Space – Sugar Coating for the Mechanics Pill

Devdas M. Pai[1], Richard Layton[2], Sameer Hamoush[3], Samuel Owusu-Ofori[4] and Shih-Liang (Sid) Wang[5]

[1] *Department of Mechanical Engineering, North Carolina A&T State University, Greensboro, NC 27411, USA, Tel (336)334-7620, Fax (336)334-7417, pai@ncat.edu*

[2] *Department of Mechanical Engineering, North Carolina A&T State University, Greensboro, NC 27411, USA, Tel (336)334-7620, Fax (336)334 -7417, rlayton@ncat.edu*

[3] *Department of Architecture Engineering, North Carolina A&T State University, Greensboro, NC 27411, USA, Tel (336)334-7620, Fax (336)334 -7417, sameer@ncat.edu*

[4] *Department of Mechanical Engineering, North Carolina A&T State University, Greensboro, NC 27411, USA, Tel (336)334-7620, Fax (336)334-7417, ofori@ncat.ed u*

[5] *Department of Mechanical Engineering, North Carolina A&T State University, Greensboro, NC 27411, USA, Tel (336)334-7620, Fax (336)334 -7417, wang@ncat.edu*

Abstract: In this paper, the authors describe their experience in developing methods of delivering basic engineering mechanic courses with examples and case studies that might be more palatable to students that thrive on hands-on learning experiences. The course modules developed are centered on space exploration activities – specifically, the NASA Mars Global Mission, which has received a lot of press coverage in the recent past. Principles of statics are demonstrated using a suspension system model and explaining the equations of equilibrium as applied to trusses and structures. Motion simulation files are developed to simulate the Mars Rover's mobility system and emphasize the need for dynamic analysis. A variable amplitude, variable speed, spring-damper system with an on-board video camera is intended to simulate the suspension of a Mars Rover vehicle and bring to life the principles of frequency response. Class surveys are used for feedback and module improvement.

Keywords: case study, space, courseware, instrumentation.

1. Motivation

Instructors of the basic undergraduate mechanics courses everywhere probably share the authors' experience that many students perceive these courses to be external (and thus irrelevant) to their major discipline. Not until they enter their professional careers do many electrical engineers realize that designing motion control systems requires an understanding the underlying kinetic principles; civil engineers that free body diagrams are needed to design bridges; and industrial engineers that the proper use of kinematics can help them eliminate wasted motions and improve product ergonomics. Such courses when taken by non-majors are often treated with undue dread, leaving the hapless instructor to face the music of less-than-desirable teaching evaluations.

The common practice of delivering basic engineering mechanic courses is through classroom lectures coupled sometimes with implementation of computer technology. There exists a need for teaching aids that appeals more to the target audience in terms of demonstrating "real world" field applications. NC A&T State University is a lead university in a NASA grant entitled - Partnership Award for the Integration of Research into Mathematics, Science, Engineering & Technology Undergraduate Education (PAIR). The PAIR grant is intended to leverage the value of existing NASA research programs in academic institutions and their governmental and industrial partners. Research outcomes and facilities are used to strengthen undergraduate education in the areas of mathematics, science, engineering and technology (MSET) as well as to foster early involvement of undergraduate students in the research endeavor.

At NC A&T State University, mechanics courses are usually taught by faculty members from mechanical, civil and architectural engineering. The PAIR grant has enabled the authors to collaborate across traditional departmental boundaries in developing teaching modules that bring out the relevance of these foundation courses in real-world applications. The modules are typically a mix of paper-based and hands-on learning activities.

2. Theme of Educational Modules

The Mars Pathfinder spacecraft, part of NASA's Mars Global Mission, landed on Mars on July 4, 1997 following a seven-month cruise through interplanetary space[1]. Upon landing, a Rover vehicle named Sojourner (after Sojourner Truth - an abolitionist and feminist of the early 18th century) was deployed from the Lander. Sojourner then conducted technology experiments including wheel-soil interactions, autonomous navigation and hazard avoidance. It survived much longer than its design life. The success of this mission rekindled public interest in space mission, and NASA setup a popular website[2] on this mission containing numerous photographs and videos. The Mars Mission has received renewed attention in recent times. Since one of the PAIR grant's objectives is to enhance core courses in the MSET curriculum through the development of portable learning modules, sub-systems and aspects of the Sojourner Rover were chosen as the subject to develop course modules for statics and dynamics courses, and for instrumentation laboratories. The rest of this paper discusses the on-going development and dissemination of this work, and the feedback received.

3. Statics

Figure 1 shows the details of a mock 2-dimensional suspension. The system consists of two horizontal structural members and one vertical pinned at the ends by removable pins. The removable pins allow the system to be sub-structured to its basic elements. The vertical member is fixed to a wheel that can be easily removed and replaced with a different size. The system's equilibrium is ensured by a spring and a shock absorber. The connection of the spring and the absorber allows for replacement with different sizes.

The system demonstrates three types of supports conditions pinned, fixed and linked. Free body diagrams shown in Figure 2 connect the conceptual understanding of the support conditions to actual applications. Figure 2a shows the unknowns of a rigid connection. Students will be able to understand the concept of a rigid body of a single element as a part of a system subjected to actual known forces. Figure 2b shows the free body diagram for the system. In addition, the system demonstrates the concepts of two and three force members held in equilibrium, Figure 2c. Free body diagrams can easily be isolated. Linked elements, trusses elements and structural systems can be modeled within the developed system.

The developed system is capable of demonstrating the overall response of the system to any specific change to any of its elements. A spring and a shock absorber are used within the system to maintain equilibrium. The system enables students to evaluate the dynamic response of the system with the change in the spring stiffness. Initially, three spring constants selected for the investigation, the system response to any change in the spring or damper constants can be easily identified. This system is mounted on a rigid post fixed to a base plate. The base plate sits on a cart to allow the system to be transported to classrooms.

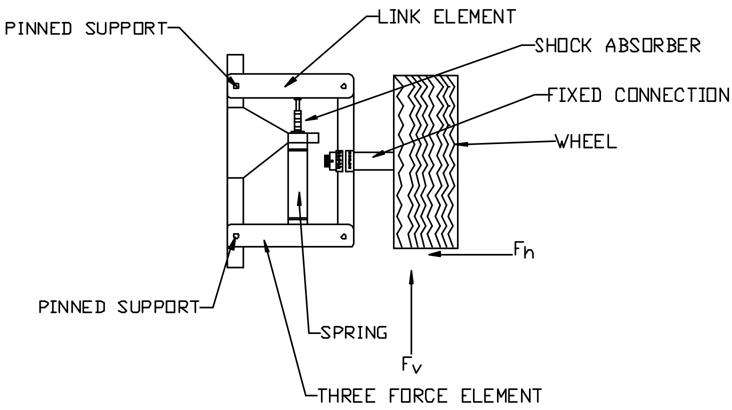

Figure 1. The developed suspension assembly

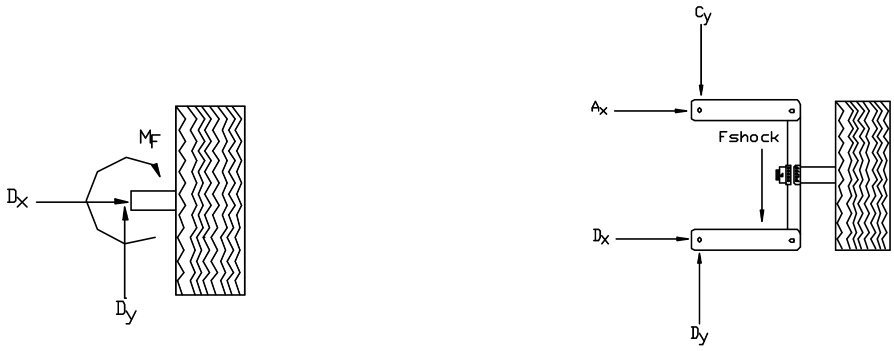

Figure 2 (a,b) Free body diagrams

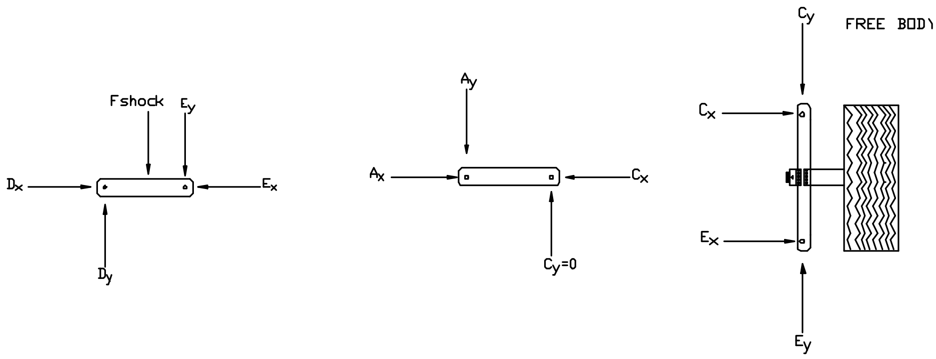

Figure 2c Free body diagrams for two and thee force elements

Dynamics and Kinematics

Motion simulation files based on Working Model 2D™ (referred to as WM2D) are developed to simulate Mars Rover's mobility system. WM2D allows the user to sketch a mechanical system using a variety of simple geometric primitives, accompanied by additional constraints (joints, springs, and dampers) and actuators (cylinders and motors). WM2D then uses its simulation engine to set the mechanical system in motion. Stand-alone executable simulation video files can also be generated. The author (Wang) has used the software with some success over the past few years to simulate various mechanisms.

The Rover is about the size of a medium microwave oven. Its suspension, called the Rocker-Bogie Mobility System, consists of six wheels on mobile links to provide the maneuverability to traverse rocky and sandy surfaces on Mars. The front and center wheels are joined on each side to form bogies that pivot freely at the front of rocker links. The rockers are connected to the main body with a differential mechanism so that the pitch angle of the body is the average of the pitch angles of the two rockers[3]. The front and rear wheels are independently steerable, providing the capability for the vehicle to turn in place. Since the simulation files are developed on WM2D, the rocker-bogies on both sides are assumed to be synchronized, and the rocker joint is fixed. Figure 3 shows the process of the Rover going over an obstacle.

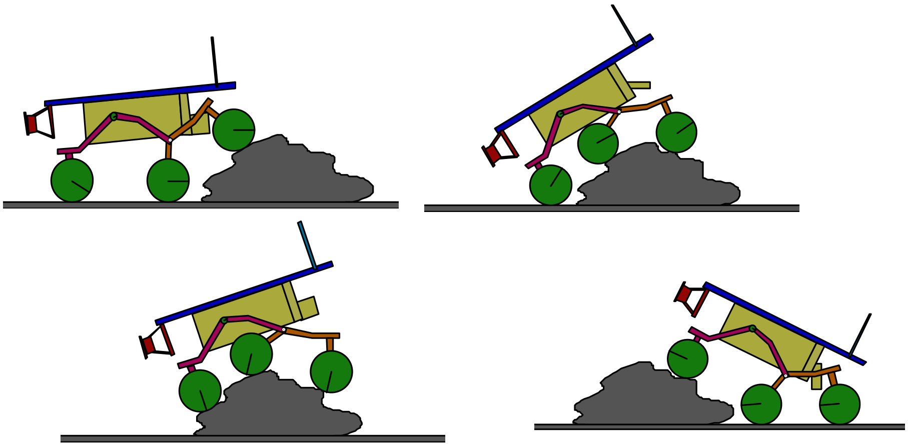

Figure 3 Obstacle Climbing Simulation with Rocker-Bogie Suspension

With the rocker-bogie system, the rover can climb over a step, with its height one and a half times the diameter of the wheels. Rover' s step climbing capability is much superior than that of a truck. Six wheels are used in the rover design because when front wheels are over an obstacle, they get pushed by the other four. This results in more climbing traction, and a lesser fraction of the weight being lifted, as compared to a four-wheel vehicle.

The mobility system has no springs, which improves Sojourner's traction. When a wheel is raised with an elastic system, the downward force (or normal force) increases according to the spring rate of the suspension system. The greater force makes it more difficult to raise this suspended wheel as it takes downward force (normal force) away from remaining wheels, reducing their traction (friction force). An automotive suspension system is also modeled, as shown in Figure 4, for comparison with the rocker-bogie system.

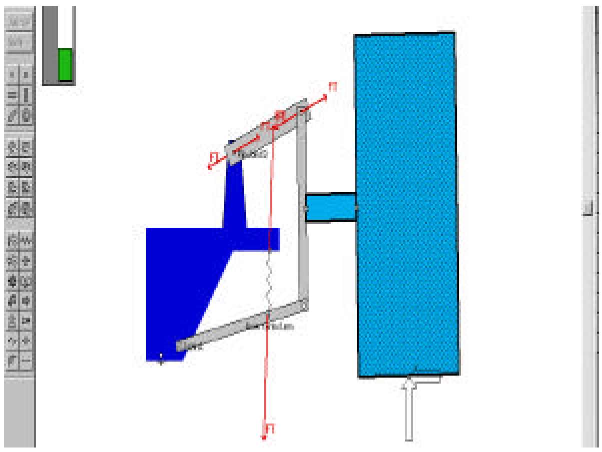

Figure 4 Automotive Suspension Simulation

Simulation files are presented to dynamics classes to demonstrate the need of dynamic analysis. Through these simulation files, students have a better appreciation of suspension system of the rover and of an automobile, and have a deeper understanding of topics in friction and vibration addressed in the textbook.

Instrumentation and Vibration

The Mars Rover vehicle has two cameras (CCDs) mounted on the front end, used for navigation. As the Rover moves slowly across the Martian landscape, the cameras will rise and fall as the Rover climbs over obstacles. This motion inspired the idea to design an apparatus that would subject a small video camera to vertical motion and to run the video feed to a monitor so that students could see visual results of the experiment in real time. The apparatus developed from this initial concept is a mass-spring-damper second-order system that can be used to illustrate several concepts in instrumentation and system dynamics. Unlike the Mars Rover, this system has spring-damper suspension. A conceptual sketch of the apparatus is shown in Figure 5.

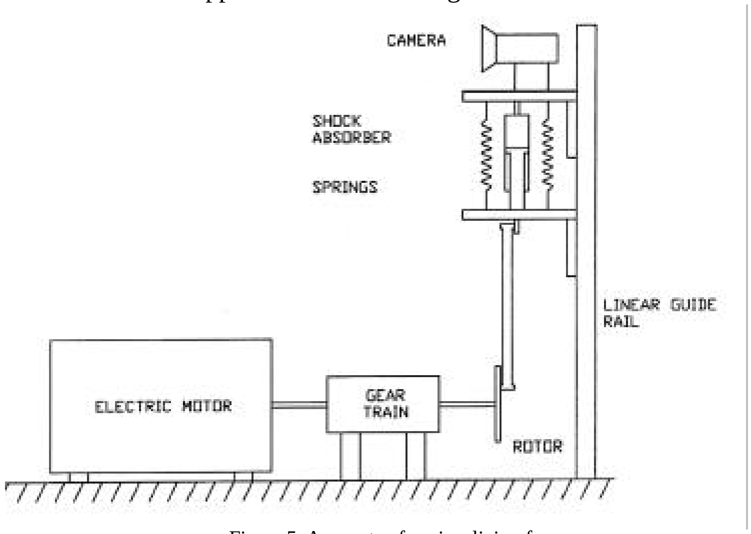

Figure 5 Apparatus for visualizing frequency response

A variable DC motor drives a vertical slider-crank mechanism. The upper end of the connecting rod is attached to a platform secured to a slider on a rail. A spring and damper connect this platform to a second platform secured to a second slider on the linear rail. A small video camera is mounted on the upper platform. The motor and slider crank assembly provide a sinusoidal displacement input to the suspension/camera system. The system output is the resulting motion of the upper platform. This motion is recorded by a small video camera mounted on the upper platform, that outputs to a video monitor in real time for visualization.

The parameters of the system are adjustable. The variable speed motor allows us to vary the input frequency to the system. The crank has several holes at different radii from the axis of rotation. The connecting rod is pinned to one of these holes. By selecting a different hole, we select a different input amplitude to the system. The springs can be changed out. The air damper has an adjustable orifice for changing the damping coefficient. The upper platform has provision for adding weights so that the mass of the upper platform can be varied. Instrumentation includes an accelerometer attached to the upper platform, an LVDT attached to the upper platform, and a rotary encoder on the motor shaft. Students will study changing the mass, spring, and damper characteristics affects the camera motion in the presence of base excitations. Second-order frequency response concepts such as natural frequency, damping ratio, amplification ratio, and phase lag can be demonstrated.

To design and build the apparatus, the instructors developed the conceptual design and selected the components such that the system could provide the desired outputs, namely, flat response at low frequency input, resonant response near the natural frequency of the system, and highly attenuated response at high frequency input. The hardware was purchased and then a team of PAIR paid undergraduate students and a team of Layton's graduate students working for a graduate course grade was formed to design, fabricate, and test the apparatus. The project description to the graduate team stated: Given a mechanical mass-spring-damper apparatus, design, build, test, demonstrate and write an operations manual and a lab manual for this experiment with instruments and data acquisition to demonstrate the frequency response behavior of this system. Design a second experiment to illustrate the effects and correction of instrument loading. Experimentally determine the frequency response plot. Model the system and compare experiment to theory. Improve the model as necessary to bring the experimental and theoretical results to within 5% of each other. Write a lab manual (and solutions manual) for junior-level students with necessary theory, experimental method, and a list of study questions.

Thus, the apparatus is used for both graduate and undergraduate learning. In development, it is used as a project for a graduate instrumentation course and is used by those students to study loading, an issue in instrumentation. Once operational it can be used in both graduate (MEEN 789) and undergraduate (MEEN 300) instrumentation courses to demonstrate the operation and theory of accelerometers and LVDTs. As an experiment in system dynamics, it is used to visually demonstrate the concepts associated with frequency response. This demonstration supplements the material in the system dynamics course (MEEN 660).

Feedback

Each module is accompanied with learning activities and questionnaires followed by assessment surveys. Initial surveys suggest that student response to these activities is good. However, the modules are a continuous work in progress, and feedback from past batches of students plays a major role in fine-tuning the product for future students. For instance, based on student suggestions, the differential mechanism to balance the difference of pitch angles of either side will be modeled with Working Model 3D. The authors envision such modules playing a 'sugar-coating' role in delivering the important message of mechanics as well as providing evidence of continuous end-user driven assessment and improvement of the core curriculum.

Acknowledgments

This work was developed with support from a NASA grant entitled "Partnership Award for the Integration of Research into MSET Undergraduate Education."

References

[1]. Bickler D., 1998, "Roving Over Mars," Mechanical Engineering, ASME, April 1998, pp. 74-77.
[2]. JPL, Mars Rover, http://mars.jpl.nasa.gov/MPF/sitemap/rover.html
[3]. Bickler D., 1992, "A New Family of JPL Planetary Surface Vehicles', Missions, Technologies, and Design of Planetary Mobile Vehicle, pp. 301-306, Toulouse, France, September 28-30, 1992.
[4]. Working Model User's Manual, Knowledge Revolution, San Mateo, CA, 1999.