Session: 3268

Simulating Complex Systems in Introductory Dynamics

Kurt M. DeGoede
Elizabethtown College, Elizabethtown, PA

Introduction

In my past offerings of courses in dynamics, I felt that the problems I assigned were all of a rather idealized nature. We seemed to make numerous assumptions in all the problems and only analyzed one or two moving parts and usually only analyzed the problem at one particular instant in time. The students have certainly found these assignments challenging, but I couldn't help but feel many students left the course wondering how practicing engineers analyzed "real" dynamic systems. It seems my sense was not unique, as recently as 6 years ago an in-depth study of 12 engineering programs found "computers are usually not used effectively in undergraduate engineering science courses. Often, they are not used at all" [1].

In order to open up an introductory dynamics course to less idealized analysis than is typical in the text books, I have included several problems requiring numerical differentiation and other numerical analysis assignments culminating in a multi-body simulation project. These activities were designed with several goals:

- Introduce students to the types of tools used in practice.
- Allow students to work on more realistic problems of particular interest to them.
- Require the students to make their own appropriate and justified simplifying assumptions.
- Require the students to think more broadly about application of the course material.
- Help the students develop mechanical intuition and visualization as with other canned simulations [2].

The simulation project accounted for 10% of the final grade in the course. These projects were done by the students in parallel with the more typical assignments, in what the students consider a very demanding course. Several aspects of these assignments worked very well and other aspects were unsuccessful.

The students were encouraged to use numerical differentiation frequently throughout the course. The text used for the course was Thornton and Marion Classical Dynamics: of particles and systems, 5th Edition. Brooks/Cole - Thompson, 2004. This text included several problems well suited to numerical integration of the differential equations of motion. This type of analysis was done using MATLAB® © 2003, MathWorks Natick, Massachusetts. In particular, the students analyzed several problems using the function ode45.

The simulation projects were done using Dynamic Designer, © 2003 MCS.Software Santa Anna California, embedded in Solid Edge, © 2003 EDS Plano Texas. This combination provided a nice platform for these simulations since most of the students had learned Solid Edge in their introduction to engineering sequence and were therefore quite comfortable working with this package.

In sections that follow, I will provide the simulation assignment distributed to the students and examples of student projects. The final section of the paper will summarize what worked and what did not work with these projects, including student reactions and my own reflections.

Assignment

Teams of two were assigned based upon having at least 1 member who had experience with Solid Edge. The students were given the following project assignment:

> Select a dynamic system to model and study. You should propose open questions to answer or hypotheses to investigate. If you need help thinking of ideas please meet with me as a team. I hesitate to put a sample idea here as it tends to stifle creativity.
>
> For the first phase of the project you will construct a single-mass model of your system. You should have only one moving part. If your system does not lend itself to this type of model I will help you select an alternate system for this phase of the project. The purpose of this part of the project is to get you familiar with using Dynamic Designer (embedded in Solid Edge). You move into dynamic designer from within assembly by selecting Environment – Motion. You can then add forces, torques, springs, constraints, and much more to your model along with measures of force, position, velocity, acceleration, etc. Start early, because you will need help learning how to use this software! You are going to learn by building models and asking questions when you can't figure out how to do what you want – this is the best way to learn these types of applications.
>
> The second phase is then to build a more complicated model which will have appropriate rotational inertia properties and multiple rigid bodies.

The project duration was ten weeks:
- Two weeks – Project proposal due
- Two weeks – Phase 1 status report due (1 page maximum)
- One week – Phase 1 report due (3 pages maximum)
- 2.5 weeks – Phase 2 status report due (1 page maximum)
- 2.5 weeks – Phase 2 report due (5 pages maximum)

The following guidelines were provided for the reports:
A. Introduction: What hypotheses are you testing? What questions are you going to answer? Why?

B. Methods: Fully describe your model. What assumptions have you made? Based upon what? Include illustrations and all model parameters.
C. Results: What were the results of your simulations? Summarize with graphs and tables of data. Keep it concise and to the point. It is not impressive to try to snow the reader under with a lot of irrelevant data.
D. Discussion: Interpret your results. Discuss the limitations of your model. How could you improve upon what you have done? What are the strengths of this model? Are there other applications of the results?

Example Projects

There were 8 students in this offering of the course for a total of 4 projects. The following descriptions are included in order to provide a sense of the types of projects the students selected and some insight into the capability of the software. None of the student groups successfully tested their original hypotheses. This significant shortcoming is addressed in the discussion.

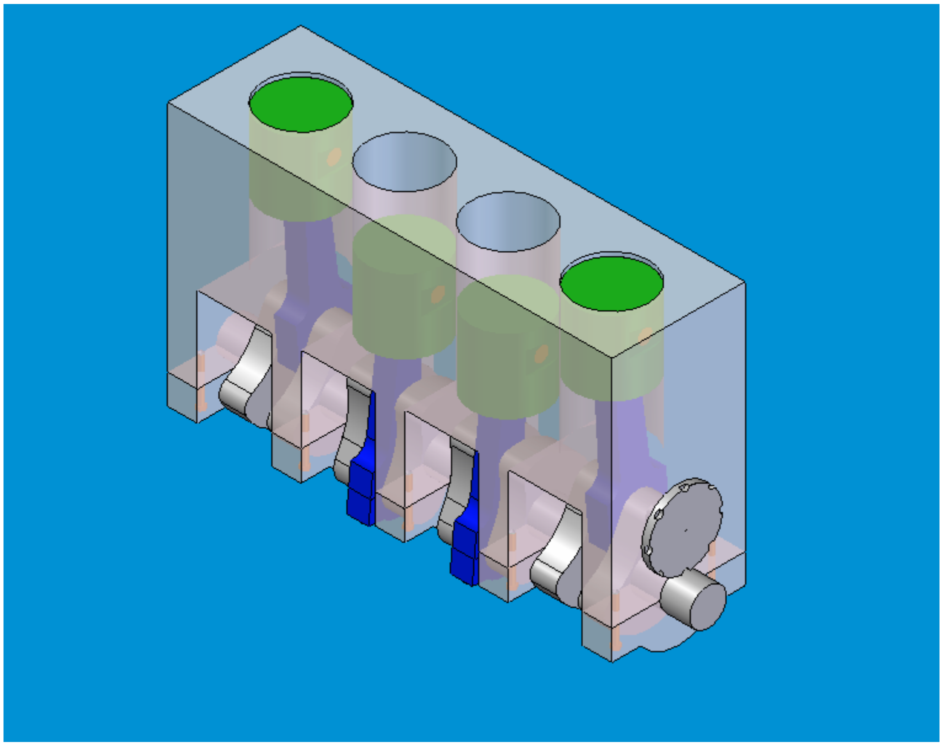

Figure 1: 4-cylinder automotive engine model.

One group developed a model of a four-cylinder automotive engine to investigate the effect of combustion timing on operation (Figure 1). The model was nicely developed; although the students did not have time to analyze the effects of poor timing. The students struggled to get the engine to turn through a full cycle (Figure 2). This difficulty itself however did shed light on the importance of the spark timing even without a detailed analysis. A separate group attempted to model a rotary engine with limited success.

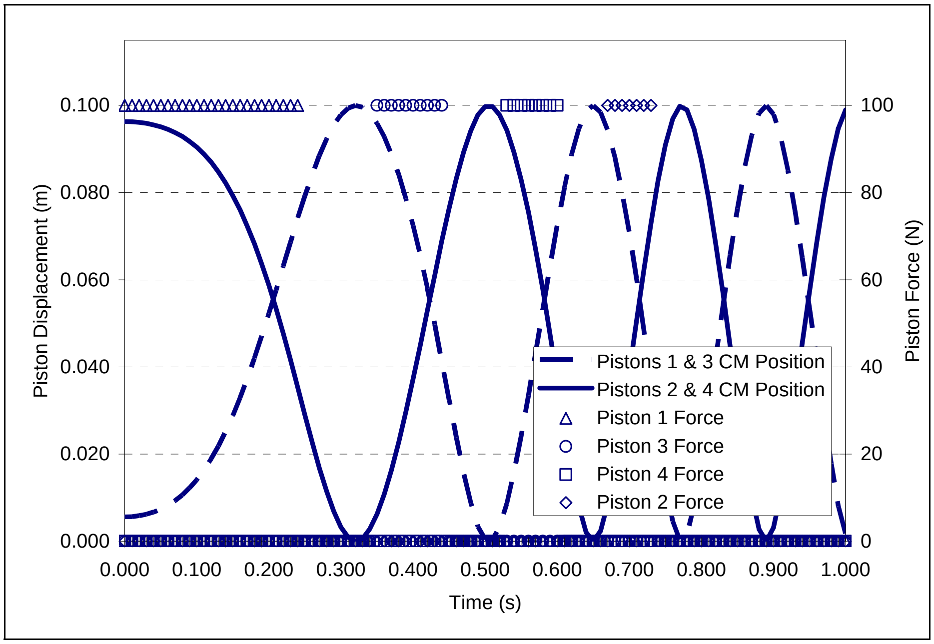

Figure 2: 4-cylinder automotive engine simulation data.

The third group designed and modeled a simple suspended roller coaster using the model to test for desired motions and safe velocity and acceleration limits. This project was moderately successful and exciting for the students. Rather than testing a hypothesis the students sought to use the model to design a track profile that would produce a desired dynamic response. They were able to keep accelerations at a safe level and produce the 360 degree rotation they were looking for in the first corner, but did not have time to go beyond this point.

The final project team modeled the striker action of a piano (Figure 2). They were interested in the peak force of the hammer striking the string as a function of the applied key force. The students were able to complete a first pass analysis of this force ratio (2.8) and learned a powerful lesson about modeling an impact, but did not quantify the effects of various design parameters.

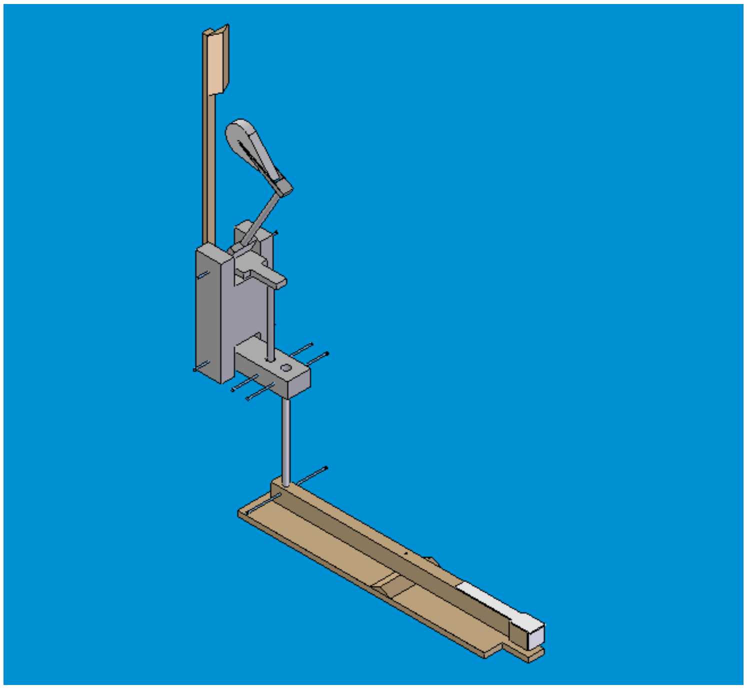

Figure 2: Piano striker mechanism.

Discussion and Conclusions

Overall I was pleased with the introduction of these projects into the introductory dynamics course. The students were able to quickly build nice models using the familiar solid modeling platform. The models constructed demonstrated great potential for further analysis. The students did indeed gain valuable experience with this type of tool, particularly in developing appropriate models.

The inclusion of the Solid Edge/Dynamics Designer project helped me better understand how the course material can be applied to problems outside the classroom.

Answers	Percent Answered
Definitely False	0%
More False than True	14%
In Between	42%
More True than False	29%
Definitely True	14%
Unanswered	0.0%

Table 1: Question and student response to the inclusion of the Simulation project in the course.

However, I expected too much from the students in these projects, since I did not reduce the scope of the course in many other ways. Negative student feedback focused on the additional workload these projects introduced to the course. One student commented "The project, wow. Useful and educational...yes. A lot of work, also yes." Many of the students found the project far more time consuming than they anticipated. The students offered limited endorsement of the projects (seven of eight students completed course evaluations): one student did not see the value of the project for learning how to apply the course material, three were in-between and three felt it did improve their ability to apply the material (Table 1). However, anecdotal evidence suggests that the students did appreciate the power of these tools. One student, who was critical of the assignment during the course, has now, a year later, has elected to pursue a senior project involving modeling a dynamic system with this software.

All of the projects fell short of my expectations in terms of detailed design analysis. The students felt a great sense of accomplishment in simply completing working models. The models were nicely done for the most part, but a systematic analysis using these models would have made the exercise more meaningful. I can't help but think many of the students never saw the full point of their modeling (despite the limited anecdotal evidence described above). They started some excellent open questions in their proposals, but none of the groups actually explored these questions appropriately. For example, the 4-cylinder engine project could have established power produced as an output for a given driveshaft load and engine speed and studied the effects of spark timing, force profile assumptions, design parameters. I believe this shortcoming was primarily due to an underestimation (by both the students and myself) of the time required for these projects for students who are still novices with the tools.

Despite the difficulties with this first use of these projects I will definite use the projects again. However, I would make one major change in the structure of this project, and would recommend this to those thinking of incorporating this type of project into their class. I will assign the project the first week of class. Much of the work can be done in parallel with learning the underlying theory, which is an advantage for these projects [3] that I did not capitalize on. It was not necessary to wait until the midpoint of the semester to start these projects. The initial modeling did not require any knowledge of dynamics beyond that that of the prerequisite physics course. This change will improve the projects in three ways.

- The most labor intensive (and lease rewarding) parts of the project will be undertaken earlier in the semester when other academic loads are a little lighter.
- It will allow the instructor to create more ties between the theory in the other portions of the course and the projects. In hindsight, it would have been easy (and extremely valuable for avoiding the "black box" effect) to use the projects as the basis for more traditional textbook type dynamics problems linking the projects to the underlying theory and providing valuable "reality checks" for the simulation results by looking at solutions for particular components or at specific points in time [4]. I should have designed textbook type problems from the projects they were working on.
- It will allow the students to extend the projects to include more design analysis. Giving the students more time to use the models for examining design decisions with a systematic parameter study and hypothesis testing would take these assignments to the

next level, and I believe the projects would in turn be more satisfying to both the instructor and the students. While the students did some good work in setting up the models in this assignment they did not have the opportunity to investigate the dynamics of their systems, and in terms of enhancing their understanding of dynamics that is where this type of project can make the greatest impact. Based on this, one might consider having the students perform analysis on pre-constructed models. However, starting the project in the first week of the course would allow 4 weeks for this type of analysis without any other changes to the assignment timing. I feel the process of going from a physical device or concept to a working model with appropriate and justified assumptions and approximations is still a valuable part of the project, and I do not cover as well with any other course assignment.

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Author Biography:

KURT DEGOEDE earned his Ph.D. in Mechanical Engineering from the University of Michigan and is currently an assistant professor and department chair of physics and engineering at Elizabethtown College. Previously, he spent 3 years as a project manager at Ford Motor Company. He teaches courses in mechanics, general physics and conceptual physics. His current research interest is in the biomechanics of injury.