ON THE USE OF A WINDSHIELD WIPER MECHANISM SIMULATION PROJECT TO ENHANCE STUDENT UNDERSTANDING OF DESIGN TOPICS

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Abstract

This paper presents the development of a simulation project that can be used to enhance undergraduate teaching and student understanding of mechanical engineering design subjects.

The software package utilized is SIEMENS PLM SOFTWARE® - NX and it has been introduced to our students during their freshman year (Engineering Graphics) followed by a junior level course (CAE), in which the advanced features such as parametric design and simulation capabilities are used.

The authors aim to utilize a CAE package which is able to integrate 'Component Modeling', 'Assembly', 'Motion Simulation', and 'FEA' modules seamlessly into introductory mechanical engineering courses, such as Mechanics of Solids and Dynamics in which kinematics and dynamics of rigid bodies are discussed. The goal is to use the simulation capabilities of the software to enhance the teaching environment and student learning outcomes of these courses. For instance, this example project shows how students benefit from the simulation by understanding the kinematic and dynamic behavior of the mechanism, and also verifying the stress analysis of critical members via simple hand calculations.

A preliminary assessment to the approach was conducted via a web-based survey. The survey contained several questions aiming to gauge students' overall opinion of the use of the software packages in the courses. The overall results are very positive and warrant further exploration and use of the approach.

Introduction

Nowadays most manufacturing companies rely on computer aided engineering (CAE) software for the design of their products. In a previous work [1] one of the authors discussed the advantages of using high-end CAE software in mechanical engineering design courses. In that reference an outline for the introduction of UGS – UNIGRAPHICS® into a mechanical engineering undergraduate curriculum was discussed. Students can achieve a good level of proficiency with a type of software package that they will likely use when working in an industrial environment.

CAE tools also provide an excellent teaching aid, which can be used to illustrate theory and concepts by means of computer simulations. This issue has also been discussed in previous works [2,3], where simulation tools are shown to allow for an improved understanding of concepts presented in design courses.

In this work a simulation project is discussed, which can improve student understanding of undergraduate solid mechanics, kinematics/ dynamics and mechanism design.

Wiper Mechanism Design and Analysis

The approach is intended to be used in a CAE junior level course where students have a background in basic solid mechanics, kinematics and dynamics. Given the specifications of the wiper mechanism components (called "parts" in the software) and the assembly requirements, students are required to create a “motion simulation” (a working mechanism) for the assembly. From this simulation several useful results can be gathered.

All parts are to be designed via the software and the assembly is built by constraining the components at their specific locations and with respective degrees of freedom. This is accomplished via “assembly constraints” (a feature of the software). After verifying that the assembly works as desired, the next step is to create the mechanism.

Automotive windshield wiper systems, in conjunction with washer systems, are used in vehicles to remove contaminants such as rain, sleet, snow, and dirt from the windshield. As shown in Figure 1, a typical wiper system consists of an electric motor, a linkage to transform the rotational motion from the motor to oscillatory motion, and a pair of wiper arms and blades. The areas of the windshield that must be wiped by the wiper system are mandated by the federal motor vehicle safety standards FMVSS 104.

The design of a typical wiper system starts with the technical specifications of the OEM car maker. Given a particular application platform, the geometry of the windshield glass is known. Based on the requirement dictated by FMVSS 104, the lengths of the wiper blades and wiping angles can be determined. Then based on wiping speed and blade-glass frictional loads, the wiper arms and blades can be designed. The linkage mechanism can be designed based on the kinematics, structural strength, wiping angle, and system packaging requirements. The electric motor can be chosen according to the energy required by the wiper system.

Figure 2 illustrates the simplified wiper assembly (wiper blades not shown) for the kinematic analysis in this project (shown in the NX 7.0® [4] environment).

Previously, this step required knowledge of mechanism constraints (such as joints and their correct use) and it was somewhat counter-intuitive. For instance, in this example an intuitive approach would be to use revolute joints for all the links, but that would over-constrain the mechanism. With the current software package, students can obtain a mechanism from the assembly by importing it into the motion simulation application. For the majority of classroom examples this leads to correct conversions of assembly constraints into joints and parts into links in the mechanism (redundancies are automatically eliminated).

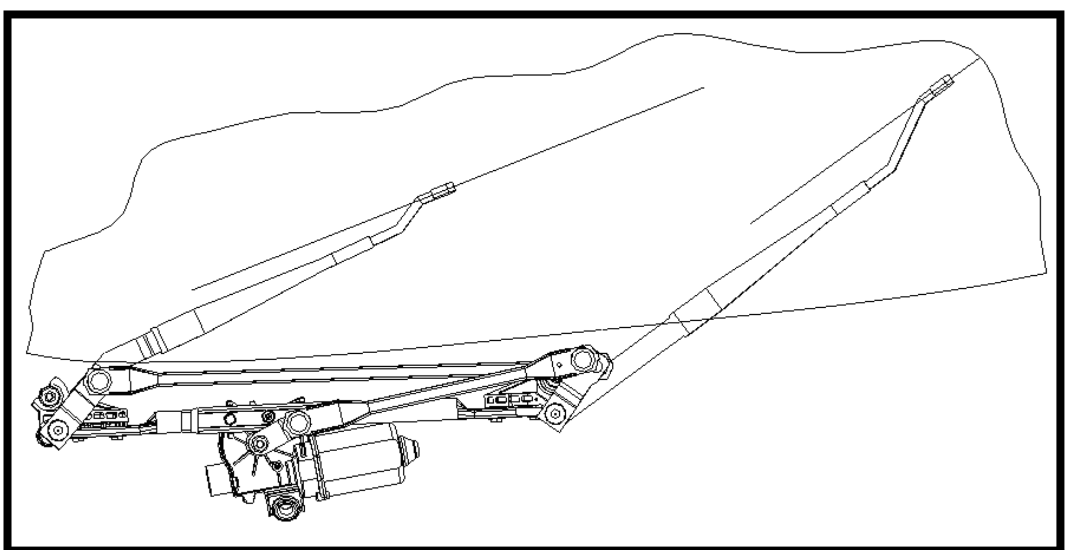


Figure 1 – Wiper Assembly.

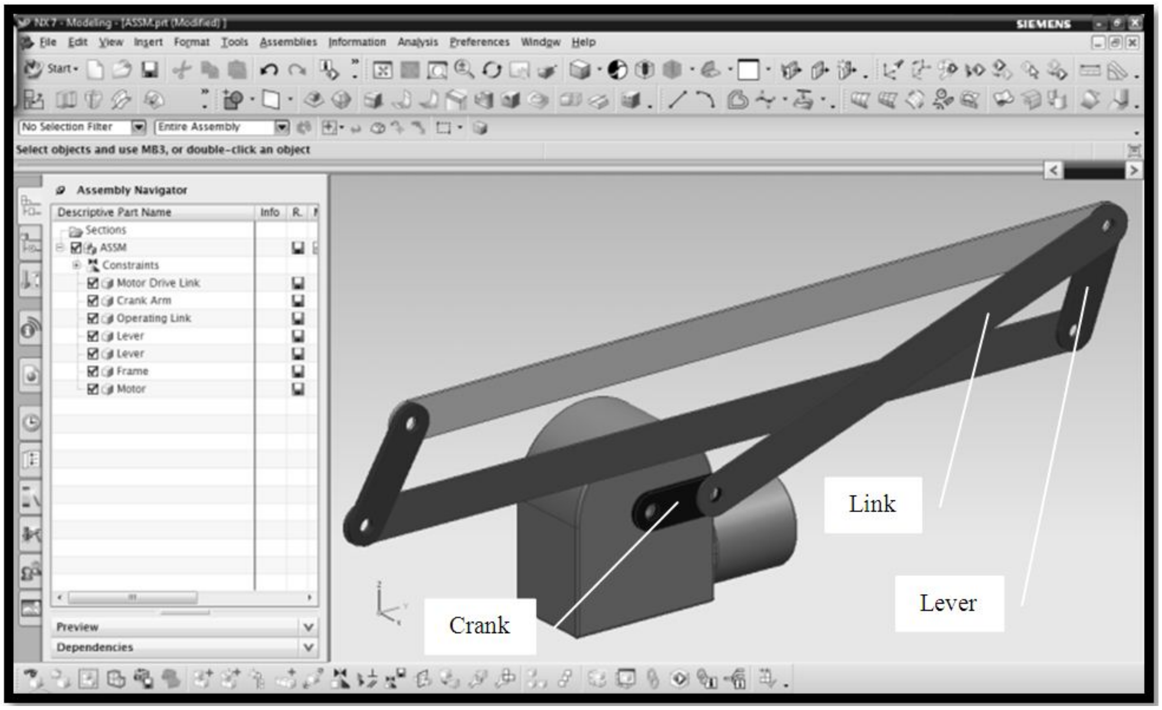


Figure 2 – Simplified Wiper Assembly.

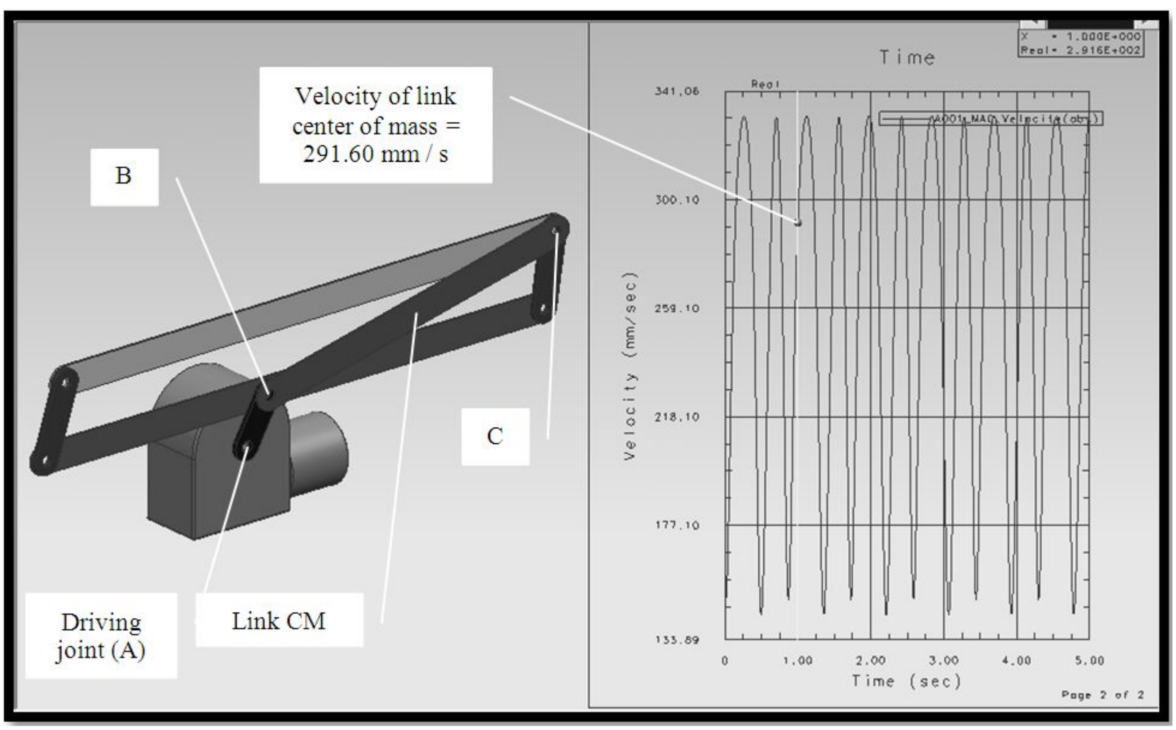


Figure 3 – Wiper Assembly and Driver Link Velocity.

After the wiper mechanism is designed and ready for simulations, the goal is to obtain some results which students can also generate via hand-calculations using their knowledge of related subjects. Visualization of the working system is also one of the goals. Kinematic and stress analyses are performed and presented in the following sections.

Kinematic Analysis

For this topic one can run a simulation with a driving joint in the mechanism and obtain results for the kinematics of any link. For instance, the question could be to determine the magnitude of the velocity of the center of mass (CM) of the drive link in the wiper assembly shown in Figure 3 (NX 7.0® environment; note that the figure also shows simulation results, which are discussed below.)

In the simulation the velocity can be determined by defining a "marker" at the CM of the link and plotting its velocity for a motion cycle. Here the specifications are that the driving joint imposes a constant angular velocity of 70 rpm (high crank speed) to the link driving the mechanism. Students would be asked to confirm the value of the velocity at, for example, 1s by using hand calculations. These can be obtained by calculating the velocity of the connections between the driving crank and the link (329.87 mm/s at 150.37 degrees) and between the link and the lever (262.83 mm/s at 171.06 degrees – perpendicular to the lever). Then the angular velocity of the link can be found (0.4161 clockwise) and the velocity of the CM can be calculated (magnitude: 291.53 mm/s).

For the kinematic example (Figure 3) students would have to follow the procedure [5]:

$$\vec{v}_B = \vec{v}_A + \vec{\omega}_1 \times \vec{r}_{AB} \tag{1}$$

Note that in equation (1) A is the connection between the crank and the housing and B is the joint between the crank and the link. This allows for the calculation of the joint velocity based on the angular velocity of the crank and the position vector from A to B ($\vec{v}_A = 0$). Next,

$$\vec{v}_B = \vec{v}_C + \vec{\omega}_2 \times \vec{r}_{CB} \tag{2}$$

Where C is the connection between the link and the lever, also note that the velocity of this joint is perpendicular to the lever. This allows for the calculation of both the velocity of C and the angular velocity of the link. Finally, the velocity of the link's center of mass can be obtained by

$$\vec{v}_{CM} = \vec{v}_B + \vec{\omega}_2 \times \vec{r}_{B\ CM} \tag{3}$$

It is seen in the example above that the calculations for the kinematics part of the question does not take long for the students to set up. A review of the subject by the instructor is, usually, not necessary (dynamics has been taken by the students or is taken during the same term as the simulation course). Questions are common but this does not detract from the main goal of the project.

The emphasis should be on relating the calculations to the values observed during the simulation and understanding what they represent.

Stress Analysis

The next topic can be accomplished by defining a load (or loads) applied to the mechanism, running a "load transfer" simulation and utilizing the results for a finite element analysis (FEA) of the component under study. Here, basic solid mechanics concepts can be reinforced and illustrated by the FEA simulation.

For example, one can prescribe loads acting on the levers that support the wipers, for instance 100 N, and calculate the reactions on the drive link via the simulation. Figure 4 illustrates the results for one component of the reaction force (horizontal) at one end of the link (134.2 N; at this instant the vertical component is approximately 44.1N).

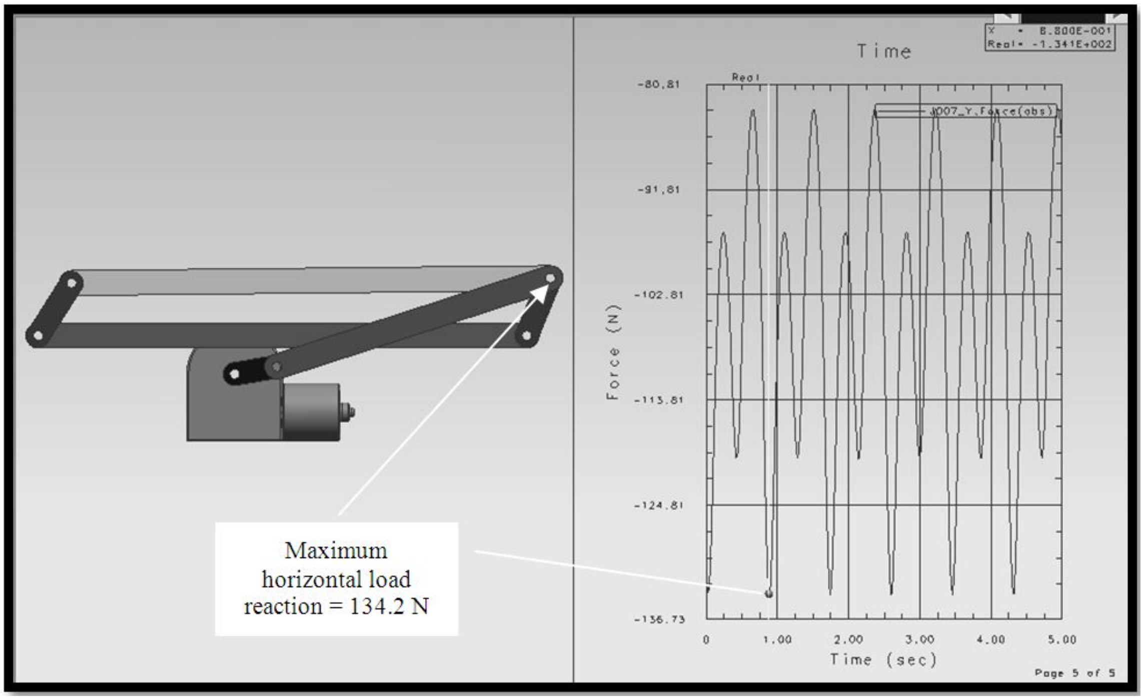


Figure 4 – Reaction Force Component on Drive Link.

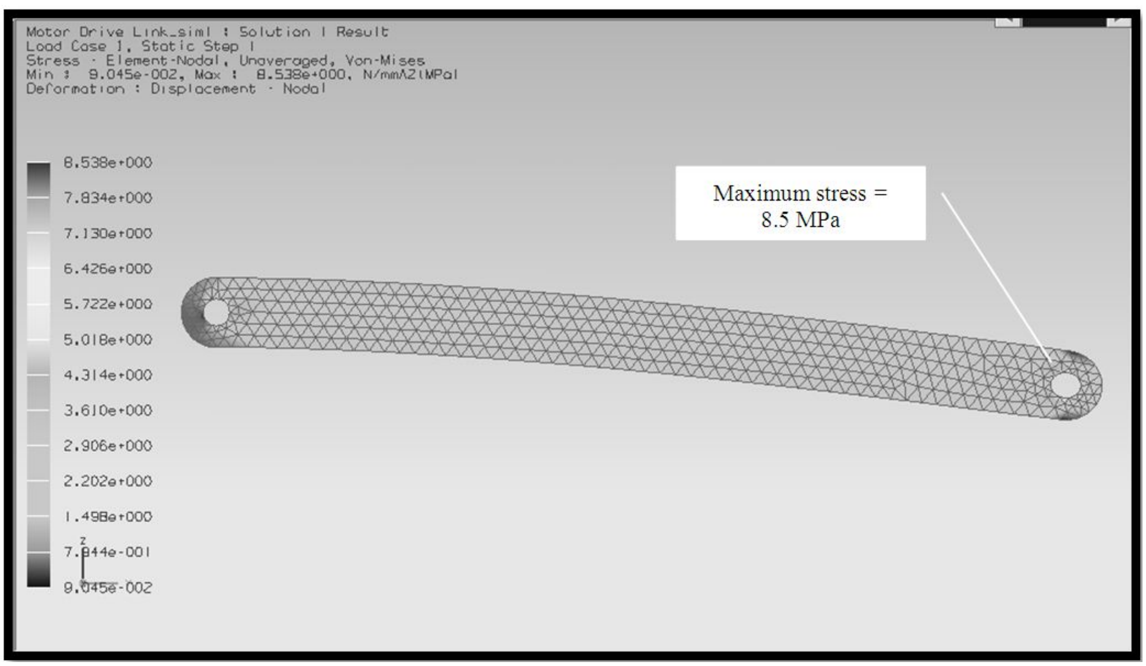


Figure 5 – Stress Results for the Driver Link.

By isolating the drive link and applying the obtained reactions, a FEA can be performed by the software in order to evaluate the stresses in the component. Again, since the loading case (static) is simple, this can be calculated by the students using basic solid mechanics approaches.

Figure 5 shows the stress distribution (Von-Mises) for the link under these loads (loads are applied to the right-end and the left-end is taken to be fixed).

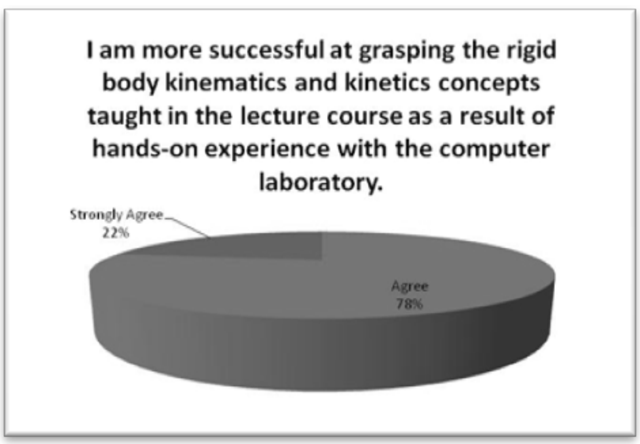
Hand calculations for this case can be done by finding the maximum stress caused by the longitudinal load (major contributor) acting on the joint location and considering the stress concentration effects caused by the circular hole[5]. This approach leads to roughly 9.6 MPa, a value about 13% larger than the FEA result, thus a good approximation.

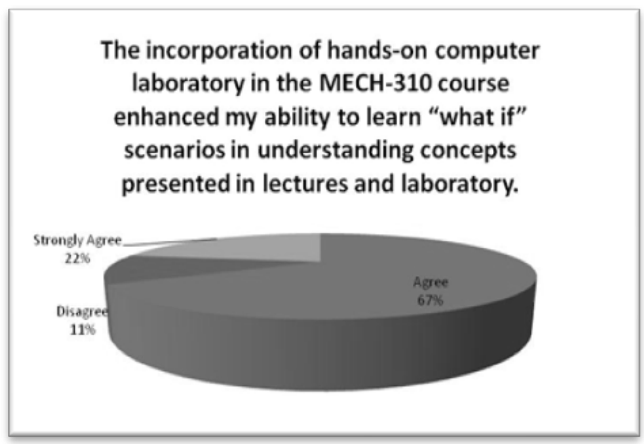
Students could be asked to evaluate component design based on this level of stress and the yield stress for the material utilized. For the case where the stress level is below the maximum value allowed (taken to be the yield stress divided by a safety factor) an optimization routine, for example to reduce weight, could be performed to improve the part. This can also be done via the software.

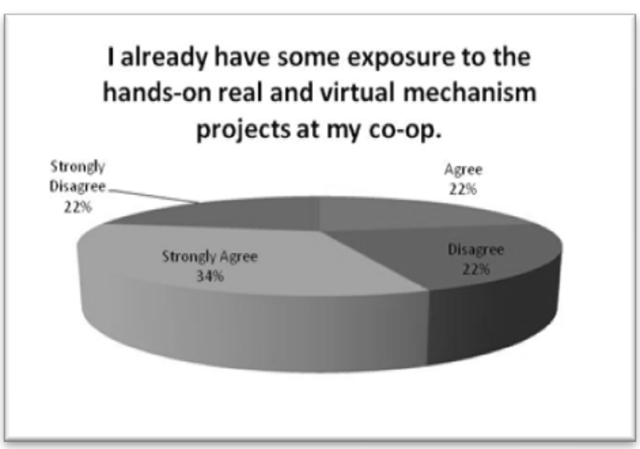
Assessment

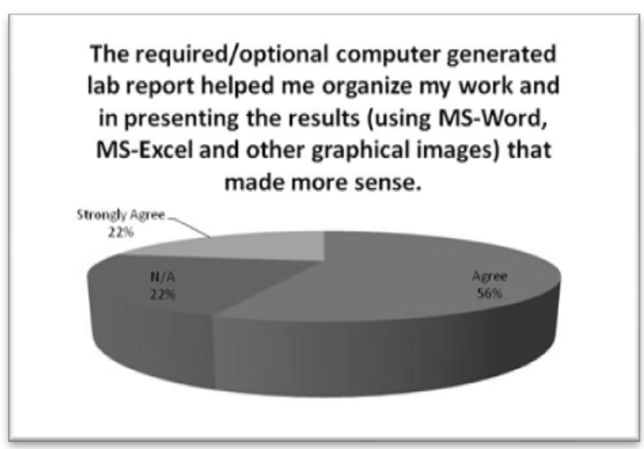
A preliminary assessment to the approach was conducted via a web-based survey. The survey contained several questions aiming to gauge students' overall opinion of the use of the software packages in the courses. This was done for a section of a dynamics course in 2011, where students used simulations to solve and analyze the mechanism. Also, hand-calculations were required for comparison purposes.

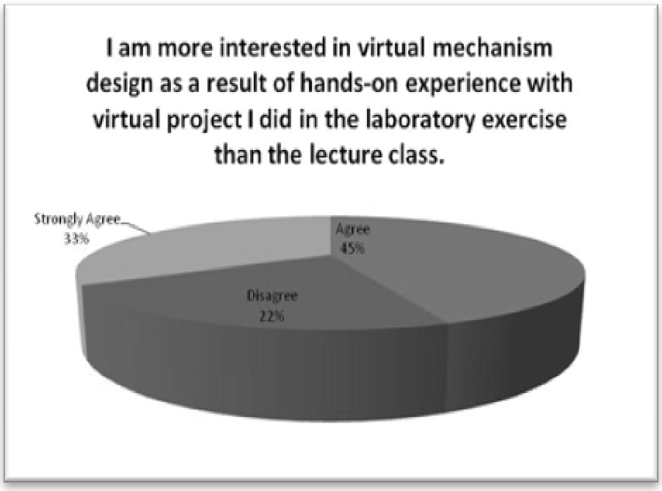
Several questions were posed in order to allow the reader to try and understand some broad aspects of the approach. Nevertheless, from the qualitative assessment, the major points gathered are the following:

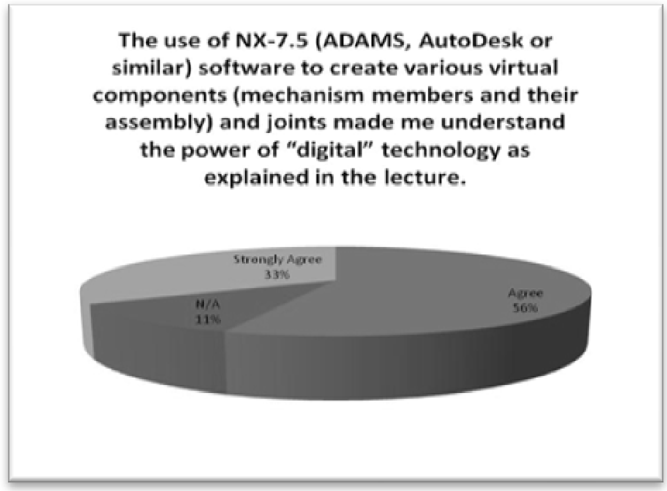


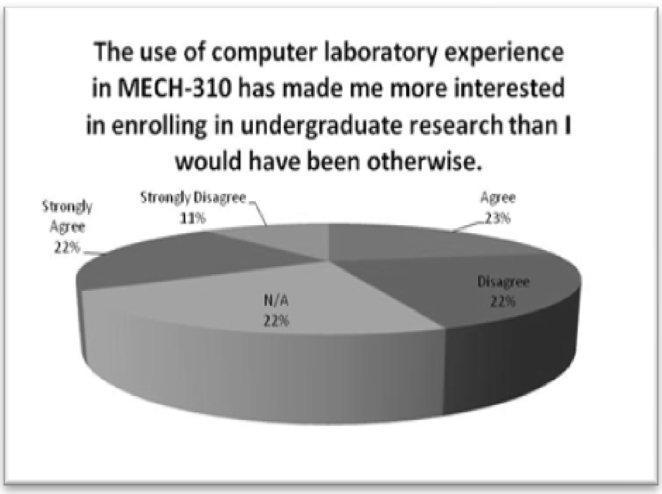


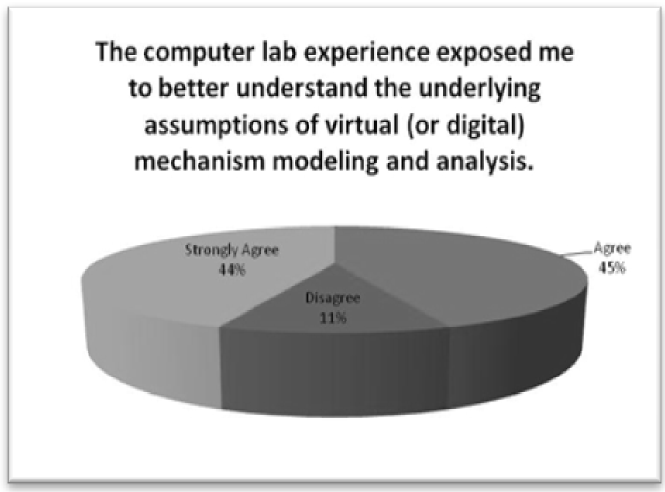


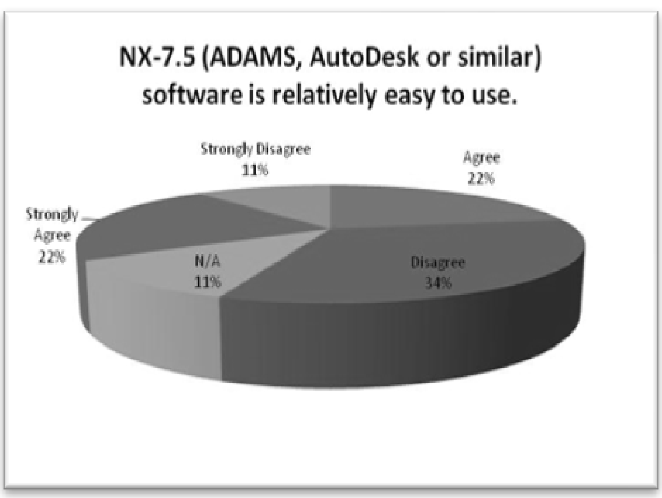


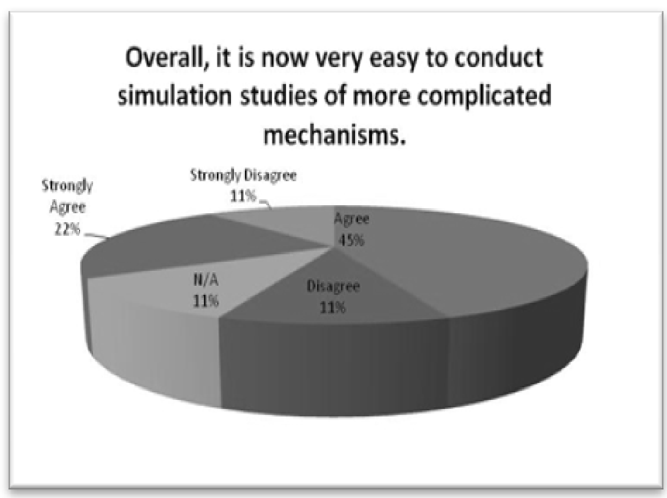

I am more interested in virtual mechanism design as a result of hands-on experience with virtual project I did in the laboratory exercise than the lecture class.
Strongly Agree 33%
Agree 45%
Disagree 22%

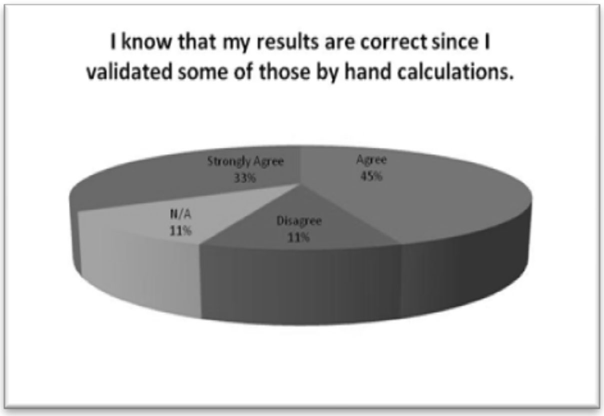

The use of NX-7.5 (ADAMS, AutoDesk or similar) software to create various virtual components (mechanism members and their assembly) and joints made me understand the power of "digital" technology as explained in the lecture.
Strongly Agree 33%
N/A 11%
Agree 56%

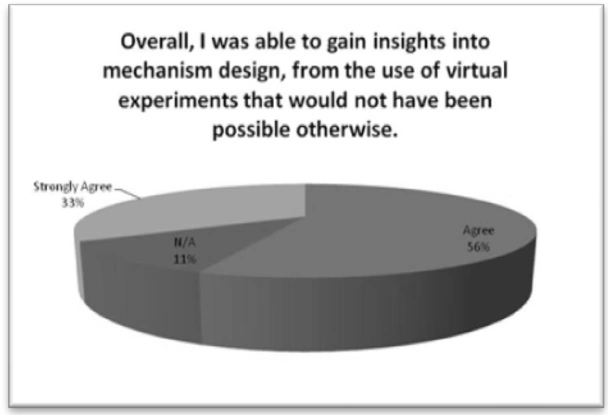

The use of computer laboratory experience in MECH-310 has made me more interested in enrolling in undergraduate research than I would have been otherwise.
Strongly Agree 22%
Strongly Disagree 11%
Agree 23%
Disagree 22%
N/A 22%

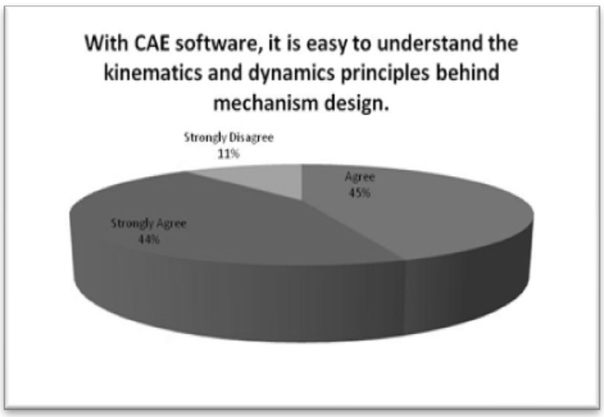

The computer lab experience exposed me to better understand the underlying assumptions of virtual (or digital) mechanism modeling and analysis.
Strongly Agree 44%
Agree 45%
Disagree 11%

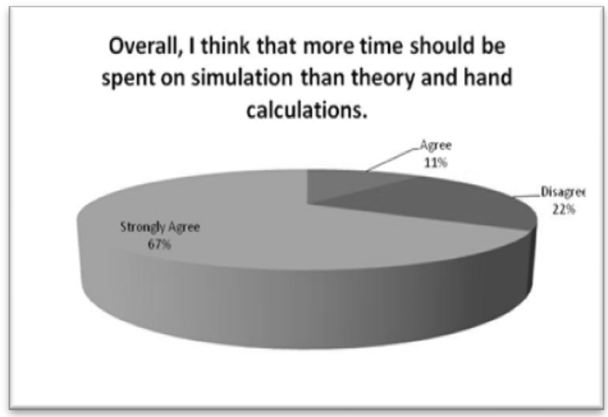

NX-7.5 (ADAMS, AutoDesk or similar) software is relatively easy to use.
Strongly Disagree 11%
Agree 22%
Strongly Agree 22%
N/A 11%
Disagree 34%

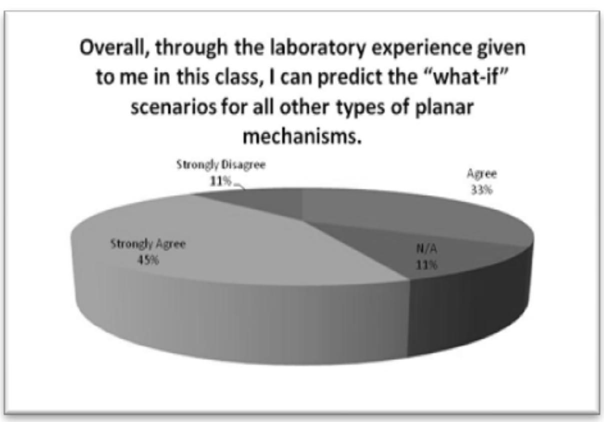

Overall, it is now very easy to conduct simulation studies of more complicated mechanisms.
Strongly Agree 22%
Strongly Disagree 11%
Agree 45%
N/A 11%
Disagree 11%











- Most students believe that the use of simulation does improve understanding of the mechanism and of the kinematics/ dynamics involved in the analysis of such systems.
- The exposure to virtual design (most students for the first time) is helpful in learning the subjects related to mechanism design.

The answers to the questions were as follows: Strongly Agree, Agree, Disagree, Strongly Disagree, N/A (do not apply). Results are summarized below in a series of "pie-charts". The charts include the questions that were posed and the percentages of responses.

Note that overall results are very positive and warrant further exploration and use of the approach.

Conclusions

This paper discusses the merits of incorporating CAE tools in teaching courses such as Rigid Body Dynamics, which can be moderately difficult to some students even though they have a background in Statics. Some of the challenges are, for example, correctly drawing free body diagrams, visualization of different kinematic components (particularly velocity and acceleration components) and understanding and applying Newton's equations of motion in various forms to solving problems. While practice makes it easier to better understand the material, use of CAE tools aids in visualization of rigid bodies in relative motion.

Several tools are available to enhance learning of these subjects. In this paper, the Motion simulation module of NX 7.5 is used to model an example 4-bar mechanism to demonstrate the kinematic and dynamic behavior of an automotive wiper linkage. Some students have already taken the CAE course taught at the university and therefore are familiar with part modeling and assembly of mechanisms. The software can output kinematic and dynamic quantities of any moving member of the mechanism. Thus students can study the effect of changing geometry, material and / or input motion parameters, such as angular velocity, into the overall behavior of the mechanism. The simulation results in the example problems have been verified by hand calculations. An end of the term web-based survey has been designed to assess students' opinion of including the NX7.5 in the class project. The survey shows that the students, in general, agree to the fact that CAE tools definitely enhance their understanding of rigid body kinematics and dynamics. Solid mechanics material was also enhanced since the project included preliminary finite element analysis of one of the linkages of the mechanism. More studies need to be undertaken to systematically include math and CAE tools into courses such as Solid Mechanics, Dynamics and Vibrations at Kettering University.

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Biographical Information

Yaomin Dong is an Associate Professor of Mechanical Engineering at Kettering University. He received his Ph.D. in Mechanical Engineering at the University of Kentucky in 1998. He has extensive R&D experience in the automotive industry and holds multiple patents. His areas of expertise include metalforming processes, design with composite materials, and finite element analysis.

Arnaldo Mazzei is a Professor of Mechanical Engineering at Kettering University. He specializes in dynamics and vibrations of mechanical systems and has conducted research in stability of drivetrains, including universal joints. His current work relates to modal analysis, stability of drivetrains, finite element analysis, and computer aided engineering. He is an active member of ASEE, SAE and SEM.

Raghu Echempati is in the Department of Mechanical Engineering at Kettering University. He has several years of teaching, research, and consulting experience. He is an active member of ASEE, ASME, and SAE. He has more than 100 technical paper publications in journals and conference proceedings of repute. He has chaired several sessions at national and international conferences and delivered numerous invited talks and keynote addresses. He has reviewed several textbooks, journal papers, and conference papers. He is an active member of many conference committees.