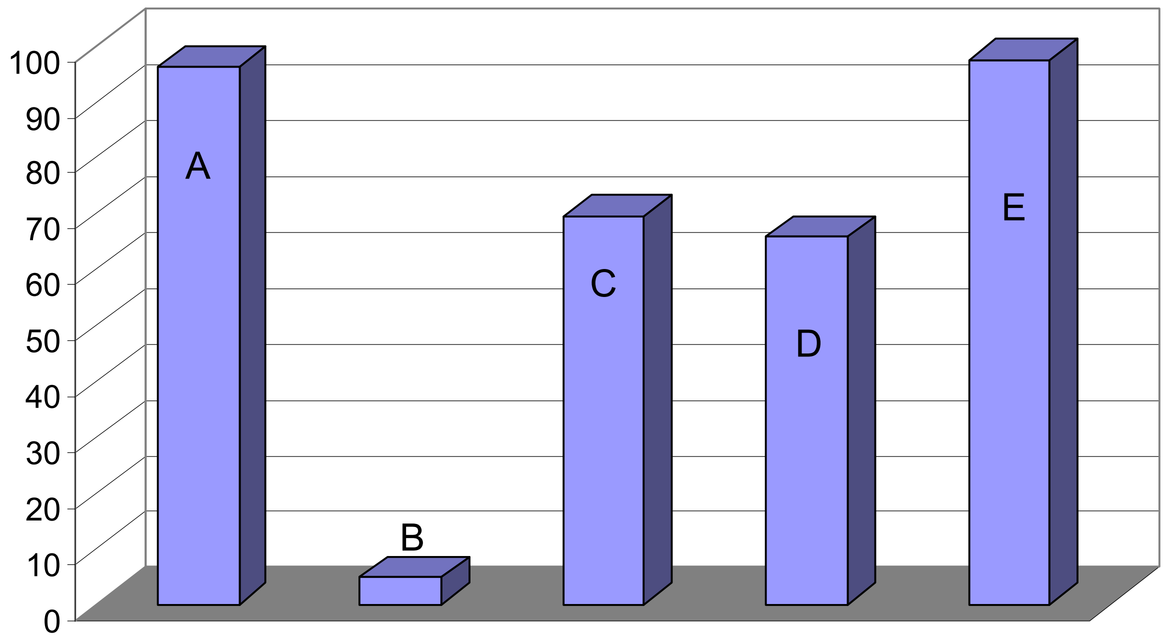

Figure 1 – Student response to ADAMS® use in MECH – 310: (A) percentage of students that completed all assignments, (B) percentage of students that found WEB tutorials difficult to use, (C) percentage of students that found ADAMS® helpful in understanding dynamics, (D) percentage of students that would like more integration between software and lectures, (E) percentage of students that approved having ADAMS® assignments given as extra credit.

Conclusions

In this paper, an approach to integrate a high-end simulation software package into a basic dynamics course is discussed. The course is MECH – 310: Mechanics III, offered at Kettering University, Flint, MI. It is suggested that a high-end simulation package be used in the integration in order to benefit students with their senior-design courses and professional careers. Based on student feedback, it was found that initial software integration has been achieved. Students learn basic software functions and can run simple mechanical models. The use of a web site with tutorials for the assignments was successfully employed to coach students on their assignments. Also, by utilizing an extra-credit approach for the assignments, students are motivated to start learning the software and to complete all assignments.

Future work

The preceding text discussed an approach to integrate simulation software into an undergraduate dynamics course. By conducting an opinion poll, it was seen that initial integration was achieved and was well received by the students. In the present form the data collected does not allow for accessing the benefits of such introduction. For future work, it is planned to access these benefits by comparing student performance. Students that were exposed to the software will be asked to solve the same problems that were used in the course before the introduction of the software. Then their grades will be compared to previous grades and conclusions will be drawn. It is expected that a better overview of dynamic system behavior will be achieved by students that worked in the simulation environment. (As it would be expected if they had conducted an actual experiment in the laboratory.) The use of high-end simulation software (MSC – ADAMS®) will continue to be emphasized, since the environment provides for high-level simulations, design feedback, and is currently one of the industry standards for simulation tasks.

References

[1] R. C. Hibbeler, *Engineering Mechanics: Dynamics,* 9th ed.: Prentice Hall, 2001
[2] http://www.pacepartners.org
[3] http://www.kettering.edu/~amazzei
[4] http://university.adams.com

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Appendix A

MECH-310: Mechanics III

2002 catalog data: Credit: 4
Pre-requisites: Statics

This course deals with a discussion and application of the following fundamental concepts: (1) application and basis of Newtonian mechanics and physical laws; (2) a study of the kinematics and kinetics of a particle including relative and absolute motion, friction concepts; (3) additional analysis of particle dynamics using work-energy and impulse-momentum methods, analysis of impact events; (4) analysis of a system of particle using work-energy, impulse, linear and angular momentum; (5) kinematics and kinetics of rigid bodies analyzed in various reference systems; (6) additional analysis of rigid body dynamics using work-energy and impulse-momentum; (7) inertia quantities. Computational techniques will be incorporated into several design projects throughout the semester to illustrate alternative solution methods.

Textbook(s): Engineering Mechanics: Dynamics by R.C. Hibbeler, 9th ed, Prentice Hall

References: Engineering Mechanics: Dynamics by Beer and Johnston, 6th ed, McGraw Hill

Course learning objectives and outcomes:

Objective 1: Model a real physical system for dynamic analysis [ME PEOs 1,3,4]

1.1 Given the drawing or sketch of a physical system (particle or rigid body), students will be able to draw free body diagrams which include corresponding representations of the forces and accelerations to which the body is subjected.
1.2 The students will be able to present the modeled system in a variety of coordinate systems including: cartesian, radial-transverse, and normal-tangential.
1.3 The students will be able to distinguish between rigid and deformable analysis techniques.

Objective 2: Analyze a modeled system to predict the forces and motion of a body or bodies (rigid body or particle) using Newton's laws [ME PEOs 1,2,3,4]

2.1 The students will be able to predict the ensuing motion of a body given an acceleration boundary condition and will be able to predict ensuing motion given a force boundary condition.
2.2 The students will be able to apply the concept of friction to predict the ensuing motion of a body.
2.3 The students will be able to understand the difference between internal and external forces when analyzing contact and non-contact phenomenon including impact loading.
2.4 The students will be able to analyze the system in a variety of coordinate systems with fixed and non-fixed reference systems.
2.5 The students will be able to determine the center of mass, moment of inertia, and radius of gyration for a given body.

Objective 3: Analyze a modeled system to predict the forces and motion of a body or bodies (rigid body or particle) using work-energy and impulse-momentum methods [ME PEOs 1,2,3,4]

3.1 The students will be able to predict the motion or forces of a body using work-energy principles for conservative and non-conservative force systems.
3.2 The students will be able to predict the motion or forces of a body using impulse-momentum principles for conservative and non-conservative force systems.
3.3 The students will be able to understand the difference between internal and external forces when analyzing contact and non-contact phenomenon including impact loading.
3.4 The students will be able to analyze the system in a variety of coordinate systems with fixed and non-fixed reference systems.

Objective 4: Analyze a system to determine forces and motions using computational techniques [ME PEOs 1,2,3,4]

4.1 The students will be able to predict the motion or forces on a body using commercially available software (i.e. ADAMS).

Prerequisites by topic:

1. Partial and ordinary derivatives, vector algebra
2. Basic trigonometry, sine and cosine rules
3. Newton's Laws of motion
4. Basics of free body diagrams
5. Basic Computer Skills

Topic covered:

Week	Topic
1	Introduction Review of Vector Mechanics, Free Body Diagrams, and Trigonometry, Definitions of Particle/Rigid Body Mechanics, Newton's Laws
2	Kinematics of a particle, relative motion, rectangular coordinates
3	Kinematics of a particle in normal-tangential and radial-transverse coordinates
4	Kinetics of a particle using Newton's Laws
5	Kinetics of a particle using work-energy and impulse methods, Impact
6	Particle dynamics applications
7	Kinematics of a rigid body, relative motion
8	Kinematics of a rigid body, different reference systems
9	Kinetics of a rigid body using Newton's Laws
10	Kinetics of a rigid body using work-energy and impulse methods, Impact
11	Planar rigid body dynamics applications

Schedule: Two *sessions per week of 120 minutes*

Computer usage: Basic Computer Skills (ex: MathCAD, Excel), Simulation Package: ADAMS

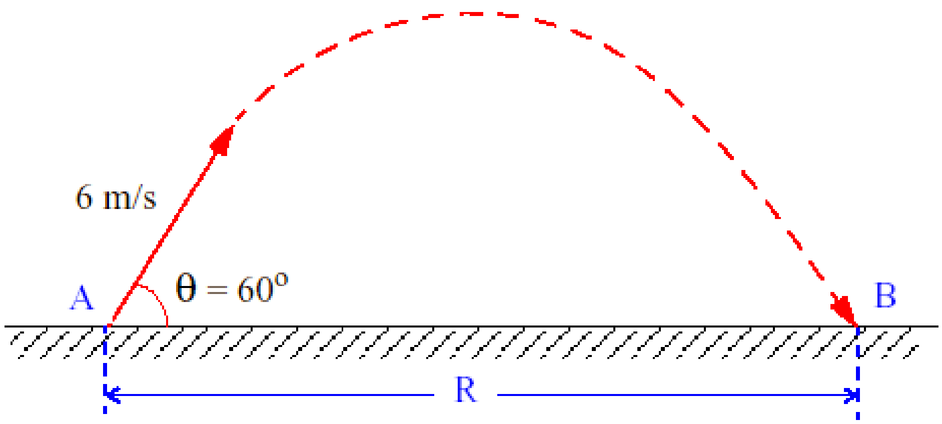
Laboratory projects: Several open-ended projects are planned that involve parametric studies performed using computational tools.

Relationship to professional component:
This course is 100 % Engineering Science.

Appendix B – Sample ADAMS assignment

Problem statement

Compute the range, R, when a stone is launched as a projectile with an initial speed of 6 m/s at an angle of 60^o, as shown next.



ADAMS results

R = 3180 mm (Can vary slightly depending on several factors, most likely the sampling rate.)

Closed-form solution

Analytical solution:

The analytical solution for R, the range covered by the projectile, is as follows:

$$x_o = 0 \quad x_f = R$$
$$y_o = 0 \quad y_f = 0$$

$$V_{x_o} = 6000 \times \cos 60^\circ = 3000 \text{ mm/sec}$$

$$V_{y_o} = 6000 \times \sin 60^\circ = 5196 \text{ mm/sec}$$

$$y_f = y_o + V_{y_o} t - \frac{1}{2} g t^2$$

$$0 = 0 + 5196t - 0.5 \times 9806 \times t^2$$

$$0 = (5196 - 4905t)t$$

$$t = 1.06 \text{ sec}$$

$$x_f = x_o + V_{x_o} t$$

$$R = 0 + 3000 \times 1.06$$

$$R = 3180 \text{ mm}$$

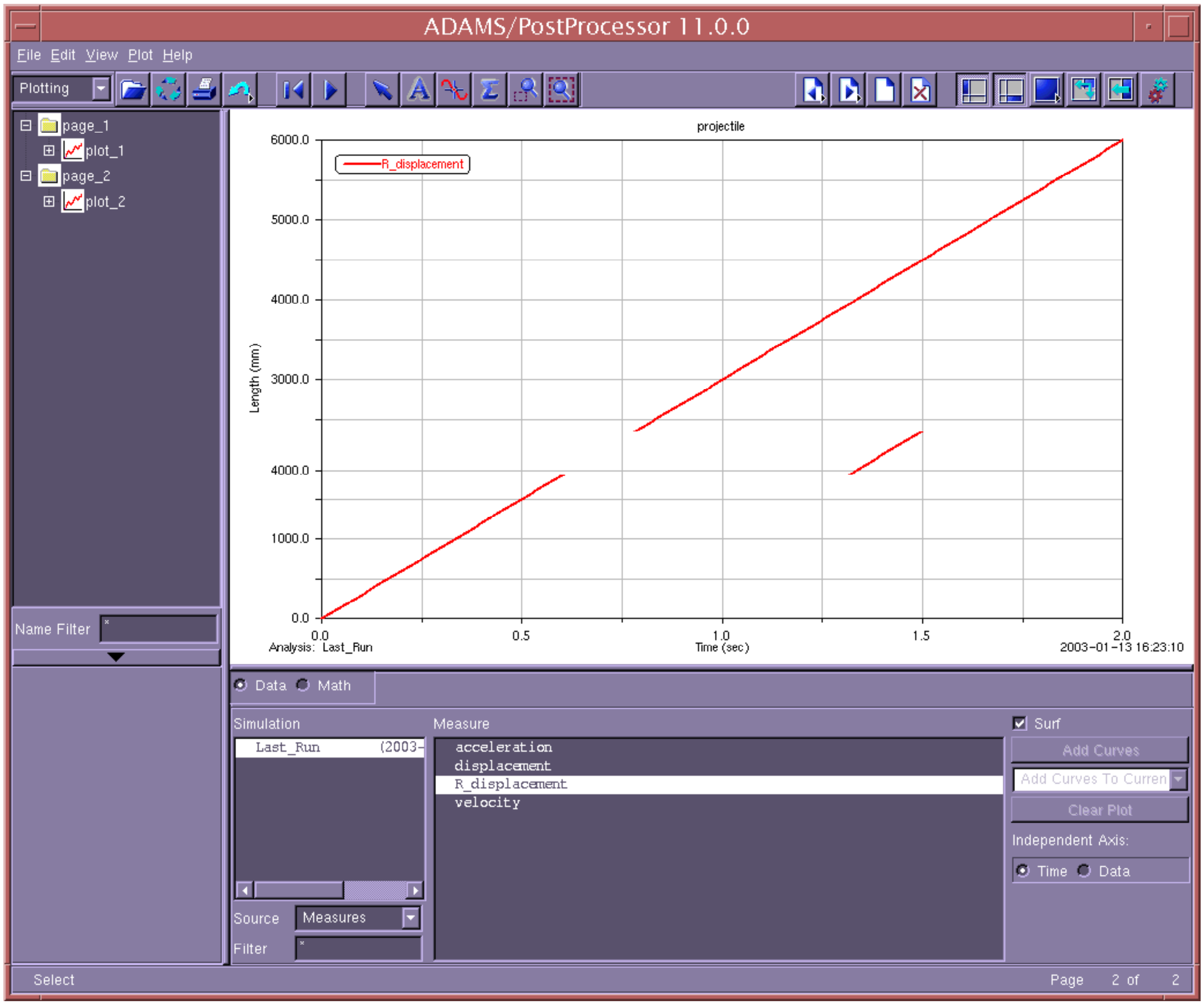


Figure 2 – Projectile range (ADAMS assignment)

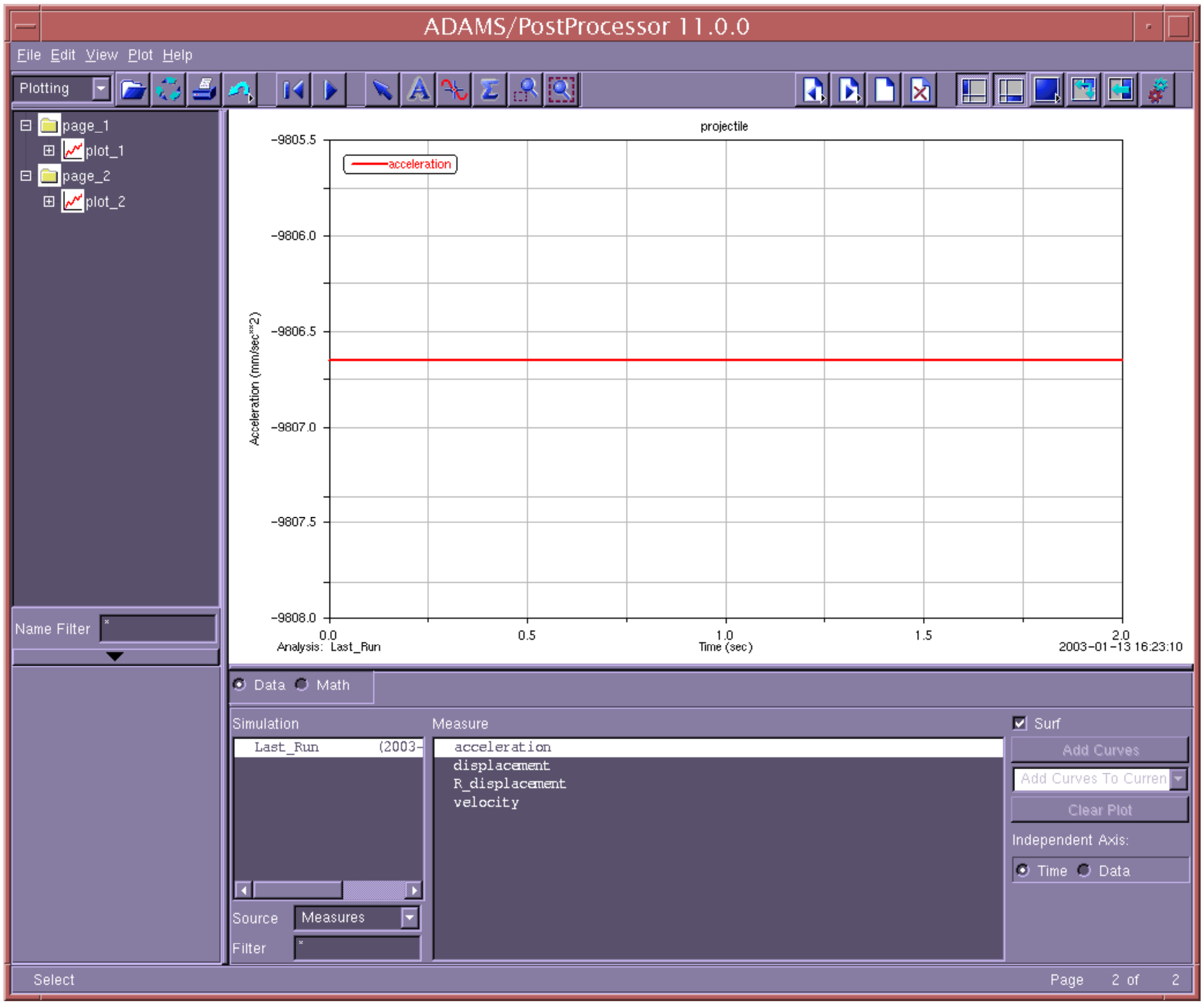


Figure 3 – Projectile acceleration (ADAMS assignment)

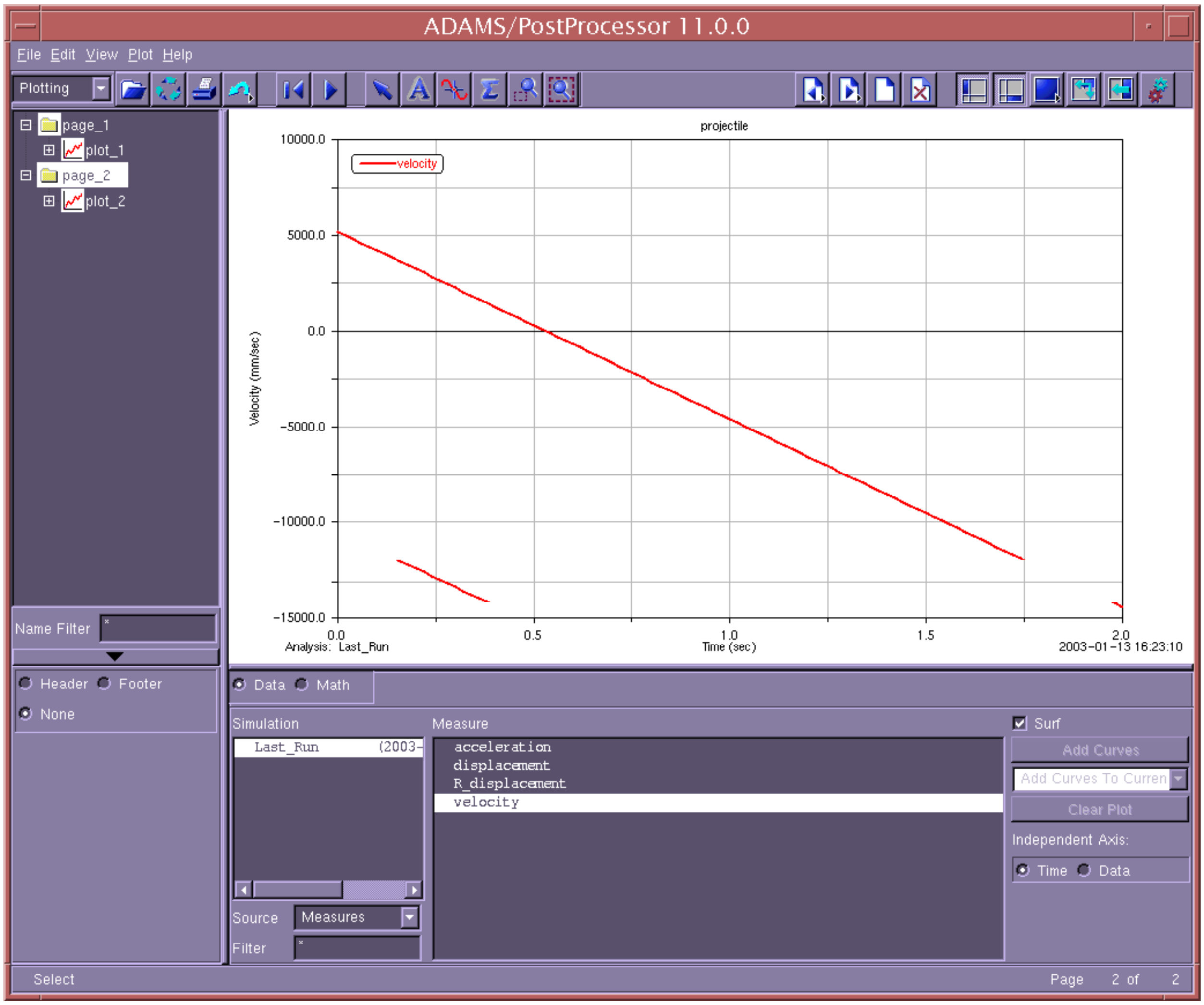


Figure 4 – Projectile velocity (ADAMS assignment)

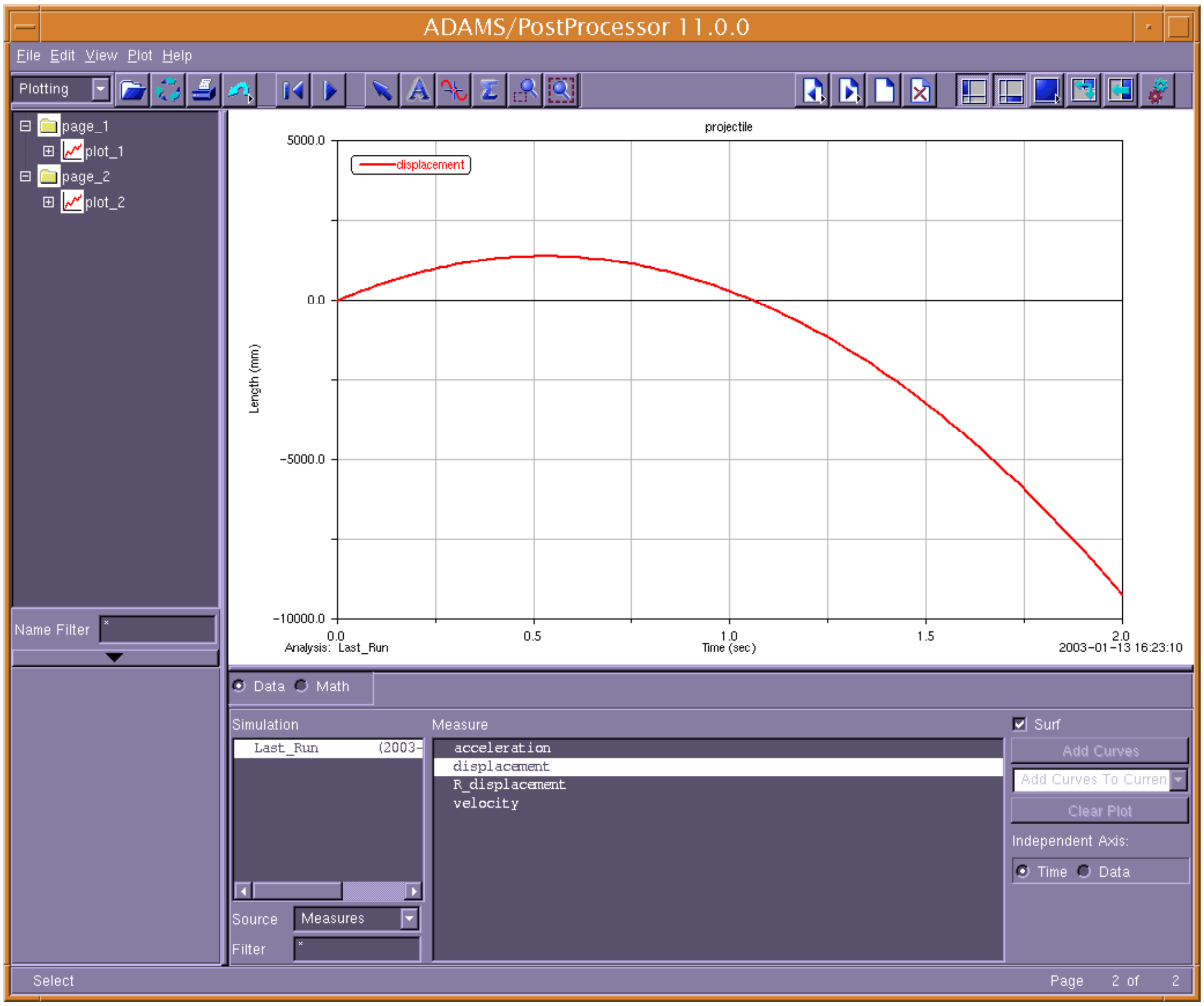


Figure 5 – Projectile displacement (ADAMS assignment)