Session 2666

Case Based Multimedia in Engineering Education

Imran Yusuf, Kurt Slater, and Kurt Gramoll
Georgia Institute of Technology

Abstract

This paper discusses the issues in the design and development of case based multimedia in engineering education. The user's of these case studies are junior and senior engineering students in the aerospace, civil, and mechanical engineering disciplines. Of particular interest are problems dealing in vibrations and structural dynamics. Practical engineering problems are posed in which a design satisfying the constraints is required. A virtual laboratory is simulated in the program in which the case studies are proposed and solved. Included in this laboratory are a computer, file cabinet, chalk board, book shelf, and a design board at the disposal of the student.

Introduction

The main idea behind case based learning is to recognize the user's cognitive and intuitive (or visual) skills complemented with their verbal and arithmetical (or learned) skills to tackle engineering problems in realistic environments. A tenet upon which these case studies are developed is that a better understanding of a problem is created through visual representation and interaction with complex engineering problems [1]. Advancements in computer technology, computer graphics, and usage are occurring at a torrid pace, and fundamental changes should be expected in education and in the workplace. In cased based interactive multimedia, a high emphasis is placed upon developing and enhancing the students visualization skills in conjunction with learned skills. It recognizes the fact that these skills are essential and valuable commodities for engineers of the future.

Using multimedia in the engineering education domain is one way which accentuates the student's visual skills as it pertains to solving practical engineering problems. Several scenarios can be created to develop case based studies, the key point to remember is "what is the overall objective?" In a case based study, an interactive medium between the student and the computer is created through multimedia, with its ability to simulate real situations through video, sound, graphs and text. Visual representation of complex engineering principles are enhanced through multimedia. A better understanding of the problem can be created through the manipulation of certain parameters. This interaction complemented with instantaneous feedback gives the student a better understanding of the problem. Thus in this way the student can comprehend the functions and significance of the relevant parameters of the problem. As noted by Stone at the University of Western Australia [2], there is a great restriction when teaching vibrations in lectures because it is informative for students to observe motion. The case based projects developed at the Georgia Tech Aerospace Engineering Multimedia Lab (AE MM Lab) deal with structural dynamics and vibrations problems. They are developed as part of the 'GT Vibrations' series of modules on vibrations that deal with basic concepts and theory in vibration of single degree of freedom (DOF) systems, two DOF systems, and distributed parameter systems (continuous systems) [3].

The basic goal of this work is to develop and implement an interactive case based multimedia program to assist engineering students in learning basic concepts in vibration of simple structures. This work assumes and relies upon the user's prior knowledge of the subject, that is, basic theory, and presents them with a problem or a case that needs to be examined and solved. Thence this factor governs the depth and complexity of the case study [4]. A case study has to be designed so as not to lose or confuse the student yet still present them with interesting and challenging problems. Three problems are formulated upon which the case studies have been developed. They include design of a shock absorber for a motorcycle, seismic effects on buildings, and rocket vibrations.

The case studies developed are designed primarily for students taking undergraduate Vibrations and System Dynamics courses. The idea is to have a package that incudes practical problems or applications to complement the theory. This program is designed to be a supplemental tool for an undergraduate course in vibrations and system dynamics. It is important to note that under no circumstances is this package a substitute for the text book or the class.

Design of Case Studies

In designing these case studies, usability was a key factor [4]. Thus careful attention was paid in the design of lab and on the functions of the equipment in lab. This is important because for each case study, the functions of the equipment in the lab are modified slightly due to the nature of the problem and the parameters involved. The three problems are carefully chosen so that they will be compatible with the 'GT Vibrations' program so as to create a complete package for the student. The main thrust of the project is to incorporate case based multimedia into engineering education.

The three case studies are presented in a virtual lab which is simulated in a program. In the lab, there is a computer, desk, chair, file cabinet, chalk board, drawing board etc., and the student has access to various learning resources like books, libraries, experts, etc. The purpose is to give the student a sense that he is in a laboratory and a problem has come up and he is asked to it. To acclimate the student to the lab environment, a guided tour of the lab explaining the functions of various equipment in the lab is given. The student is asked to solve a problem in each of the three respective case studies, but is not told how to solve the problem, rather the student can inquire as to what information is accessible in the lab. As the student tackles the problem, feedback is also given when the student changes the control parameters to meet the design constraints of the problem. This methodology relies upon game simulation where the student makes mistakes and discoveries which, implemented in a professional manner, can have a positive influence.

Navigation in the lab is relatively simple. There are six pieces of equipment in the lab that are accessible to the student, see figures 1, 2, and 3. Each piece of equipment is as important as the others, and each contain vital pieces of information pertinent to the problem. Their functions becomes clear once the student works through the case studies. As seen in figure 1, navigation is not linear, there is no single path or sequence that can be taken in order to solve the problem.

Case 1: Bike Vibration Design

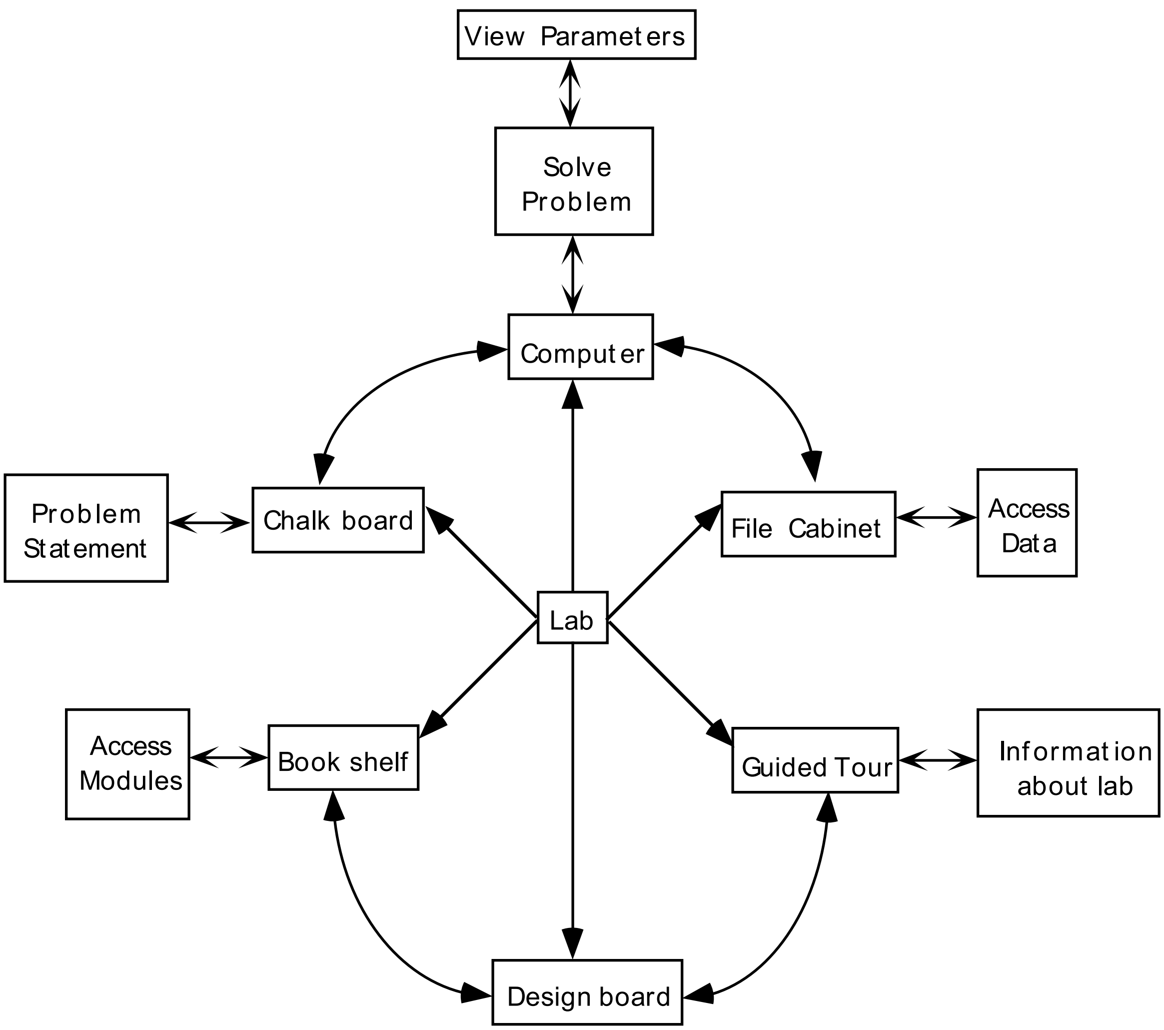

Figure 1. Navigation Flow Chart

The first case study, design of shock absorbers for a motorcycle, is a single DOF spring-mass-damper system. The problem requires the student to design a shock absorber by chosen so as to present an interesting and a somewhat challenging problem. Only two parameters, k and c, are to be obtained from the design, but they depend on several factors.

Figure 2. Bike Vibration Module

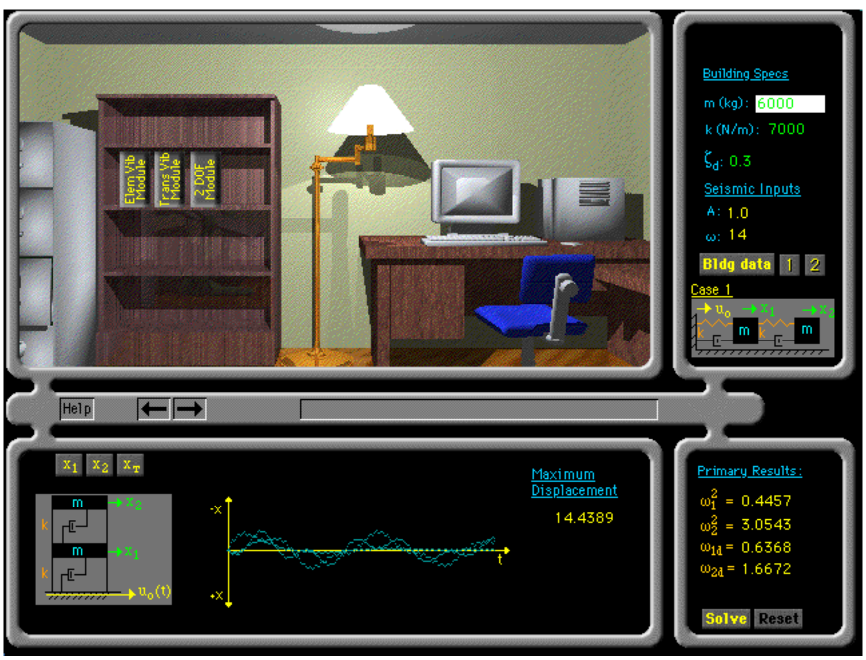

Figure 3. Building Vibration Module

selecting proper stiffness, k, and damping constant, c, for the absorber subject to constraints like the type of terrain, limit on the transmissibility ratio, and on the force transmitted to the motorcycle. These parameters and constraints are prudently

In trying to solve this problem, the student has access to files in the file cabinet containing shock absorber parameters for different motorcycles. An on-line access to basic theory is available from the book shelf that contains modules on basic theory and other technical issues. There is also the computer which displays the parameters that are involved in the problem and allows the student to simulate the response of the motorcycles once the design values are obtained.

At the onset, the student is given suitable values for k and c, and has to iterate on these two parameters to satisfy the constraints. Feedback is given to the student to lead them in the right direction as they iterate on k and c to satisfy the constraints. There is no single correct answer to the problem, therefore the student has to look at the final values and see if it is feasible to design such an absorber. Ample feedback is given to the students as they undertake this task. For instance, when k and c have been selected, one form of feedback is given by the plot of the steady-state response of the motorcycle over the bump as a function of time. From the plot, determination on whether or not the design has satisfied the constraints can be ascertained.

Case 2: Building Vibration Design

This case study deals with seismic effects on the response of buildings. The form of a solution in this problem requires buildings to have some degree of resistance to seismic effects.

The building is modeled as a two DOF spring-mass-damper system. Since this is a two DOF system, constraints on the displacements of the two floors are specified. That is, for an acceptable design solution, the maximum displacements of the floors have to be less than the specified constraint values. The mass of each floor, its stiffness, and overall damping are the parameters that have to be determined. The seismic loading is modeled as a harmonic loading function. Details as to how the mathematical formulation was incorporated into the program are discussed later.

The module begins in the same fashion as the first one. The navigation flow chart for this case is the same, see figures 1,2, and 3. The basic navigation is pattern remains constant, however, the functions of the different pieces of equipment in the lab are modified slightly due to the different nature of the problem.

In this problem, the student has control over three parameters of the building, those being the mass and the stiffness of each floor and the overall damping that is included in the two normal modes. The student can analyze two different types of two story buildings in the program. This essentially implies that the normal modes for each case are different, and thus the vibration response will change.

Unlike the first case study, the student has access to the drafting table where different types of buildings cases can be accessed. Selection of the type of building specifies the normal modes of the system that form the basis for analysis of the problem. In trying to minimize the vibrations of the two floors, the student has to iterate on m, k, and the overall damping constant. As part of the design process, the feasibility of the design solution have to be considered.

Case 3: Rocket Vibration Design

The rocket vibrations module of the GT Vibrations series is a case study intended to develop understanding of longitudinal vibrations. By allowing the users to vary certain parameters and see the results visually, their intuition on the subject and engineering judgment will increase.

The case being studied is the design of a rocket structure. When a rocket engine fires, the sudden onset of thrust can create oscillations in the structure that lead to unacceptable stress values and possible failure. The goal of the case study is to design the structure so that the stress values produced by these oscillations are reduced while keeping an acceptable design for liftoff, i.e. low weight.

The module begins with the user in a virtual room which he must explore to find various information and analysis tools. A drafting table gives the ability to change the physical size of the structural members. Accessing a file cabinet gives material information from which a suitable material must be chosen. A drawing board gives the problem description and design goals while a bookcase allows the user to connect to other parts of the 'GT Vibrations' series for theoretical information on the subject. Finally a computer allows the user to simulate the oscillations in the structure to determine the stress values. After any change to the rocket design, the new weight and natural frequencies are calculated and displayed so the user can determine the effects immediately.

Running the simulation gives the user a color plot of the structural stresses time history. Visualization of vibrations is key to understanding how different modes interact. By analyzing different combinations of vibration modes, the user can see how the modes interact and develop different stress fields.

Three design requirements are given that the user must meet. First, the structural weight must be below a certain percentage of the total thrust which is given. Second, the first natural frequency must be above a given value. Third, the maximum stress imparted to the structure must be below a percentage of the failure stress of the material chosen.

The design process is much like that of the real world. Certain goals are given but these goals are tied to decisions made by the designer. For example, choosing a different material will change the maximum stress allowed in the structure. The process becomes an iterative one in which there may be multiple solutions that perform equally well, a quite common yet seldom discussed phenomenon of engineering.

Mathematical Formulation and Implementation

As mentioned earlier, an assumption was made that the student has some prior knowledge of the subject. This factor determined how complex a problem could be formulated. If burdened with control over too many parameters and constraints, the student might get frustrated or lost, and that is not the purpose of these case studies. The objective is to formulate a challenging problem for the student and yet not make it very complex. Given in the following sections is a brief summary of the theory behind each case.

Case 1: Bike Vibration Theory

The bike vibration case is a basic single DOF system problem. The problem considers a motorcycle suspension system excited harmonically by a road surface through a shock absorber. The shock absorber is modeled by a linear spring in parallel with a viscous damper. The excitation of the system is due to the motion of the base, as shown in figure 4. This type of problem is commonly referred to as the base excitation problem [6].

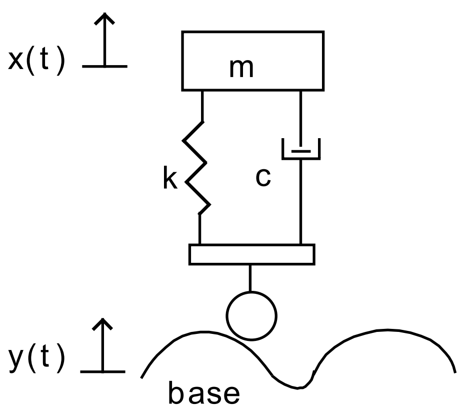

Figure 4. Base Excitation Problem

The equation of motion for this system is

$$m\ddot{x} + c(\dot{x} - \dot{y}) + k(x - y) = 0$$

and assume that the base excitation is harmonic, that is

$$y(t) = Y\sin(\omega_b t)$$

substituting this into the first equation yields,

$$m\ddot{x} + c\dot{x} + kx = cY\omega_b\cos(\omega_b t) + kY\sin(\omega_b t)$$

For this problem, the steady state response of the motorcycle is analyzed, thus only the particular solution for this problem is considered

Dividing the first equation by m and using definitions of damping ratio and natural frequency yields,

$$\ddot{x}(t) + 2\zeta\omega\dot{x}(t) + \omega^2 x(t) = 2\zeta\omega\omega_b Y\cos(\omega_b t) + \omega^2 Y\sin(\omega_b t)$$

where

$$\zeta = \frac{c}{2\sqrt{km}} \quad \text{and} \quad \omega = \sqrt{k/m}\ .$$

The particular solution of this second order ordinary differential equation is

$$x_p(t) = \omega Y\left[\frac{\omega^2 + (2\zeta\omega_b)^2}{(\omega^2 - \omega_b^2)^2 + (2\zeta\omega\omega_b)^2}\right]^{1/2}\cos(\omega_b t - \phi_1 - \phi_2)$$

where

$$\phi_1 = \tan^{-1}\left[\frac{2\zeta\omega\omega_b}{\omega^2 - \omega_b^2}\right] \quad \text{and} \quad \phi_2 = \tan^{-1}\left[\frac{\omega}{2\zeta\omega_b^2}\right]$$

Rewriting the magnitude of $x_p(t)$ as

$$X = Y\left[\frac{1}{(1 - r^2)^2 + (2\zeta r)^2}\right]^{1/2}$$

which is know as the transmissibility ratio, T.R., where $r=w/w_b$ is called the frequency ratio. For vibration isolation to occur, r has to be greater than $\sqrt{2}$.

This solution is implemented in the program. The constraints are placed on the maximum displacement X, and on the maximum force transmitted due to the bump. By specifying the maximum displacement X and knowing the amplitude Y of the bump, T.R. can be computed, and then from the T.R. plot, several possible solutions for z and w that satisfy the constraints can be obtained. The control variables in this program are k and c. The objective is to vary k and c to obtain z and w or (r) from the T.R. plot.

Case 2: Building Vibration Theory

The solution of this two DOF system was done by modal analysis. There are two levels of the building with stiffness k and concentrated mass m and an overall damping $e_i=z_d w_i$ (i=1,2) which takes into account a constant value of damping ratio z_d for the natural modes, see figure 5.

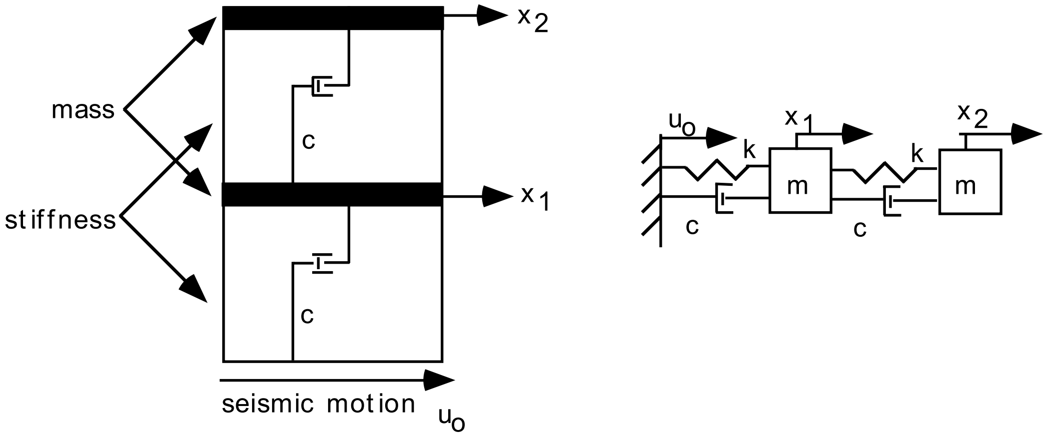

Figure 5. Two Story Building Under Seismic Loading

In modal analysis the properties of natural modes of a structure are used [7]. The goal is to solve for the values of the horizontal vibration of the floors. We express this as

$$x_i(t) = \sum_{i=1}^{2} q_i(t)\phi_i$$

where ϕ_i are the natural modes of the building. The equations of motion for this system are

$$m\ddot{x}_i(t) + c\dot{x}_i(t) + kx_i(t) = -m\ddot{u}_o(t).$$

By substituting and applying mass orthogonality condition, the following equations is obtained

$$\ddot{q}_i(t) + 2\varepsilon_i\dot{q}_i(t) + \omega_i q_i(t) = -N_i\ddot{u}_o(t)$$

where

$$N_i = \frac{\sum_{i=1}^{2} m\phi_i}{\sum_{i=1}^{2} m\phi_i^2} \quad \text{and } \varepsilon_i = \zeta_d\omega_i$$

The seismic loading is assumed to be harmonic, i.e.

$$u(t) = A\sin(\omega t).$$

Then the equation becomes

$$\ddot{q}_i(t) + 2\varepsilon_i\dot{q}_i(t) + \omega_i q_i(t) = A\omega^2 N_i \sin(\omega t)$$

This equation is solved for $q_i(t)$ and then transformed back to the original coordinate system by multiplying the generalized coordinate matrix) with the modal matrix, i.e.

$$\begin{Bmatrix} x_1 \\ x_2 \end{Bmatrix} = [\phi_1 \;\; \phi_2]\begin{Bmatrix} q_1 \\ q_2 \end{Bmatrix} = [p]\begin{Bmatrix} q_1 \\ q_2 \end{Bmatrix}$$

The harmonic seismic input is specified by A and w and is fixed. The student has control over the damping, mass, and stiffness values to satisfy the constraints.

Case 3: Rocket Vibration Theory

Longitudinal motion of a vibrating bar can be expressed as a series sum of spatial and temporal terms

$$u(x,t) = \sum_{n=1}^{\infty} U_n(x)T_n(t)$$

where each U_n is a normal mode and is determined from free vibration. For a free-free bar, which is used to model the rocket, the normal modes are given by

$$U_n(x) = \cos\left(\frac{\omega_n x}{c}\right) \quad \omega_n = \frac{n\pi c}{L} \quad c = \sqrt{\frac{E}{\rho}}$$

For a bar with a force F(t) acting at the end x=0, it can be shown that the T_n terms must satisfy the differential equation

$$\ddot{T}_n + \omega_n^2 T_n = \frac{F(t)U_n(0)}{M_n}$$

where M_n is the generalized mass and is given by

$$M_n = \int_0^L U_n^2(x)m(x)dx$$

where m(x) is the mass distribution.
The solution to the differential equation for an arbitrary F(t) can be shown to be

$$T_n(t) = \frac{U_n(0)}{M_n\omega_n}\int_0^t F(\tau)\sin\omega_n(t-\tau)d\tau$$

Therefore, the complete motion, u(x,t) is given by

$$u(x,t) = \sum_{n=1}^{\infty}\frac{U_n(x)U_n(0)}{M_n\omega_n}\int_0^t F(\tau)\sin\omega_n(t-\tau)d\tau$$

which for constant F has a simple closed form solution.

From u(x,t) it is a simple process to get the strain and hence stress at each location for all time. Characteristically the first few terms of the series dominate the motion since the magnitude generally decreases with increasing n; therefore the rocket vibrations case study has cut the series off at n=4 for speed of computations.

Implementation

These three case studies developed are part of the 'GT Vibrations' series on vibrations. The objective of this package is to augment the student's understanding of the subject of vibrations. This program is being used in the undergraduate course in vibrations in the School of Aerospace Engineering at Georgia Tech. The program is made available to the students via the network. Also, the program can be stored and operated from a CD that can be used on any Macintosh computer with a CD-ROM player required for storage of the program. Requirements of the hardware include a color monitor and a minimum of 8 megs of RAM. The program is developed on the Macintosh platform. A windows version is currently being developed.

The program is developed as a supplemental tool for use in conjunction with the theory learned in class. The modules on basic theory follow the format of a typical undergraduate book on vibrations and system dynamics. Therefore, this program can also be tied to a book as an additional package.

Conclusion

The goal of this work is to introduce case based multimedia in engineering education. These case studies are part of the 'GT Vibrations' series. The intention is to create a multimedia package that complements the theory so the students can achieve a better understanding of the subject. Practical problems are posed in each case study, and the programs are designed to simulate a design process that is similar that of the real world. The program allows that the student to determine the effects of varying parameters and see the results instantaneously. The program simulates vibrations and oscillations as it pertains to each case study. and by designing a system and then simulating its response, the student can gain a deeper appreciation of the problem.

Bibliography

1. Higuchi, H. and E.F. Spina, "Improving Undergraduate Engineering Education Through Scientific Visualization," 1993 ASEE Conf. Proc., Urbana-Champaign, June 1993, pp. 1581-1583.
2. Stone, B.J., "A Computer Assisted Learning Package for Two-degree of Freedom Vibration," 1994 ASEE Conf. Proc, Edmonton, Canada, June 1994, pp. 1262-1266.
3. Yusuf, I., K. H. Slater and K.C. Gramoll, "Using 'GT Vibrations' in System Dynamics and Vibrations Courses", Conf. Proc. ASEE, Edmonton, Canada, June 1994, pp. 952-958.
4. Gramoll, K.C., "Using 'Working Model' to Introduce Design into a Freshmen Design Course," Conf. Proc. ASEE, Edmonton, Canada, June 1994, pp. 1628-1633.
5. Hix, V. and H. R. Hartson, "Developing User Interfaces," John Wiley and Sons, Inc., New York, NY, 1993.
6. Inman, D.J., "Engineering Vibration," Prentice Hall, Inc. Englewood Cliffs, New Jersey, 1994.
7. Juhasova, E., "Seismic Effects on Structures,", Elsevier, New York, 1991.

IMRAN YUSUF

Imran Yusuf graduated from the Georgia Institute of Technology in 1992 with a BS in Aerospace Engineering. He earned an MS in Aerospace Engineering from there in 1993. He worked as a graduate research assistant in the Aerospace Engineering Multimedia Lab. Imran Yusuf is currently pursuing a doctorate degree in Aerospace Engineering.

KURT SLATER

Kurt Slater graduated from Georgia Tech in 1993 with a BS in Aerospace Engineering. He worked as a research assistant for the Aerospace Engineering Multimedia Lab at Georgia Tech from 1993 until 1995 and earned an MS in Aerospace Engineering in 1995.

KURT GRAMOLL

Dr. Kurt Gramoll is currently an Assistant Professor in the School of Aerospace Engineering at Georgia Institute of Technology. He graduated from the University of Utah with a BS in Civil and a MS in Mechanical Engineering. Later, after working at Thiokol, Inc., he received his Ph.D. in Engineering Science at Virginia Tech in 1988. Since then he has taught at Memphis State University and worked at the Japanese National Institute for Space and Astronautical Science. His technical research work involves filament winding of composite structures and fluid-structure interaction. He is also heavily involved educational research, particularly in the development and use of multimedia programs in engineering.