

## **AC 2007-2238: DEVELOPMENT OF ONLINE HANDS-ON EXPERIMENTS FOR HYBRID VECTOR STATICS COURSES**

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# Development of Online Hands-on Experiments for Hybrid Vector Statics Course

## Abstract

*Student attrition has been a problem for many engineering programs across the nation such that a significant number of students drop out in their first- and second- year. Vector statics has been a bottleneck course due to its significant number of failures and repeats. In a departmental survey, approximately 44% of the students did not earn a passing grade of C- or above. The high repeat and failure rates of this course significantly hamper the students from moving up in their engineering curricula, resulting in a high attrition rate of the engineering students. A group of mechanical engineering faculty members constructed three sets of experimental apparatus for hands-on statics experiments based on the problems in the textbook in an effort to increase better understanding on vector and static equilibrium concepts. One apparatus is a simple pulley-and-rope system to learn 2-D vector resolution and decomposition and force equilibrium of a particle. A second apparatus is a universal force and moment equilibrium tester for students to learn physical natures of the 3-D force and moment vectors, rigid body force and moment equilibrium, and equivalent force-couple system. The third apparatus is a reconfigurable metal truss model with strain gauges attached to the critical members for online monitoring of the resulting member forces over the Internet. The students can conduct a truss design project in conjunction with custom MATLAB computational tools for optimum design configuration and then test the constructed model under physical loading conditions for prediction of failure. High-end multi-and uni-axial force transducers and pneumatic loading mechanisms are interfaced with an advanced data acquisition system using LABVIEW. This paper presents our experiences in developing these sets of hands-on experiments. This new change in teaching traditional vector statics courses will precipitate concomitant revision in offering other traditional engineering courses as well.*

## Introduction

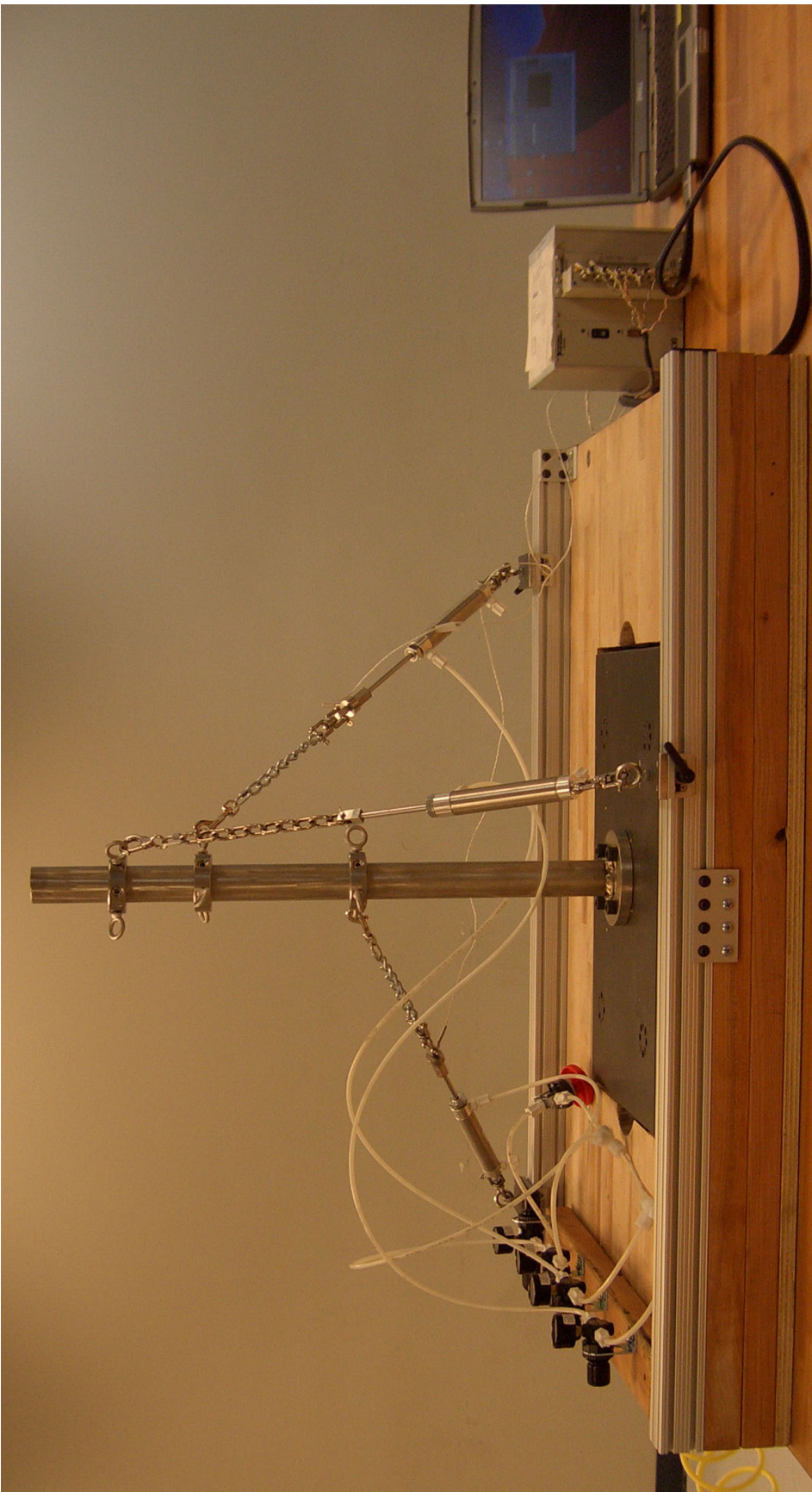
Engineering education is under considerable pressure to include more and new materials, to restructure the course content using new approaches and technologies and to manage a spectrum of students with diverse backgrounds in spite of the reduced total number of credits for graduation. Most engineering curricula have become more intensive and thus students are required to spend more time for each subject. On the other hand, student attrition has been a problem for many engineering programs across the nation such that a significant number of students drop out in their first- and second- year. California State Polytechnic University, Pomona has one of the largest engineering programs in the US with over 4,600 undergraduate engineering students. More than 84 percent of the students are working during the week.<sup>1</sup> As indicated in an intramural report on student attrition<sup>2</sup>, the primary non-university related reasons students claimed for leaving their studies were the difficulties managing work and class schedules, and commuting to campus. Thus, time-efficient learning is in greater demand than ever to assist in student retention.

Vector statics is the first hardcore engineering class, as required by almost all the majors at the beginning of sophomore year in most engineering programs. During the academic year of 2004-2005, 27 sections of vector statics (ME215 Vector Statics) and 8 sections of the accompanying group discussion course (ME225L Mechanics Laboratory) were offered for approximately 800 students. It has been a bottleneck course due to its significant number of failures and repeats. In an ME departmental survey with 319 students who took the course from various majors during fall 2001 and winter 2002 quarters, over 44% of them did not have the passing grades, and that was a small increase from 40% taken from the survey during the academic year 2000-2001 with 517 students. The high repeat and failure rates of this course significantly hamper the students to move up to their engineering curricula, resulting in a high attrition rate of the engineering students. The ME department has painstakingly addressed this problem in many different ways. One feasible way was to provide an additional one-unit group discussion course ME225L, which was developed based on the study on cooperative learning in engineering through academic excellence workshop.<sup>3</sup> Under the cooperative learning environment, the students demonstrated significantly better performance in learning vector statics as noted in their final grade of 2.88 as compared with 1.33 for those who took the lecture only.<sup>4</sup> In ME225L, the students learn fundamental concepts of vector statics through teacher demonstrations, group projects & discussion, and additional exercises. It is a co-requisite for ME majors, while other majors are encouraged to take it optionally. Subsequently, ME majors tend to have lower rates of failure and repeat in the course (32% vs. 52% from the former survey during fall 2001 and winter 2002 quarters). This also indicates the effectiveness of the supplemental group activities involving students' participation in better understanding of the subject matter.

As a continuing effort to develop a hybrid vector statics course that combines both the lecture and the lab requirement for ME students for credit reduction without compromising the depth of understanding, our team have been developing a universal statics experiment system for understanding concepts of 2D and 3D force and moment vectors, equivalent force-couple system, 2D and 3D force and moment equilibrium, and truss design and analysis. It should be noted that the discussion in this paper is limited to our experience on development of the universal statics experiment system. Since student assessment is underway, the assessment outcome will be presented in the future.

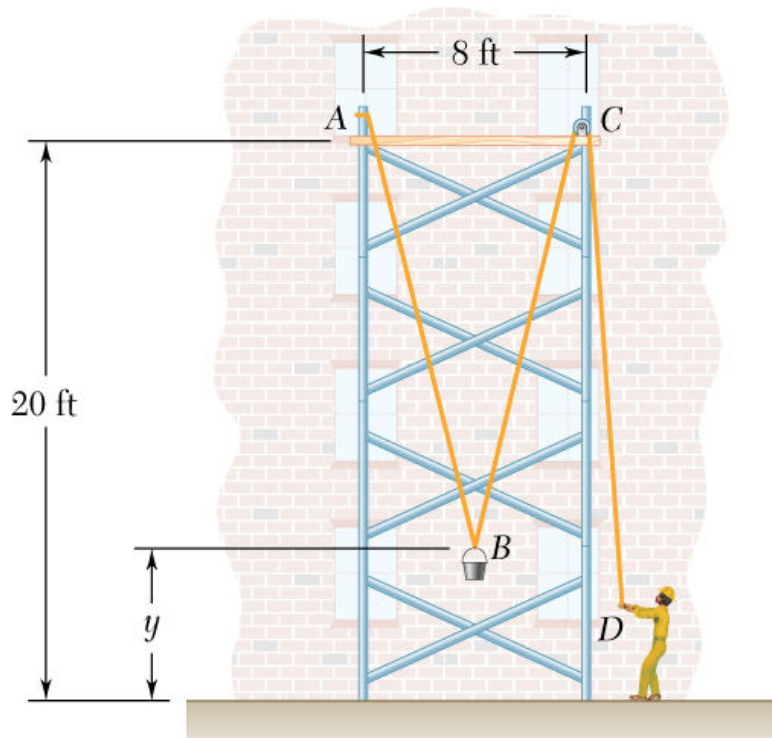
### **Schematics of the universal statics experiment system**

We initiated an effort to construct three sets of hands-on vector statics experiments for online operations through Internet in mind. The universal statics experiment system (Fig. 1) consists of three separate experimental apparatus mounted on the same testing platform. The testing platform is a wooden platform made with a 48" wide  $\times$  36" deep  $\times$  1-3/4" thick maple workbench top and a same size plywood panel backing with 3/4" thickness. A rectangular cutout was made in the center to house a commercial force plate (size: 24" wide  $\times$  20" deep  $\times$  2" thick, model: 4060-10, Bertec, Inc, Columbus, Ohio; load capacity 10 kN). The force plate is capable of simultaneous measurement of three force and three moment components with built-in pre-amplifiers. The original covering of the force plate is replaced with an individual custom covering made of phenolic tops for the three experimental apparatus.

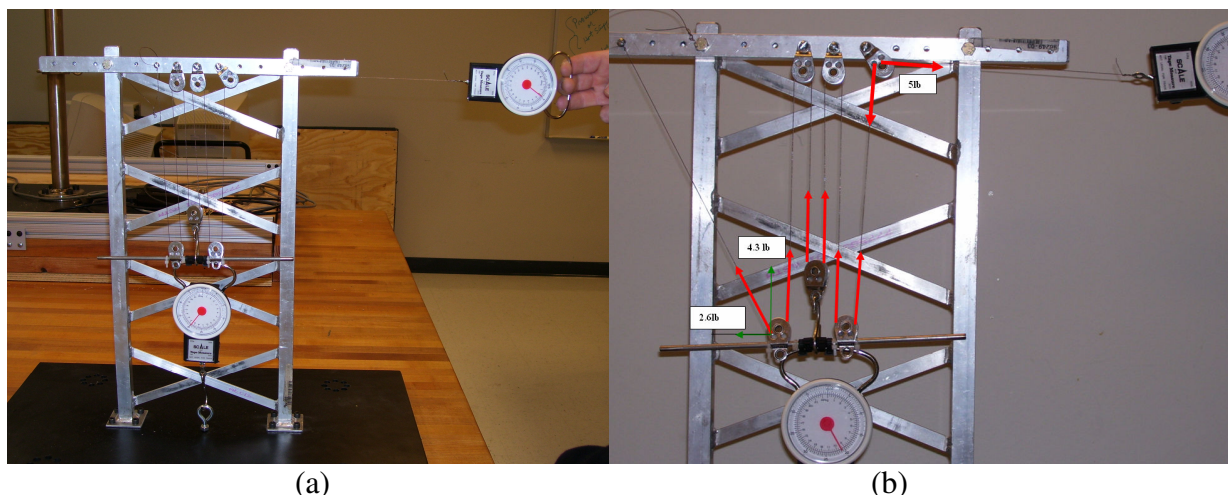


**Figure 1** Universal statics experiment system

The first apparatus is a simple pulley-and-rope system. In this system 2-D vector resolution and decomposition and force equilibrium of a particle is under investigation. It is designed to solve a computer problem in Beer & Johnston's textbook.<sup>5</sup> A painter plans to raise a paint bucket by pulling the cable and the students are asked to determine the cable force as a function of the height of the bucket and to evaluate the painter's plan (Fig. 2). The cable forces are measured using simple force transducers at intervals of the bucket height  $y$  (Fig. 3a). Students estimate the cable forces by considering 2D force equilibrium and compare the estimated cable forces with the measured values. This would be a typical homework problem that the students can readily solve. This experiment is an eye opener for the students who lack ability to connect mathematics with the practical application of the problem. Moreover, different experiments can be performed during the lecture in order to demonstrate the effectiveness of the pulley system as well. For instance, as shown in Figure 3b, which is one of the many configurations of this experiment, students can see that by applying a 5 lb force on one end of the pulley, there will be 30 lb force developed by the cables and the pulley system. In Figure 3b, it is demonstrated to students that why the scale is reading less than 30 lbs is because the horizontal component of the cable in the last pulley is being waited and does not help raising the bucket. Several other experiments are performed using the apparatus during the lecture to engage students, specially those that have difficulty connecting mathematics involved in understanding the reason for using pulleys and cables in order to be able to raise a load.

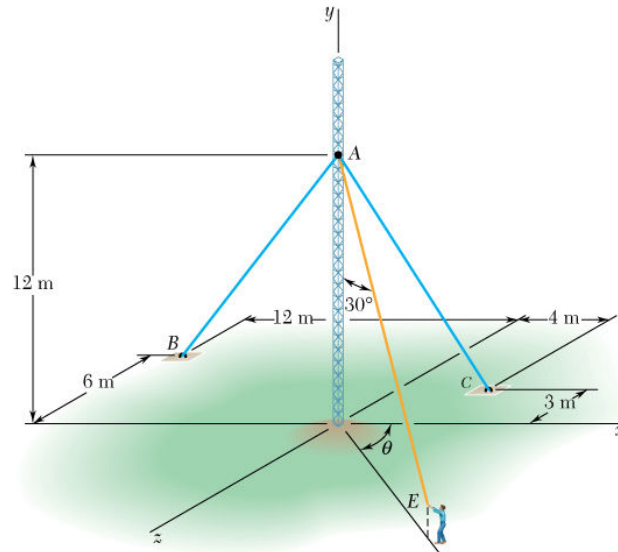


**Figure 2.** Painter problem from Beer & Johnston's textbook<sup>5</sup>.



**Figure 3.** (a) Implementation of the painter problem in Fig. 2, (b) Demonstration for additional pulley problems

A second experimental apparatus is a 3D tower system (Fig. 4), another computer problem from the same textbook<sup>5</sup>, for students to learn physical natures of 3-D force and moment vectors, rigid body force and moment equilibrium, and equivalent force-couple system. It was also conceived to solve an open-ended problem that a person pulls a guy wire to stabilize a tower in a way that the three resultant forces acting vertically downward. In the actual experimental apparatus (Fig. 1), the tower was modeled using a 1-1/2" diameter, 3' long stainless steel pipe welded with a 5" outer diameter stainless forged flange socket and bolt-mounted on the custom phenol covering. Three 2-1/4" outside diameter, 3/4" wide stainless steel shaft collar with set screws are used to adjust the vertical position of each guy wire. Eyebolts are threaded to each shaft collar for guy wire attachment. Then, each guy wire is pulled by an individual double-acting pneumatic cylinder (McMaster-Carr Part No: 6498K377) pivot-mounted on a double-flange guide block with a hand brake sliding along an extruded aluminum rail to individually adjust the anchor locations (B, C and E in Fig. 2). The cable load is individually controlled by a miniature pressure regulator (McMaster-Carr Part No: 3823T32) and individually measured by ENTRAN uniaxial force transducers stated above. The BERTEC force plate measures 3D force and moment components of the tower base. Using the same apparatus, a series of experiments can be conducted for understanding concepts of 1) 3D force and moment vectors by pulling a single cable and measuring the reactions of the tower base, 2) equivalent force couple system with the same setup above, 3) 3D particle force equilibrium as stated in the original problem, 4) 3D rigid body force and moment equilibrium by applying cable forces at different vertical positions of each cable. All the voltage signals from the force transducers are amplified to a volt level using a commercial amplifier (Model: SCXI-1120, National Instruments, Inc, Austin, TX). The amplified signal as well as the three force and three moment component signals from the force plate are simultaneously collected at a sampling rate of 200 Hz with a high-speed PCMCIA data acquisition card (Model: DAQ Card-6024E, National Instruments, Inc, Austin, TX). Custom LabView programs are used to control the apparatus and to collect the data using a notebook PC.



**Figure 4.** Tower problem from Beer & Johnston's textbook<sup>5</sup>.

The third apparatus is to replace current truss bridge projects (Fig. 5) with a reconfigurable metal truss model with strain gauges attached to the predicted critical members for online monitoring of the resulting member forces over the Internet. The students conduct a truss design project by using custom MATLAB computational tools<sup>6</sup> for optimum design configuration and then test the constructed model under the physical loading conditions for prediction of failure.



**Figure 5.** Truss bridge project.

## Discussion

A universal vector statics experimental testing system has been constructed for hands-on experiments in an effort for the students to stimulate students' interests by dealing with real problems and to gain better understanding and insights into fundamental vector statics problems. This testing system allows students to experiment various conceptual aspects of vector statics, which can not be done with a few simple spring scale experiments. It is also intended to conduct additional experiments and student projects with this advanced data acquisition system and high-end force sensors. More examples will be presented in the future study.

Construction of this advanced experimental testing system can be done at an affordable cost. Students have engaged in most of the design and construction phases through senior projects so that labor cost was minimal. Though its total cost of construction including all the sensors and data acquisition systems is estimated to be around \$15,000, we spent about \$2,500 only for construction materials since most of the experimental equipment and sensors are available from the department through equipment sharing. More importantly, our experience gained through this project will help us to improve the current vector static class and to bring concomitant changes in offering other traditional engineering courses in a similar online/hybrid format.

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