

Using 'GT Vibrations' in System Dynamics and Vibrations Courses

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Abstract

This paper presents an overview of an interactive multimedia vibrations program called GT Vibrations. GT Vibrations contains a series of modules that deal with elementary vibrations, transient vibrations, and continuous systems. The program is intended to be used as a supplemental tool for undergraduate courses in vibrations and system dynamics at Georgia Tech. The underlying goal of the program is to enhance the student's knowledge of vibrations by supplementing complex problems with text, graphics, animation, sound, and interaction. The program presents the student with what-if design scenarios in which he can modify different parameters of a mechanical system; in this fashion the student can see how different parameters affect the overall response of a system. The program is essentially a visual design tool which complements the theory and problem solving done in the classroom.

Introduction

GT Vibrations is an interactive multimedia program designed to be used as a supplemental tool for introductory courses on vibrations to help engineering students gain a better understanding of vibrating systems. The program is essentially a visual design tool which complements the theory and problem solving done in the classroom. The premise under which this program is being developed is that visual representation of relevant principles creates a better understanding through direct interaction that calls upon physical intuition and cognitive skills [1-2]. A primary objective of this project is to create a link between what a student learns in class and what can be learned from the software. The intent is that this partnership will complement the student's creative and cognitive skills and will augment his knowledge on the subject of vibrations. Through this collaborative learning process, the student can visually see the response of a dynamic system to an input, modify system parameters and see the output, or do case studies of complex vibration problems. In this fashion, the student can gain a deeper understanding of the parameters that govern the response of a system. Consequently, the program not only reinforces what the student learns in class, but adds another

dimension to the learning process by relying upon the creativity of the student as he interacts with the program to analyze complex vibration problems.

The integration of the usage of computers with the course creates a dynamic environment where the student can interact with the computer. The time needed for the student to learn and effectively use the program is to be kept to a minimal, therefore the interactivity of the student with the program is relatively simple. Thus usability is an important factor because students have a limited amount of time to learn the program [3]. What a student can accomplish by using this program depends solely upon him as he can follow the content at his own pace. Depending on his familiarity or keen interest in a topic, the student can simply select it and proceed to investigate it further detail.

GT Vibrations has been developed as a self contained program, and it operates on Macintosh computers. Currently three modules have been developed, those being, elementary vibrations of one degree of freedom systems, transient response, and distributed parameter systems. These individual modules are integrated into one program that can be stored on a CD disk which can be used on any Macintosh computer with a CD-ROM player required for storage of the program.

GT Vibrations is a multimedia program created in MacroMedia Director which is a powerful tool designed to incorporate multimedia capabilities inherent in the hardware and software of the Macintosh. GT Vibrations program is patterned after and closely follows undergraduate text books on vibrations.

Objectives

GT Vibrations program is intended to supplement what the student learns in the undergraduate vibration's course. The program closely follows the course and the subsequent topics have currently been included in the program:

- Oscillatory Motion, Periodic & Harmonic Motion
- Free Vibrations of One-DOF Systems
- Harmonically Excited One-DOF Systems
- Transient Response of One-DOF Systems
- Free Vibrations of Continuous Systems

Three modules have been developed for the program. The key point considered here is to realize that the modules developed have to be flexible enough so that they can be easily integrated and implemented into an already existing framework. These modules are part of a puzzle that have to fit together in an overall framework, or else inflexibility will result in small programs incapable of further development and integration.

As part of the overall objective, additional models will be made as the project progresses. A detailed analysis of each topic listed above along with 'what-if' design scenarios for systems under consideration is needed. Through this type of interaction, the student can closely look at how key parameters that govern a system affect its response. For example, questions like what happens to the natural mode shapes of a beam when the boundary conditions are changed, or why systems behave in the particular way when under certain inputs, can be readily answered.

Software Issues

Several different software packages are used in solving vibrations problems for the GT Vibration program. Application packages like Mathematica, Working Model, and Strata Studio Pro are just a few. A brief description of how each of these programs are incorporated in the three modules

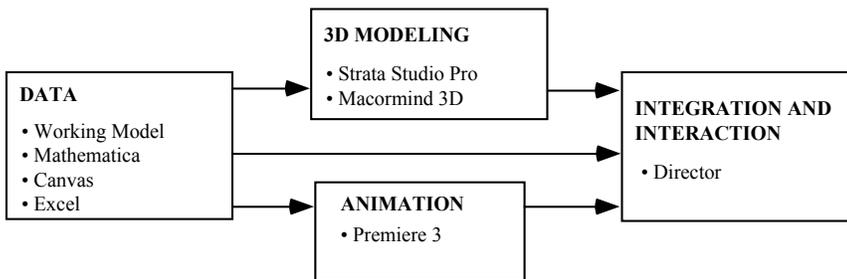


Fig. 1. Flow chart of interface software development and implementation

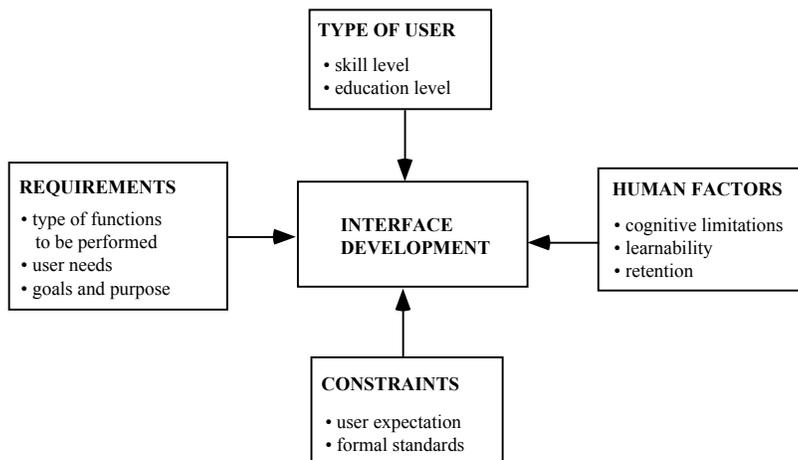


Fig. 2. Interface design process

is given herein.

The free vibration analysis of a simply-supported beam, a cantilever beam, and a simply-supported plate was first done in Mathematica to determine the resulting eigenvalues and the corresponding eigenvectors. The plots of the eigenvectors (natural mode shapes) were then saved as a PICS files and QuickTime movies for latter playback in Director to show visual animation of the modes shapes.

In the elementary vibrations module, the complete analysis of several one-DOF damped/undamped systems were done in Working Model, which is a mechanical simulation program. A description of the system's characteristics such as it's position, velocity, acceleration, etc. with respect to time was then saved from Working Model as a QuickTime movie. By using QuickTime movies, the playback animation was controlled by the scripting language, Lingo, in MacroMedia Director. By making QuickTime movies instead of PICS files, the problem of "too many frames" to show the complete motion of the system was resolved as well as that of faster speed and less memory usage. An additional advantage of Working Model was that it could be directly linked with Director. This allows the user to go from Director to Working Model to test actual examples where he can modify the system parameters and see the response. After quitting Working Model, the user is returned to Director at the same point he left. Strata Studio Pro was also used to perform three dimensional modeling, rendering, and animation, such as spring-mass animations. A basic flow chart depicting how different application packages were used in the software development of the program is shown in Fig. 1.

Human Computer Interaction

Human Computer deals with interface design, cognitive science, human factors and similar issues. In the development of this program, issues in cognition, and human and computer capabilities have been considered. The goal from this study is to attain the highest degree of usability. Usability is related to the effectiveness and efficiency of the interface, and to the user's reaction to the interface [4]. The two processes considered in human computer interaction are interface design and interface software development.

Interface design

When designing an interface, several factors have to be accounted for, perhaps the most important being the human factor. This basically deals with the user-system interaction and psychological impact. The first impression the interface has on the student is significant. A 'clean' and well organized interface reduces the anxiety of a student who is trying to learn and use the program. The mark of a good interface is high degree of retention after use and low error rate. In addition to human factors, other facets of the

interface design process are the type of user, user specifications (requirements), and constraints. These are shown in Fig. 2 and their influence on interface design are discussed subsequently.

Interface Software design

The goal of interface software design is to link the program to the student through the software. The implementation of the software with the interface creates an interactive system. The success of this linkage is crucial to the overall success of the program use. A chart showing the different phases of this process is shown in Fig. 3.

The first step in this development process is to specify the level of functionality the program has to perform. Functions like textual interaction, menus and navigation buttons are needed for this program. Sound is also important because it is used to describe to the student what a particular problem is about and adds additional insight to the problem. In order to reduce user error rates and increase efficiency, the program has to be robust. Since GT Vibrations contains a series of modules, they have to be integrated into an overall framework, this requires that the individual modules be

flexible, otherwise they will not be useful educational tools. Third party software programs, such as Mathematica and MathCad currently can not be directly linked to Director. Future revisions of Director should ease this difficulty and allow number crunching programs to solve numerical problems in the background and then display the results in Director.

This program is designed for first level undergraduate courses in vibration and systems dynamics, therefore the user is assumed to be a sophomore. It is expected that the student has been exposed to elementary differential equations. The requirements for this program are to supplement what the student learns in the classroom and draw upon his cognitive abilities and physical intuition to solve vibration problems as mentioned in the introduction. A very important constraint was to keep the interface as simple as possible. It draws upon the student's familiarity of using other Macintosh and Windows application packages. This reduces the time needed to learn and effectively use the software.

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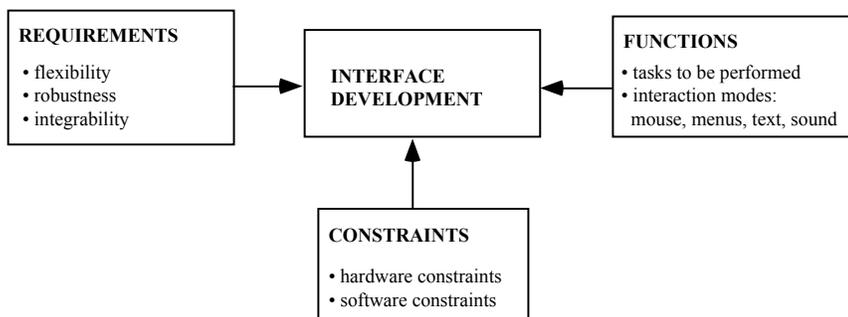


Fig. 3. Interface Software design process

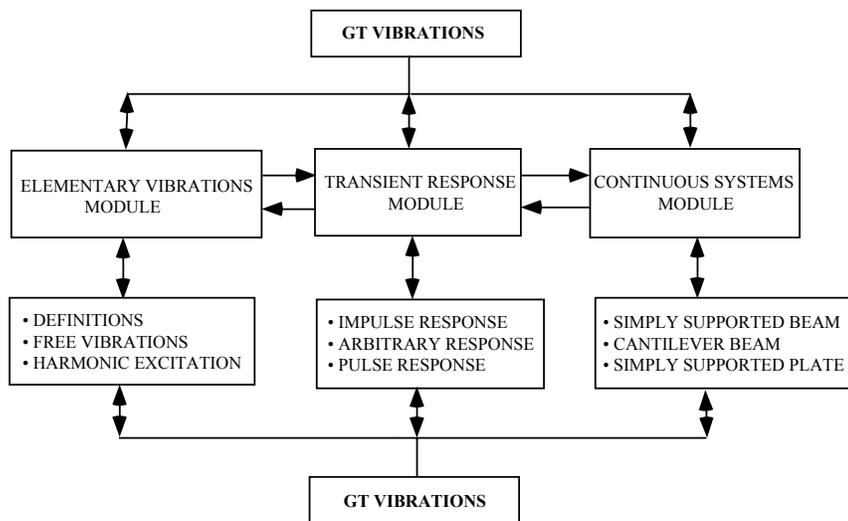


Fig. 4. Integration of modules

Content

GT Vibrations contains three modules that supplement the undergraduate course in vibrations and system dynamics. The Elementary Vibrations module of the GT Vibrations series focuses on free and harmonic vibrations of one-degree of freedom systems. The Transient Vibrations module deals with response of damped and undamped one degree of freedom systems to nonperiodic inputs. The third module, Frequency Response Analysis, deals with classical control theory and structural dynamics. The integration of these modules is shown in Fig. 4. The structure of the flow chart is hybrid. The modules are interconnected (non hierarchic) down to a certain level in order to keep the linkage simple. However, within each module at any level, the student can go back to the main program (GT Vibrations) at anytime.

Elementary Vibrations Module

This module covers basic concepts like harmonic motion, natural frequency, damping, etc. along with free and harmonically excited vibration

of One-degree of freedom systems. The module allows the user to select any one of three topics, Definitions, Free Vibrations of One-degree of Freedom Systems, and Harmonically Excited Vibration. This is shown in Fig. 5a, where the student makes a selection from the three topics. After a selection has been made, the introduction to that topic is displayed in the form shown in Fig. 5b. The larger window is used to display textual data and is the primary window. The two secondary windows show graphical/animated data. In the secondary windows, the student can play an animation of the response of a system and can control the movie through the standard play, pause, and rewind buttons as shown in Fig. 5b. The control panels at the bottom of the screen remain throughout the module, thus preserving continuity. The interaction with the module is done through the navigation buttons at the bottom as seen in Fig. 5b or through the menu bar. The navigation buttons function in a similar manner as those buttons on a VCR. The quit button is incorporated in all modules to allow the user to exit the program at any time.

Under each of these headings shown in Fig. 5a, the student has control over what aspect he wants to look at. For example, under harmonically excited vibration, he can look at either the damped or undamped case, and can see the response of the system as well as a complete solution. He can also physically change the parameters of the harmonically excited spring mass system by modifying parameters like the spring constant, natural frequency, and damping ratio. This type of interactivity is made possible through Working Model, a mechanical simulation program. In the examples set up in Working Model the student has complete control over the system. Figure 5c shows a typical setup of a problem in Working Model.

Modal Analysis Module

The Modal Analysis module of the GT Vibrations series is designed to supplement the learning of continuous systems dynamics. The module allows the user to analyze three different continuous systems: a cantilever beam, a simply supported beam, and a simply supported plate. For each system, the first four modes of vibration are animated and the theory involved as well as the boundary conditions for the system can be reviewed at the users request.

By selecting **First**, **Second**, **Third**, or **Fourth Mode**, the user determines which vibration mode is studied. As shown in Fig. 6a, the mode shape selected by the user is animated in the upper right hand corner. By selecting **Theory**, the user can follow the logical derivation of the theory related to the system studied (Fig. 6b).

The theory begins with a differential stress element and leads to the full equation of motion in space and time. Selecting OK scrolls the screen to the next step of the derivation, while selecting the left and right arrows allows the user to jump forward and back to review or skip certain aspects. By selecting Boundary Conditions the user can review the boundary conditions for the current system and then return to the theory.

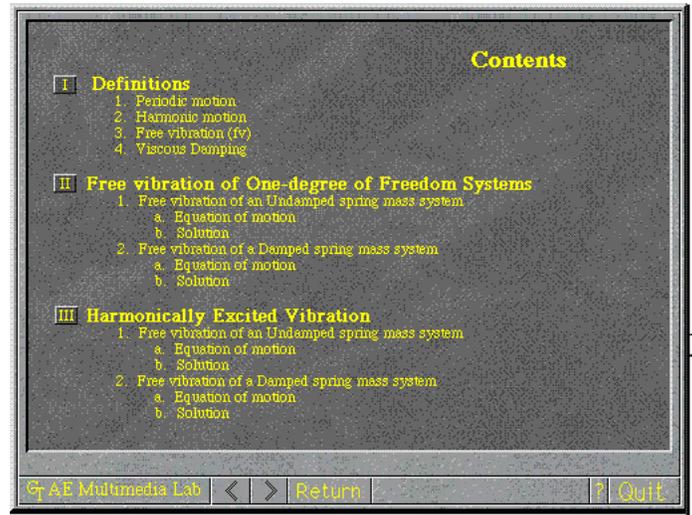


Fig. 5a. Elementary Vibrations. Content Screen.

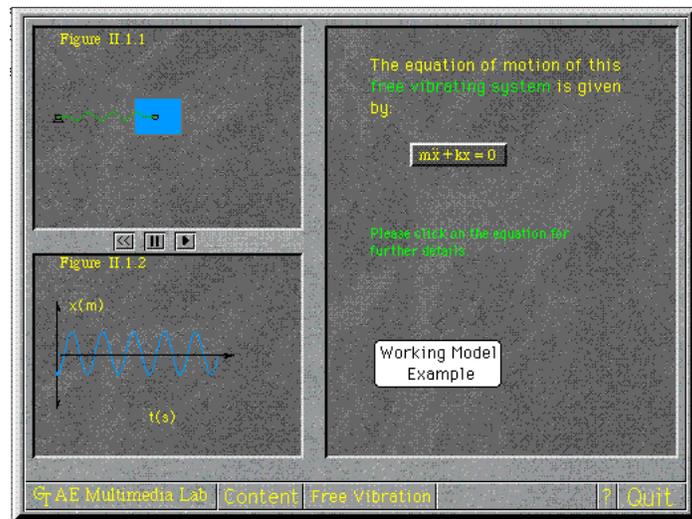


Fig. 5b. Typical Screen for Elementary Vibrations.

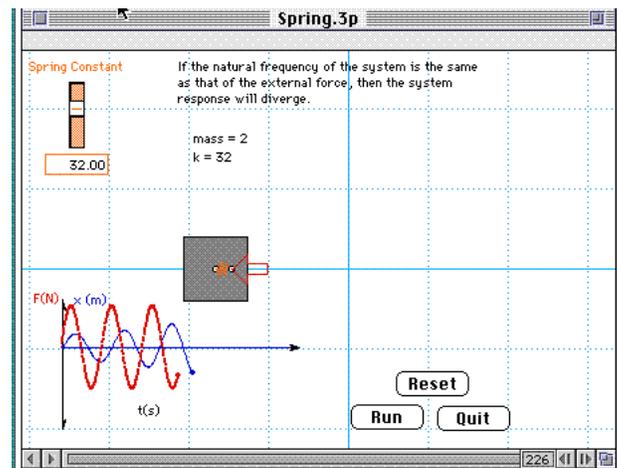


Fig. 5c. Working Model Example Interface.

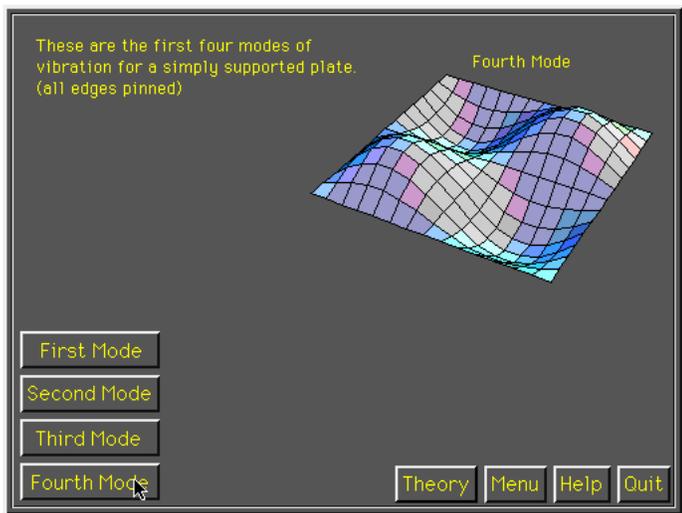


Fig. 6a. Mode shape animation.

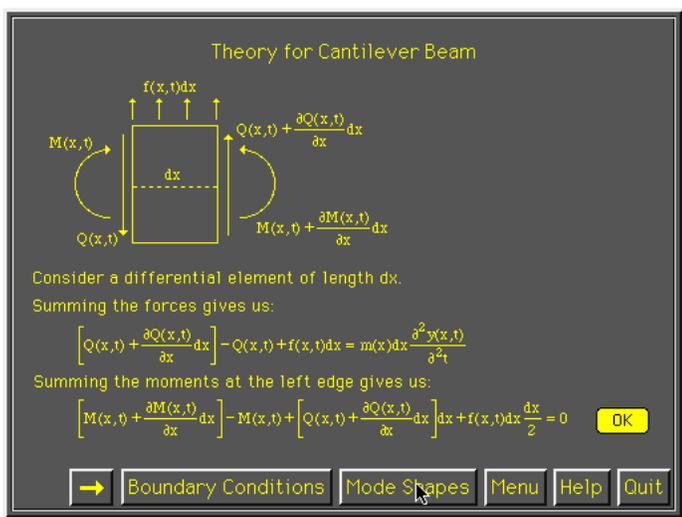


Fig. 6b. Theory derivation.

The equations shown do not include every algebraic step but instead follows along the lines of an advanced engineering manual in which key points of the derivation are shown and solution techniques are explained.

Currently the module has no on-line analysis tools but instead is a representation of results obtained elsewhere. As the future brings better analysis tools, the module will become truly interactive; allowing the user to not only review but change the boundary conditions for a system and analyze the results.

Transient Vibrations Module

The Transient Vibrations module of the GT Vibrations Multimedia Series deals with the response of damped and undamped single degree of freedom system when subjected to a short duration, nonperiodic input. The module is divided into four sections; the first three develop the necessary tools for mathematical analysis using theory and examples while the final section gives the user interactive control of a damped or undamped system for the purpose of experimentation.

The program layout of the menu is similar to the elementary vibrations module. To proceed to any sections the user selects the button corresponding to the desired topic and use the left and right arrows to move through the logical progression of the module.

The first section, **Impulse Excitation**, develops the mathematical model for an impulse function and demonstrates the effect it has upon a mass at rest. Section 2, **Arbitrary Excitation**, builds upon the content of section 1 as it is shown how any input function can be constructed through a system of impulse functions. Again, examples are used to illustrate key points as well as theory. The **Pulse Excitation** section develops results for two common input functions, the square pulse and the ramped pulse. Since many real world situations can be modeled using these two pulses, many times is unnecessary to develop the equations but instead results for a typical square or ramped pulse can be used. Like section 2, this section builds upon the previous sections. Fig. 7a shows the general layout for each section. In this example a spring mass system responds to a square pulse input.

The final section, **Lab**, gives the user complete control over the response analysis of damped or undamped spring-mass system. The user can select the type of input, impulse, square, or ramped; as well as vary the system properties, spring constant, mass, damping constant and input magnitude. After setting the system to the desired properties, the system response is animated with input and displacement functions being graphed real time. Figure 7c shows the layout for the lab interface. Note the slider controls for the mass, spring constant, damping constant and force.

Frequency Response Analysis Module

The Frequency Response Analysis module of the GT Vibrations series is currently in the design phase. The module is intended to bring the gap between classical control theory and structural dynamics.

Current plans for the module include modeling of single and multiple degree of freedom systems for analysis in the frequency domain. Analyzing systems in the frequency domain gives insight to relationships between natural frequency, input frequency, damping ratio, and mode of vibration.

Plans also include a section to describe experimental analysis techniques for large continuous structures in which classical results are difficult to obtain; i.e. a vibrating airplane wing or building.

Classroom Use

Currently, these modules have been used only over the network in the School of Aerospace Engineering. The modules have been generally well received but there has been no formal testing of the programs to determine how useful they are in the learning process. The modules were developed to support the learning process outside the classroom and not as a classroom presentation tool. Multimedia works best as a supplement to the textbook and lecture outside of the classroom. In the future, the modules, along with other modules in strength of materials and dynamics, will be distributed directly to the students on a CD and the students will be encouraged, but not required, to use the programs as they take the courses. At that time control groups will be formed and formal testing of the programs will be undertaken.

Conclusions

The main thrust of the GT Vibrations program is to enhance the student's grasp of the subject of vibrations. The intent is to integrate the use of computers in classrooms so as to produce an efficient and dynamic environment for engineering students. The program is easy to use and the time needed to learn this program for vibration's courses is minimal when compared with other complex commercial programs. This program is designed for undergraduate courses in vibrations and covers a specific number of topics, therefore the use of the program outside of the course is limited. GT Vibrations is a small topic specific program, but its flexibility allows for a merger into a larger framework of complementary multimedia programs being developed in the Aerospace Engineering Multimedia Lab at Georgia Tech.

Acknowledgments

We would like to acknowledge the financial support of the Woodruff Foundation through the Edutech Institute at Georgia Institute of Technology and for the support of the School of Aerospace Engineering for this project.

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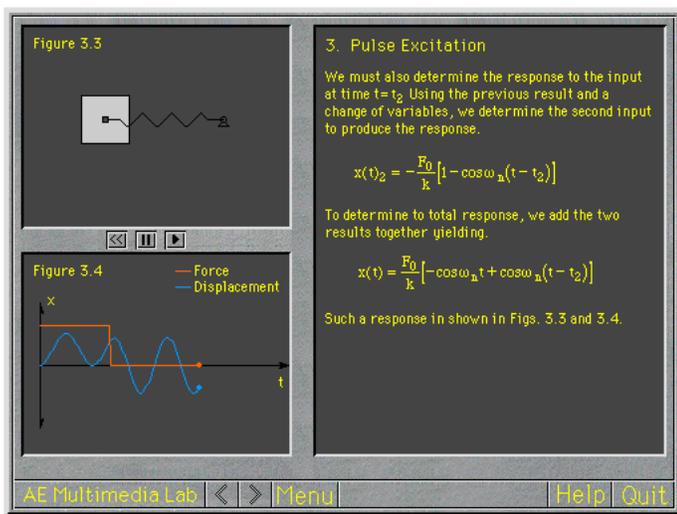


Fig. 7a. Square Pulse Excitation

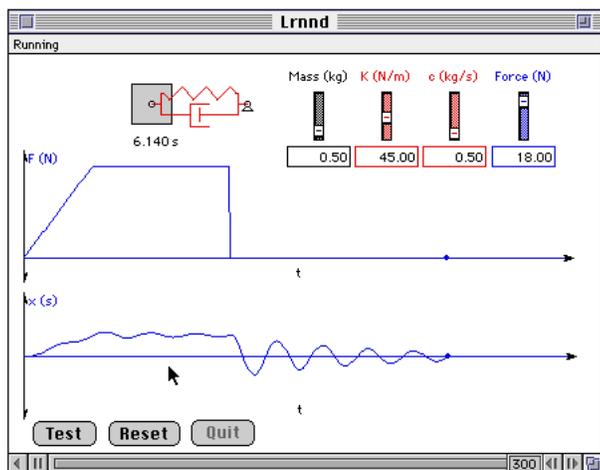


Fig. 7b. Lab Interface

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Imran Yusuf graduated from the Georgia Institute of Technology in 1992 with a BS in Aerospace Engineering. He earned a MS degree in Aerospace Engineering from there in 1993. As a graduate student he worked as a graduate research assistant in the Aerospace Engineering's Multimedia Lab. There he worked on multimedia projects dealing in vibrations and structural dynamics. His areas of specialization are in structural dynamics and composites. Imran Yusuf is currently pursuing a doctorate degree in Aerospace Engineering.

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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.