

# Multi-disciplinary Design Projects in a Capstone Design Course

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**Abstract** — In the one semester, three engineering department (Electrical and Computer Engineering, Industrial Engineering and Mechanical Engineering), capstone design course taught in the Cullen College of Engineering at the University of Houston, multidisciplinary teams (at least two of the three departments must be represented on the team) work on design projects provided by local industry, the faculty, and national student design competitions. In the last two years (2003-2004) 64 teams involving 246 students have worked on 53 different projects in the course. These projects could be classified as follows:

- Twenty-five projects provided by local industry supporting 27 teams as two projects were repeated,
- *Fourteen projects provided by the College research laboratories,*
- *Five projects associated with national student design competitions (A total of 14 teams worked on these projects.), and*
- *Nine other projects provided by faculty and the class instructors (Some were open ended product development projects.).*

*The industrial projects were provided from the following sources:*

- *Petrochemical industry: eight projects*
- *NASA Johnson Space Center: seven projects*
- *Small development /manufacturing companies: eight projects*
- *Individuals: two projects*

*The University research laboratories that have been involved are:*

- *The Nano Engineering Laboratory in the Department of Electrical and Computer Engineering that focuses on commercial applications of micro -nano scale structures (6 projects),*
- *The Opto-electronic Materials and Devices Laboratory in the Texas Center for Superconductivity and Advanced Materials that specializes in developing novel IR sensors and detectors (2 projects), and*
- *The Smart Materials and Structures Laboratory in the Department of Mechanical Engineering that specializes in active and passive vibration control and structural health monitoring. (6 projects).*

*The product development projects require that the students develop a new product which includes: performing the associated market surveys, developing a business plan, designing the device, and then building and testing a prototype. A semi-retired engineer and business entrepreneur has served as client and consultant for these projects. These projects have included:*

- *a low power light source,*
- *a foot activated computer interface,*
- *a smart crutch using an MR fluid, and*
- *a human fatigue sensor and alarm.*

This paper will describe some of these projects and how the structure of the course allows the entire class to be introduced to all class projects and how all teams are encouraged to assist other teams as they are able. In fact, the course final exam includes questions on all the projects for that semester.

**Index Terms** — capstone design, emerging technology, hands-on, multidisciplinary design, multidisciplinary teams

## INTRODUCTION

In episode 1410 of the “Engines of Our Ingenuity,” [1] John Lienhard states:

“The Greek word *tecnh* (pronounced *techne*) describes art and skill in making things. *Tecnh* is the work of a sculptor or a stonemason, a composer, or a clock-maker. *Ology* is the study or the lore of something. Technology is the knowledge of making things. Some argue that we shouldn't call our species *Homo sapiens* or the-wise-people, but rather *Homo technologicus* or they-who-use-*tecnh*, for that is who we are. We freed our hands by walking on our hind legs before we took up tool-making. When we made our earliest stone tools 2.4 million years ago, our brains were still fairly small. Our capacity for thought began growing after we began making sophisticated implements. Thinking and tool-making are wed to one another.”

Further, the American Heritage Dictionary's first definition of “technology” [2] is: “The application of science, especially to industrial or commercial objectives” which sounds much like their definition of “engineering” [3]: “The application of scientific principles to practical ends as the design, construction, and operation of efficient and economical structures, equipment and systems.”

The value of a culminating or capstone experience stressing “applications” to an undergraduate engineering program has long been recognized. However, over the past 40 years undergraduate engineering curricula in the United States have “dropped” much of its traditional “technology” and replaced it with additional analysis based instruction and computation as the content has been reduced from about 150 hours to about 125 hours. There are fewer and fewer “hands-on” opportunities for the students. Also the classic areas forming the foundations of the major engineering disciplines are beginning to branch out, for example, electrical engineering into micro electronics, computer engineering and information systems; mechanical engineering into nano-technology, smart materials, bio-medical engineering and micro-medical systems, etc. These areas are considerably more “high-tech” than electrical circuit bread-boarding, antenna design, engine testing, HVAC systems testing and classic controls which are some of the hands-on technologies utilized in undergraduate laboratories and design projects. Also, some of these “advanced” topics are not taught as part of the core undergraduate curriculum, nor even as part of special electives. The issue is then how to provide the “hands-on” experiences associated with the design of artifacts while at the same time provide exposure for students to these emerging technologies without introducing new courses. We have been attempting to solve this problem through our interdisciplinary capstone design course with the help of faculty working in these emerging areas and by requiring all students in the class to become aware of, if not actually involved with, the other projects in the class.

## CAPSTONE DESIGN AT THE UNIVERSITY OF HOUSTON

The capstone design course at the University of Houston is taken by three of the five engineering departments: Mechanical Engineering, Industrial Engineering, and Electrical and Computer Engineering. The course was originally taught in the Department of Mechanical Engineering (ME) and has existed (until recently), more or less, in its present form since 1981. At that time it was taken by only the mechanical engineering undergraduates. In the mid-80's the Department of Industrial Engineering (IE) joined the course so that project teams were composed of both ME and IE students. The course was offered in both the fall and spring semesters and was being taken by up to 75 students a year. Six years ago the Department of Electrical and Computer Engineering (ECE) added the course as a degree requirement for all students entering in the fall 1998 and thereafter. Shortly thereafter some ECE students began taking the course as an elective. That number has grown over the past four years to about thirty in the fall, 2002. Fifty-six ECE students (for a course total of 87) were enrolled for the spring, 2004. It is anticipated that between 70 and 90 students from the three departments will eventually be enrolled in the course each fall and spring semesters on a continuing basis. More complete descriptions of the new capstone course can be found in [4-7].

The general guidelines for the capstone projects are that they:

- Should be only of the highest possible technical quality,
- Should be presented (proposals, progress reports, final reports, etc.) using only the highest possible quality written and oral communication,
- Should have “tangible” results that can be tested and/or validated, or in the absence of such results a satisfactory justification and project critique provided,
- Should be multi-disciplinary (i.e., allowing contributions from at least two of the three disciplines represented in the class), and
- Should require about 350 person-hours of effort from four person teams composed of senior-level engineering students representing (to the extent possible) at least two of the three departments.

One of the features of our capstone course is that most of the interaction with and among the teams occurs in cohorts composed of three or four teams. For example, for spring 2004, eight sets of 90-minute cohort meetings were scheduled at approximately two-week intervals. (Each set is actually six meetings as the 87 students in the class are divided into 22 teams, and the teams assigned to one of six cohorts.) Project planning and communication issues (as well as many other “professional” issues) are discussed with the current projects used as examples or case studies. The teams with projects involving similar technology are grouped in the same cohorts. Teams make informal presentations and present samples of their work at each cohort meeting. The teams are encouraged to work together as appropriate. There are four rounds of oral and written reports before the final report. These four reports are individual requirements, and the oral reports are presented to a rotating audience of different cohorts throughout the semester. By the end of the semester each student has heard at least one report on each project. Therefore the all projects receive a significant exposure throughout the cohort and a limited exposure throughout the entire class. In addition, at the end of the semester, all teams prepare poster presentations and extended abstracts (as well as the usual final oral and written team reports) that are on display for three days in the Commons area for the Cullen College of Engineering for all engineering students and faculty to view. A final exam is administered in which approximate 50% covers ones own project, 30% covers projects in ones cohort and 20% covers the other projects.

In 2003 (spring and fall semester combined), there were 140 students formed into 36 teams working on 27 different projects divided among the three instructors. The projects are listed in Tables 1 and 2. Abstracts are included for the projects from the University’s Research Laboratories (Table 1).

Two projects, completed in the spring 2003, have been selected for detailed description in this paper. These projects were proposed and funded by Gangbing Song, the faculty-in-charge of the Smart Materials and Structure Laboratory in the Department of Mechanical Engineering, as part of the work on his NSF Career grant. These projects have been singled out because they are good examples for having students face and solve a variety of engineering design problems from several disciplines and for providing “hands on” access for all engineering students in the program to elements of two emerging technologies in the controls area. The teams were given similar instructions for both projects: Develop interactive, hands-on experiments to illustrate the features of 1) a magneto-rheological (MR) fluid and 2) a shape memory alloy (SMA).

## **THE TWO PROJECTS [8]**

A magneto-rheological (MR) fluid is a liquid whose viscosity changes in proportion to an applied magnetic field. When the magnetic field is controlled by a computer, an MR fluid system can also become a very effective control device. Shape Memory Alloys (SMAs) are “smart” materials that have the ability to return to a predetermined shape when heated or cooled. This property enables a SMA to be used as a sensor or actuator and is becoming a popular choice for many modern controls applications. Both of these materials, SMAs and MR fluids, are relative new control devices and not normally prominent in the core undergraduate curriculum, although they are normally covered in elective controls courses. With the intent both to provide meaningful electro-mechanical system design problems for the capstone class and to raise the awareness and interest in these materials for students at and visitors to the University of Houston, the development, design and fabrication of the demonstration projects were assigned to the two design teams. One team was composed of two Electrical and Computer Engineering (ECE) students and two Mechanical Engineering (ME) students; the other, of one ECE student and three ME students. Three demonstration/experiments were developed using a hydrocarbon-based MR fluid (MRF-132AD)[9]: a disk brake, a vibration damper and a crane. Two sets of demonstration/experiments were developed and implemented using a nickel-titanium alloy (Nitinol) as the SMA: a lifting device and a flexible limb mechanism. Both sets of demonstrations were housed in ventilated, acrylic cases that are now displayed in the lobby of the Department of Mechanical Engineering.

## **THREE DEVICES DEMONSTRATING THE USES OF A MAGNETO-RHEOLOGICAL FLUID**

### **Introduction**

As noted above an MR Fluid is a liquid whose viscosity changes when a magnetic field is applied to it. The stronger the magnetic field applied to the fluid, the more viscous the fluid becomes. The fluids have been around since the 1950’s but have found few applications until recently. When computers were used to control the magnetic field being applied to the fluid, some useful engineering applications evolved. The client’s objective was to raise the awareness and interest of University of Houston students and visitors in Smart Materials by building an interactive display showcasing the properties and applications of an MR-Fluid.

#### Design of In-Vacuum Cold Sink

A backside helium cooling system was designed to reduce stencil mask distortion due to overheating during x-ray lithography used for integrated circuit fabrication. Thermistors, placed on the membrane surface as carbon cement, were used to measure the temperature of the fragile membranes. The thermistors were calibrated with the aid of a digital hot-plate.

#### Manufacturing Research Data Base

A user-interface to an existing database was developed using MS Access database software and ColdFusion web-application software to establish a more efficient method for tracking the data associated with the manufacturing films and masks from silicon wafers. The final product was a thoroughly tested, web-based system in which the user has the ability to scan a bar code and retrieve or input data associated with a wafer's manufacturing process. A comprehensive user's guide was provided.

#### A "Feeling" Robotic Hand

This was a haptic feedback, demonstration project, and represented the first step in the design and implementation of a "Feeling" Robotic Hand that could be used, along with other sensors, to practice medicine at the distance. A pressure sensor (acting as a "probing finger") was calibrated and used to produce a proportional current to drive a force actuator, a voice coil, that applied a calibrated force to the "sensing finger".

#### Demonstration of a Magneto-Rheological Fluid

Three interactive experiments/displays illustrating the properties and applications of a Magneto-Rheological (MR) Fluid were designed, fabricated and tested. An MR fluid is a fluid whose viscosity changes in the presence of a magnetic field. The three experiments are: a MR fluid disk brake, a vibrating platform with MR fluid dampers, and a crane that raises and lowers an electromagnet in and out of an MR fluid. All three experiments possess interactive controls and were mounted in a ventilated, acrylic display case.

#### Demonstration of a Shape Memory Alloy

Two electrically controlled, interactive Shape Memory Alloy (SMA) actuator demonstrations were designed, fabricated and tested. A SMA is a metal that demonstrates the ability to return to some previously defined shape or size when subjected to the appropriate heating or cooling. The first demonstration is a weight lifting mechanism that uses seven strands of 0.015 inch diameter Nitinol wire to lift twenty pounds when the wires are electrically heated. The other demonstration is a flexible limb mechanism composed of a strip of flexible metal that has 0.015 inch Nitinol wire actuators attached to both faces of the limb. The coordinated, alternating electrical heating of each wire allows controlled movement of the flexible limb. The Nitinol has a transformation temperature of 90°C, at which its crystal lattice structure changes from Martensite to Austenite that results in contraction of the wire. Both demonstrations are housed in a ventilated acrylic case currently on display in the lobby of the Department of Mechanical Engineering.

#### Implementation of a Positional Feedback System for Metrology Tool

The x-y stage of a metrology tool used to examine semiconductor wafers was upgraded by implementing a positional feedback system using a proportional-derivative control scheme and coded with LabView software that interacts with a charge-coupled-device camera to determine the coordinates of the stage. Testing of the system revealed that the system's precision was about 20 microns which was not acceptable. Part of the problem was traced to way the camera acquires images and to the positioning errors associated with the DC motors.

#### Remote Sensing Hand Using the Internet for a Haptic Interface

The "Feeling Hand" project from the previous spring was repeated. Different techniques were utilized for both the "probing" and the "sensing" finger, and an internet link was added between the probing and sensing functions. A unique "probing finger" sensor was designed fabricated, calibrated, and tested successfully. The internet link was established using LabView. An attempt was made to develop a novel "sensing finger" using a (variable viscosity) MR fluid (see above) as the working fluid in a cylinder-orifice system but it was not successful due to the clogging of the orifice.

#### Smart Crutch Using an Electro-Magneto Fluid

A Magneto-Rheological (MR) Fluid (see above) sponge damper controlled by an electromagnet was used in the design of an innovative crutch. A predetermined (and controllable by the user) electrical signal was generated with each crutch impact with the ground and then used to control the "damping" constant of the system (through the MR fluid) to reduce the impact shock of the crutch. The design was fabricated but met with only limited success because a damper system with a satisfactory orifice opening was not found. The iron particles present in the MR fluid tended to plug up the orifice.

#### Active Guide Wire for Angioplasty

A method was developed and implemented (in principle, not in patients) to overcome the lack of control in current procedures for directing the guide wire into position in the artery for an angioplasty procedure (displacement of plaque buildup in coronary arteries). Two Shape Memory Alloy (SMA, see above) actuators were micro-welded to opposite sides of the wire. By selectively heating and/or cooling the two opposed SMA actuators (by applying a pulse-width modulated current), the guide wire can be forced to turn to one side or the other as dictated while the progress of its tip is followed on a real time fluoroscopic x-ray screen.

TABLE 1

PROJECTS SPONSORED BY RESEARCH LABORATORIES IN 2003

Projects for outside sponsors:

An Active Defense Robot for Practicing Free Kicks (two projects)  
A Dressing Station for Upper Bi-Lateral Amputees  
A Multiple Station Extrusion Device  
An Inventory/Distribution/Transportation Synchronization Decision-Making Tool  
A Software Tool for Use as Part of NASA Shuttle Simulation Training  
A Mechanized Fire Hose Lay-up Device  
Preparation of NASA Nanocomposites  
Re-engineering of a Commercial Borescope for Space Applications

Projects for faculty:

An Interactive, Controllable, Demonstration of a Variable Speed Transmission  
A Human Powered Electric Generator with Mechanical Energy Storage (two projects)  
A User-Friendly, Computer Based System for Assisting Visitors in Finding People and Rooms in the College of Engineering (two projects)

Product development projects:

Commercialization of a Foot Activated Computer Interface  
Commercialization of a Low Power Light Bulb  
Commercialization of a Human Fatigue Sensor

Eight projects for regional student design competitions:

Seven Teams in the IEEE Robotic Competition (a 2<sup>nd</sup> and 4<sup>th</sup> place regionally)  
One Team in the ASME National Design Contest (3<sup>rd</sup> place regional)

TABLE 2:  
ADDITIONAL PROJECTS FOR 2003

Jacob Rabinow invented the MR Fluid in 1947 [10]. The original MR fluids designed by Rabinow were nine parts iron particles and one part carrier liquid, which at the time was either silicone oil, petroleum oil, or kerosene depending on which one better suited the particular application. Additional additives improved the stability of the fluid and retarded the settlement of the particles. Even though the settlement of the iron particles remains an issue, it is mainly overcome by the dynamics of the applications. Since the relevant property of these fluids is their viscosity and our ability to control it, most of the applications are concerned with the shear forces applied to the fluid; therefore the relationship between magnetic field strength and shear yield stress is very important. This relationship varies with the composition of the fluid, but yield stresses in the order of 50 to 100 kPa and with initial fluid viscosities (without magnetic effects) of 0.1 to 1.0 Pa-s are commercially available. Figure 1 presents a yield stress vs. magnetic field intensity plot for a commercially available material.

Three interactive MR fluid experiments were designed and fabricated: a magnetic-lift crane, a vibrating platform, and a disc brake. The experiments were designed to display the fluid's properties as well as a few of its applications. All three experiments are fully interactive with the user via a control panel located on the front of the display case. Safety was a key concern in the design of the experiments. Another important feature was designing a visually pleasing set of experiments that required low maintenance.

### **MR Fluid Morphing Experiment**

The MR fluid morphing experiment illustrates how the MR fluid solidifies when a strong magnetic field is applied to it. A pulley platform was built to hold the wire that raises and lowers an electromagnet into a vat of MR fluid. As the magnet is immersed in the fluid, the user has the option of turning on the current to the magnet thus producing a magnetic field in a portion of the fluid. The MR fluid solidifies in the vicinity of the magnet and is picked up as the magnet is raised. Once the magnet is raised, the current can be turned off. Without the magnetic field, the solid reverts to a liquid state and falls freely back into the vat and splashes, allowing the user to see this transition from solid to liquid. The electromagnet is attached to a metallic rod that runs through a linear bearing to prevent side-to-side movement of the electromagnet so the fluid will not be splashed outside the container. Two square rods were added to the platform. One prevents the rotation of the electromagnet, while the other provides a place for position sensors to be mounted. The full set up of this experiment is shown in Figure 2. The crane's electromagnet has a 3-inch diameter core with 1000 turns of 26 AWG wire. The core has a ½-inch gap where most of the fluid picked up is held. The resistance of the electromagnet is 8.0 ohms. A current of 1.0 A is required to generate the magnetic flux required for this experiment. A high torque motor was needed to lift the weight of the magnet as well as the solidified fluid. A Black & Decker™ 2.4 V electric screwdriver motor was used to provide the needed torque. A fishing line, which holds up to 25 lbs, was used to lift the electromagnet. The crane, the vat, and motor are mounted to a piece of ¼-inch acrylic for easy removal and installation from the display case.

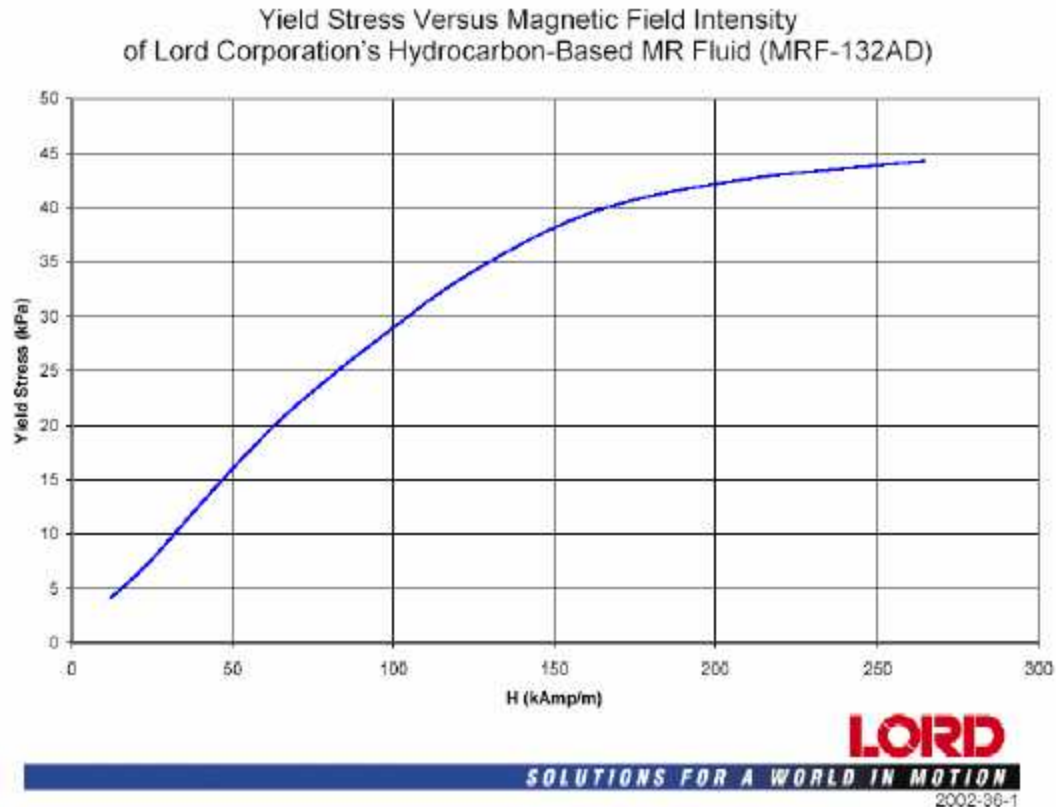


FIGURE 1  
YIELD STRESS VS. MAGNETIC FIELD INTENSITY [9]

### Vibration Damping Experiment

The next experiment is a vibration damping platform. The objective of this experiment is to show a direct application of the MR fluid to provide controlled vibration damping. The vibrating platform is shown in Figure 3. On top of the platform there is a DC motor that spins an unbalanced weight causing the platform to vibrate. A vertical metal plate is attached to the underside of the platform, and this plate extends into a long, narrow container of MR fluid. Around the container holding the MR fluid is an electromagnet that when activated, increases the viscosity of the MR fluid which restricts the movement of the metal plate, therefore damping the vibration of the platform. This container is 5.0 inches high by 10.0 inches wide by 3/8 - inch thick. It is made out of Plexiglas to allow the user to see the fluid. The stand is made of copper fittings and 1/2 -inch copper tubing. This material was selected because it is lightweight, easy to work with and available off the shelf. The vibrating platform is attached with four horizontal springs to the stand (the yellow rectangle in Figure 3). The internal dimensions of the stand are 12.0 by 10.0 inches.

These dimensions provide room for the platform and for the springs to be slightly stretched. The platform itself is 6.0 by 4.0 inches and 1/4-inch thick. The springs are 1 1/2 -inches long and have a spring constant of 2.0 lb/inch. The (yellow) stand is detachable from the aluminum base plate. The legs of the stand are screwed into copper hubs that are permanently attached to the base so that the stand can be removed from the rest of the device for easy access to the container. Also, the container is held in place by a set of brackets that allow for the container to be removed from the base. Every part of the device is removable to allow for easy replacement of any defective part. The DC motor has an initial input current of 2.4 A to overcome inertia and static friction. As soon as the motor starts spinning the microcontroller lowers the current to 1.0 A to keep the motor running at a low speed. The objective is to produce a rate of vibration that can be totally damped by the fluid. A detachable "L" bracket is used to hold the motor. The bracket allows the motor to be placed in different locations along the platform. The electromagnet used has a diameter of 6.0 inches with two coils connected in parallel each having approximately 1000 turns of 26 AWG wire and a total resistance of 8.0 ohms. The electromagnet is held in place by Plexiglas extensions that are glued to the container. The user has control over the starting and stopping of the motor but not over the

Control  
Circuit



the temperature of the magnets rises above a predetermined level, the experiment will shut down automatically. The experiment was given a coat of fire-engine red paint with white magnets, to make the experiment visually appealing. By turning the crank (in the center of Figure 4) the user obtains a direct indication of the fluid's "resistance" which, of course, increases as the strength of the magnetic field increases. The user has access to a knob that increases or decreases the current provided to the electromagnet, regulating the strength of the magnetic field applied to the fluid. The knob is a 10-turn potentiometer that prevents the user from increasing the current too fast. The circuit therefore has no "spikes" or sudden changes in the current flow so the need for a differential controller is avoided.

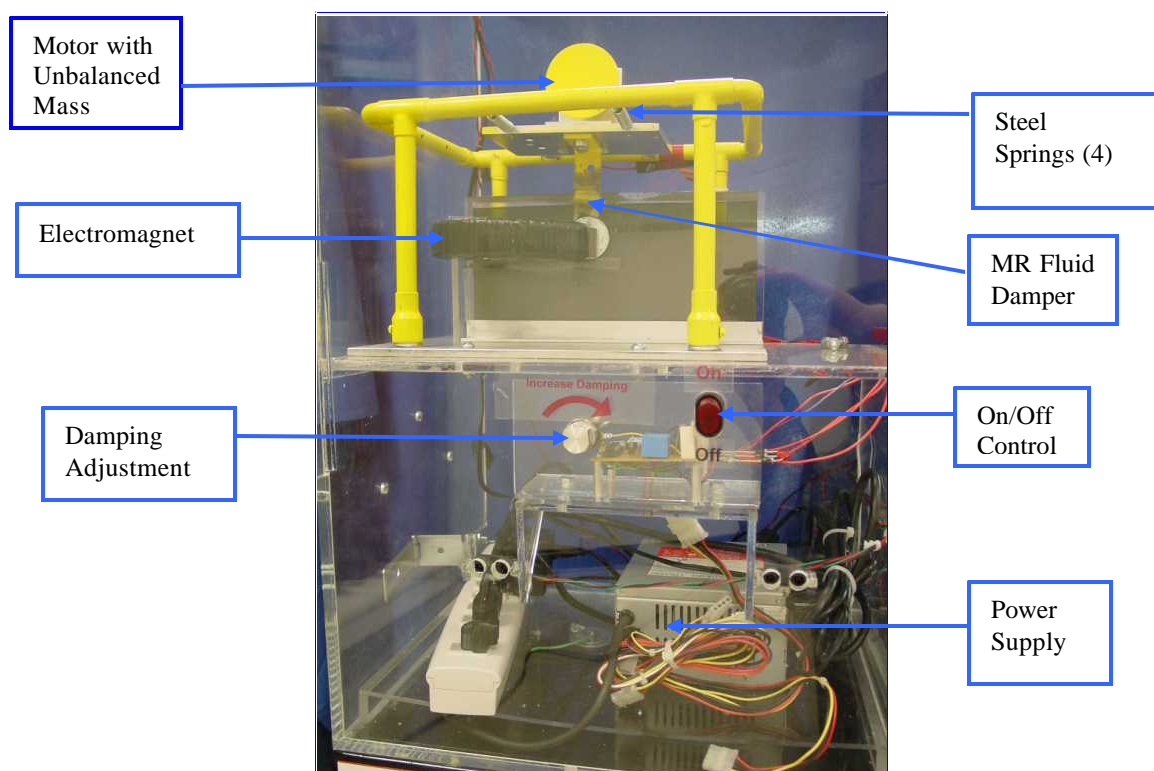


FIGURE 3  
VIBRATION DAMPING PLATFORM

### Electronics and Controls

To control each experiment, the PIC16F84A microcontroller (from Microchip Technologies) operating at 4 MHz was selected. This controller has two I/O ports, an 8-bit free running counter with pre-scaler, four interrupt sources, and can sink or source 25mA per I/O pin. The cost is under \$7.00, and the development environment can be downloaded for free from the manufacturer's website [11]. The electromagnet cores were built of steel-1018 (low carbon steel), and the wire gauge used was 26 AWG except for the crane (23 AWG). The magnets were wound as superimposed independent coils that were later connected in parallel to minimize the magnet's resistance. All the circuits were mounted in individual prototyping boards to allow each experiment to function as a stand alone if necessary. The flow charts describing the logic of operation of the experiments and the assembly language code are available in [10].



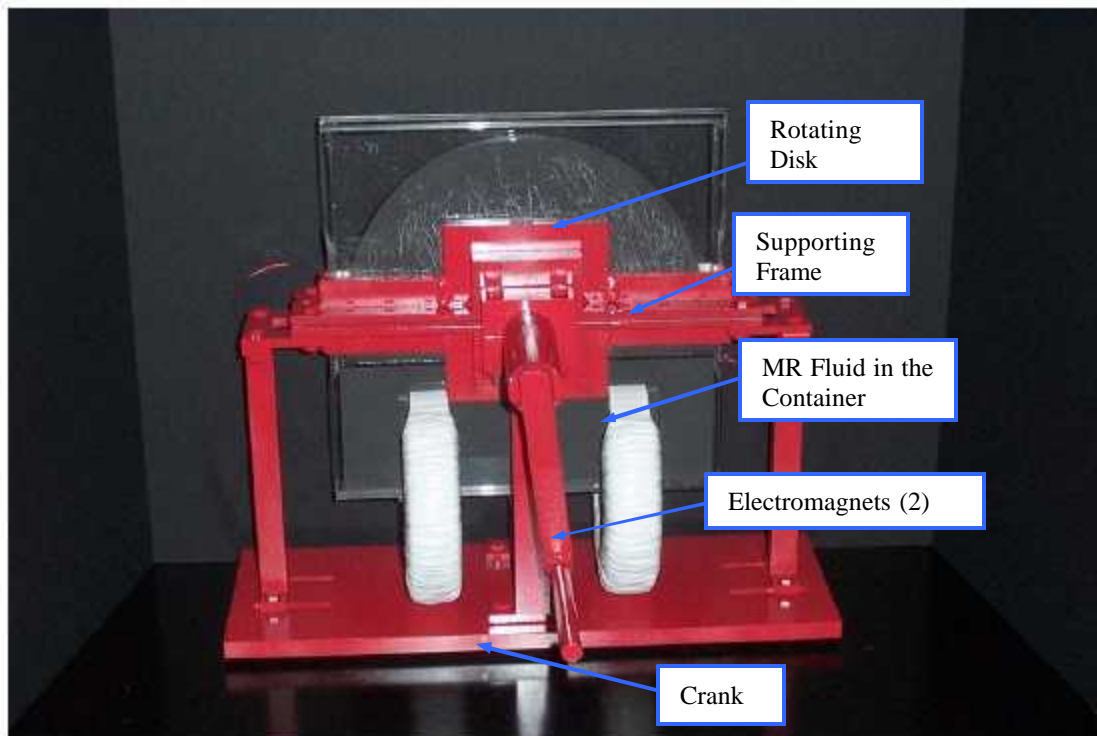


FIGURE 4:  
THE MR DISK BRAKE

### Safety Considerations

The experiments are powered from two 160 Watt computer power supplies. These pre-built devices are extremely stable and offer good surge protection. In addition, the two power supplies are connected to an extension cord with surge protection. The experiments have been carefully designed not to exceed the power supplies' limits, and there are fuses in every critical part. As an additional feature, the display case is equipped with a supervisory circuit that turns off all the experiments if there is no system adjustment for two minutes. Most internal circuitry includes calibration potentiometers to allow fine-tuning and calibrating different parameters as components degrade over time. Relays were used to provide isolation between the high-current side of the circuit (i.e., motors and magnets) and the low current side (i.e., microcontrollers).

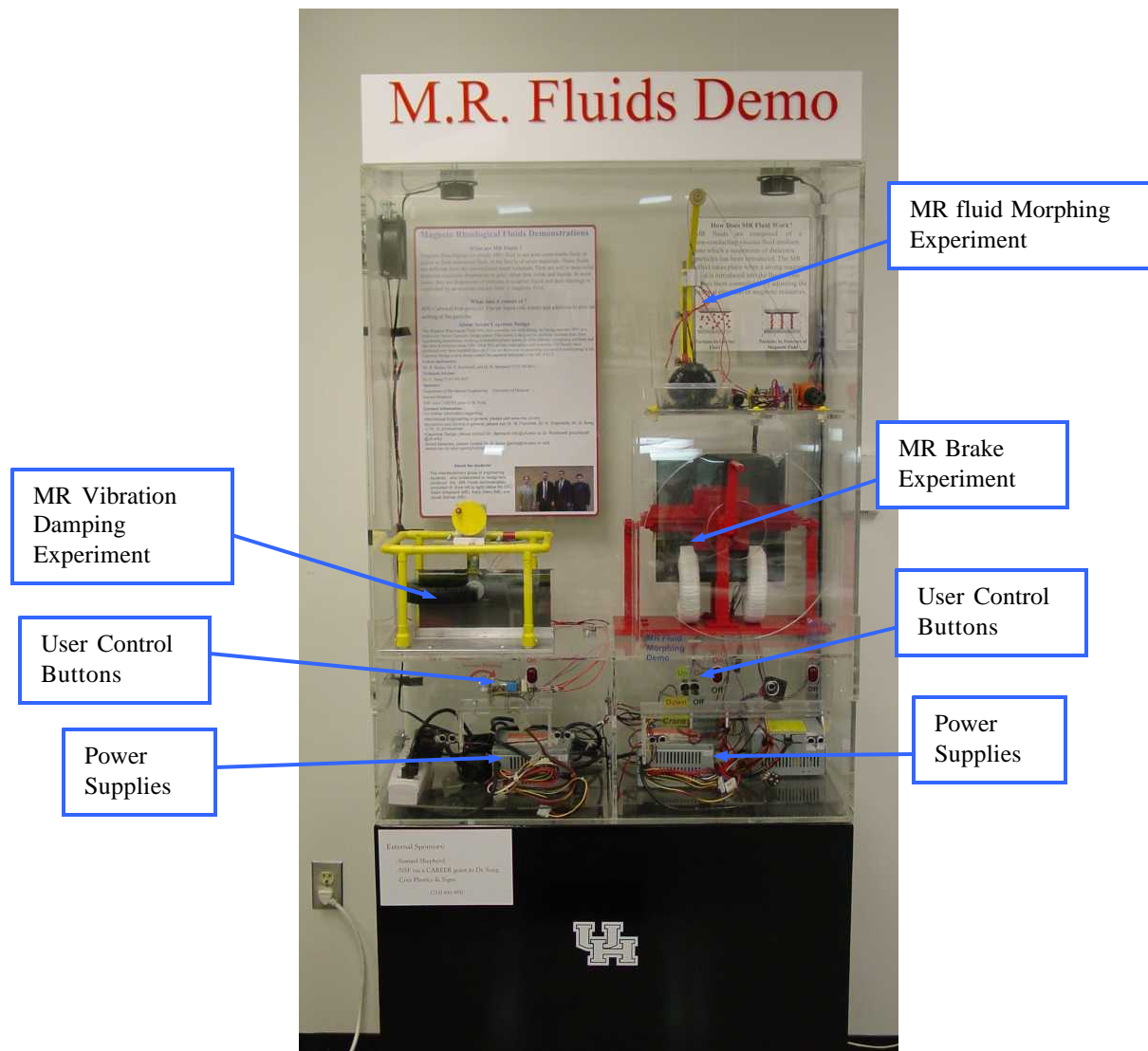
### The Display Case for the MR Fluid Experiments

The three interactive experiments were mounted together in a display case as shown in Figure 5. The display case is fully interactive and self-explanatory. Nevertheless, instructions for each experiment are posted with the case. In addition, a brief background of the history of MR fluids is exhibited behind the experiments.

## Two Devices Demonstrating the Uses of a Shape Memory Alloy

### Introduction

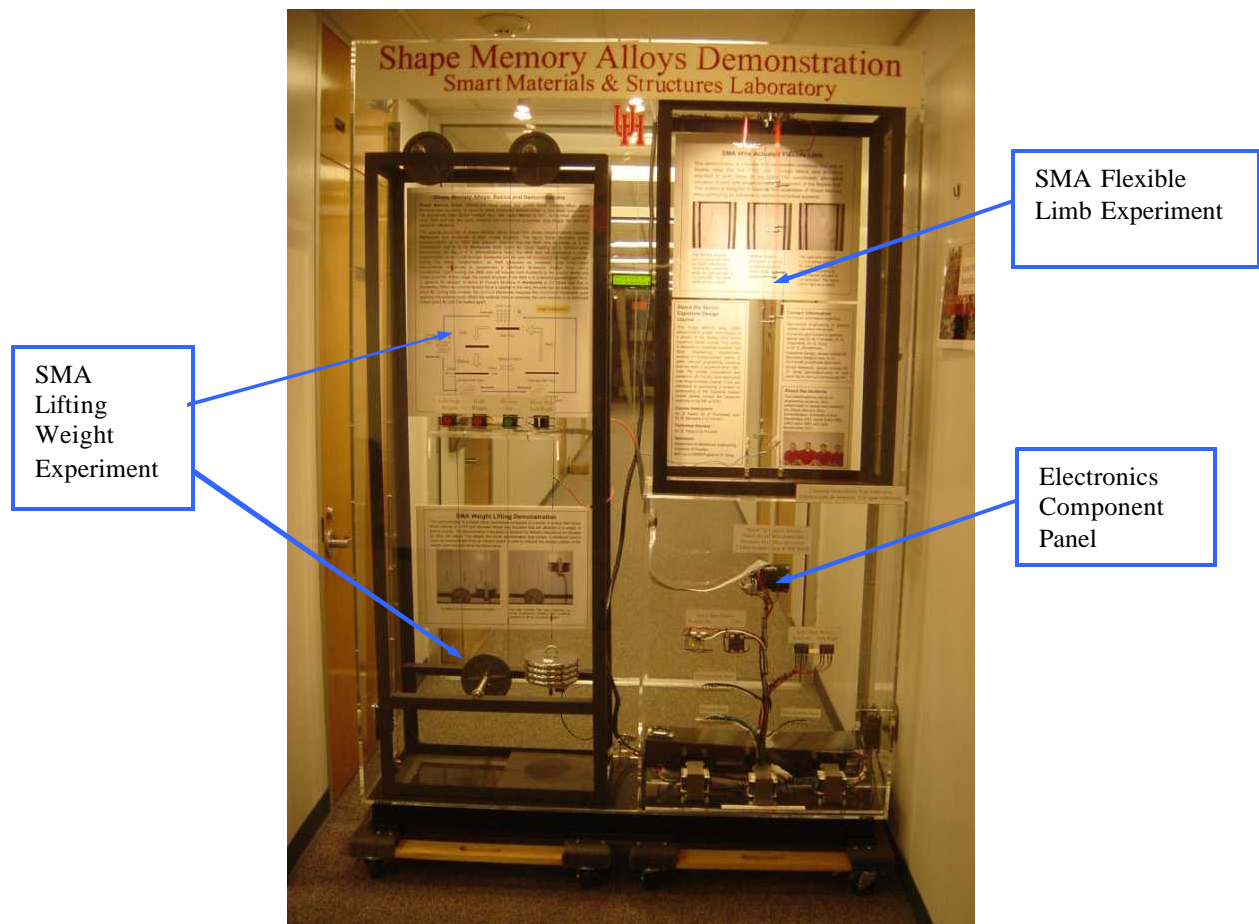
The control of dynamic mechanical systems is becoming more important. Recent research and development has resulted in a class of materials popularly known as Shape Memory Alloys (SMAs). In many cases these materials may replace complex controls devices presently used in the industry. It was desired to design and fabricate an electronically operated SMA demonstration and display case to increase engineering students' awareness of the existence of SMAs and to promote graduate research in this area.



**FIGURE 5**  
DISPLAY CASE FOR THE THREE INTERACTIVE EXPERIMENTS INVOLVING AN MR FLUID

Shape Memory Alloy is the name applied to that group of metallic materials that demonstrate the ability to return to some previously defined shape or size when subjected to the appropriate thermal procedure. Generally, these materials can be plastically deformed at some relatively low temperature, and upon exposure to some higher temperature will return to their original shape. Only those alloys that can recover a substantial amount of strain, or that generate significant force upon shape transformation, are of commercial interest. One such material is a Nickel-Titanium alloy called Nitinol (NiTi). This particular alloy has useful electrical and mechanical properties, long fatigue life, and high corrosion resistance. This novel material has a very high resistivity that enables it to be actuated electrically by Joule (resistance) heating, making it an appealing type of actuator for numerous applications. In 1962, William Buehler at the Naval Ordnance Laboratory discovered a binary alloy composed of equi-atomic Nickel and Titanium that exhibited a shape recovery effect when heated after being mechanically deformed [12]. This alloy was given the name Nitinol (derived from Nickel-Titanium Naval Ordnance Laboratory). Nitinol is available in the form of rods, wires, barstock and thin films. It can be used in numerous applications such as actuators, sensors, and heaters. For the application of the SMA demonstration system of concern here, the Nitinol element will be a wire used as an actuator. On the microstructure level, SMAs have the characteristic of changing from a low temperature Martensite phase to a higher density Austenite crystal structure at a given transition temperature. In the wire configuration,

the transition results in 4% elongation as compared to the 0.01% or less elongation per degree centigrade for simple thermal expansion.



**FIGURE 6**  
INTERACTIVE DEMONSTRATION AND DISPLAY FOR NITINOL, A SHAPE MEMORY ALLOY

The two SMA interactive mechanical system demonstrations were designed, fabricated and then placed in an acrylic case. In the upper right portion (Figure 6) is an electrically controlled flexible limb. On the left side of Figure 6 is an electrically controlled weight lifting device. A control system was created for each demonstration, including the power sources (lower right side of Figure 6).

As illustrated in Figure 7, the flexible limb is a strip of flexible spring steel extending vertically downward, with attached eyelets that extend horizontally outward from the limb. The Nitinol wire actuator is threaded through the eyelets. The controlled, coordinated, alternating actuation of each wire allows movement of the limb in two directions. Whereas the original length of the wire is approximately 69 inches, the contracted length of the wire after activation is approximately 66 inches due to its 4% strain recovery. The contraction of either side of the limb displaces the end of the limb a horizontal distance of approximately nine inches, to either side. A set of springs has been added to each of the two actuators to limit the tension in the wire and prevent permanent deformation of the actuator. The method of activation is through Joule (resistance) heating. In order to maintain stability and avoid over heating the actuator when the limb is sustained in a flexed position, the processor delivers the electrical power by pulse width modulation. The frame structure that houses the limb is made of carbon steel, with precision welds at each joint. The control for this device is a two-way spring-loaded rotating dial. The control allows the specific movement of the limb, in response to the direction of the turning angle in the dial indicator.

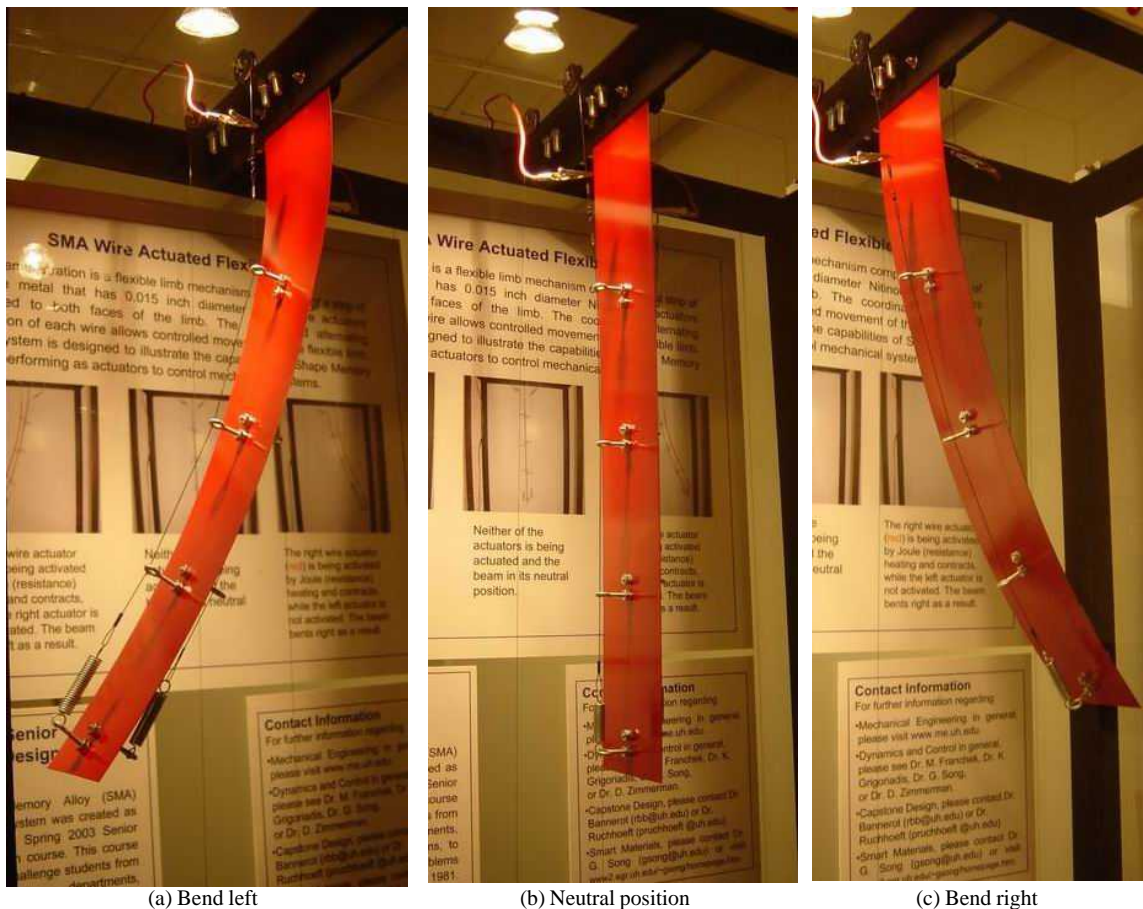


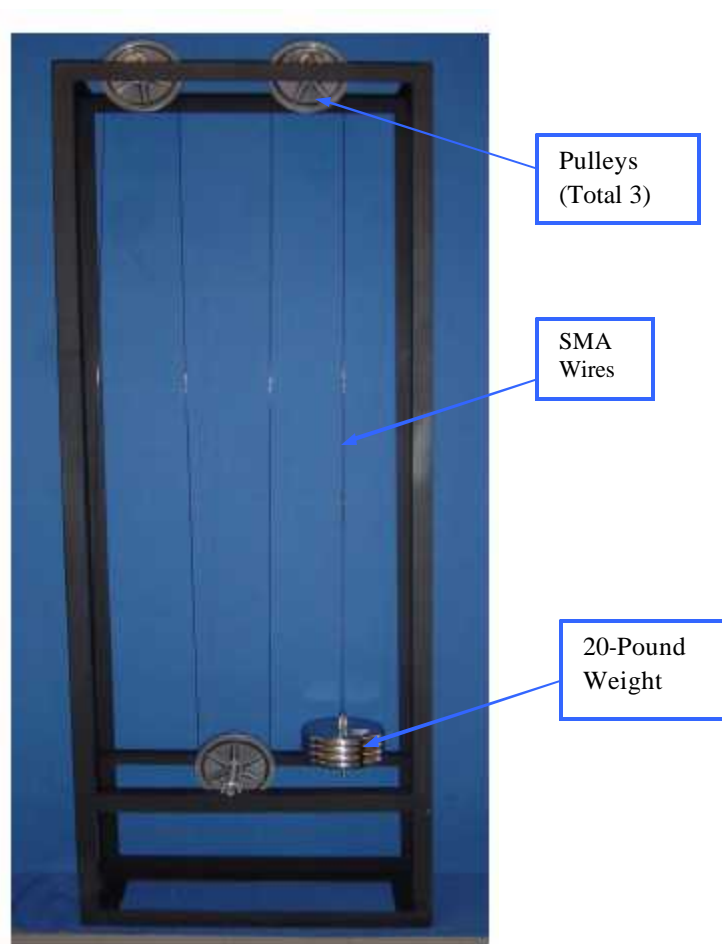
FIGURE 7  
SHAPE MEMORY ALLOY ACTUATED FLEXIBLE LIMB

The weight lifting demonstration is illustrated in Figure 8, and it was designed and constructed with the intention of demonstrating the large force that the Nitinol actuator can exert when the alloy is in the process of transforming from the Martensite to the Austenite phase. It was also designed to illustrate stability in a controlled displacement, and its maneuverability using an infrared distance sensor to provide displacement feedback. Again, Joule heating with pulse width modulation is used to prevent over heating of the Nitinol actuator and to ensure the displacement stability for the weight lifting demonstration. Seven strands of 0.015 inch diameter Nitinol wire pass over the three pulleys and are attached to the weights. In theory the twenty feet of the seven strands of wire will achieve a total linear extension/contraction of ten inches while supporting a weight of 30 pounds. The system uses 20 pounds, and the ten-inch extension was observed. The pulleys and shafts used for the system are made of ceramic and stainless steel materials respectively. The frame structure that sustains the shaft is made of carbon steel angle iron, with precision welds at each joint. This system is controlled using two push button controls that activate the lift, hold and drop actions. The acrylic case that contains the control platform and houses both mechanical systems was manufactured by an outsider supplier. As seen in Figure 6, the case was built with three compartments and special modifications for cooling and lighting. The bottom right compartment contains a retrievable acrylic platform that houses the processor, solid state relays, and transformers among other electronics. A control platform and a Liquid Crystal Display (LCD) have been installed in the front panel of the case to allow the user to interact with the system. The openings located in the lower extremities of the display case were designed for a pair of cooling fans that provide convective cooling to the actuators and electrical compartments.

The control system was designed in the following manner: The heart of the system that receives, processes, and delivers the signals and information is the microcontroller. The position of the weight in the weight lifting device is sensed with an infrared sensor located at the base of the case. This information is forwarded to the controller. With the location of the weight always known, the control system can override user instructions to extend an already "extended" wire. The microcontroller receives information from the control panel, and processes it using the guidance of the code written in



Interactive C. With the assistance of the transformers, solid state relays and other assisting power amplifiers, the proper static or pulsating signals are delivered to the actuators. The same processor activates lighting and ventilation in predetermined time relays. Figures 9 and 10 illustrate the electrical compartment panel and control panel respectively.



**FIGURE 8**  
SHAPE MEMORY ALLOY ACTUATED WEIGHT LIFTING DEVICE

The control system is prepared to avoid an overload of power by implementing a set of fuses. Each mechanical system has its own individual power source, to avoid a complete system failure. Shape Memory Alloy literature is posted near the case to provide a sufficient understanding of Shape Memory Alloys and their potential functionality.

## DISCUSSION

While we have chosen to highlight two emerging technology projects from our capstone design course in this paper, there have been at least twelve other projects related to emerging technologies in our capstone course in the spring 2002 through fall 2003 timeframe. These were among the 57 projects completed by 64 teams during that time.

An important issue for engineering curricula is to address ABET Criterion 4. For the two projects described in this paper the ABET Criterion 4 issues addressed are listed in Table 3.

As noted these two projects were intended as demonstrations to acquaint faculty, students and visitors to these emerging technologies. These projects are currently on display in the lobby of the Department of Mechanical Engineering where they will remain for the foreseeable future. There are several occasions during the year when the College is visited by groups of high school students interested in engineering. As part of their tour of the Department, we now have two additional stops.

Our freshman course, Introduction to Mechanical Engineering, introduces new student to academic life, the University of Houston, and the activities of the Department of Mechanical Engineering. They too will visit the demonstrations as well as students in our junior level controls and materials science courses.

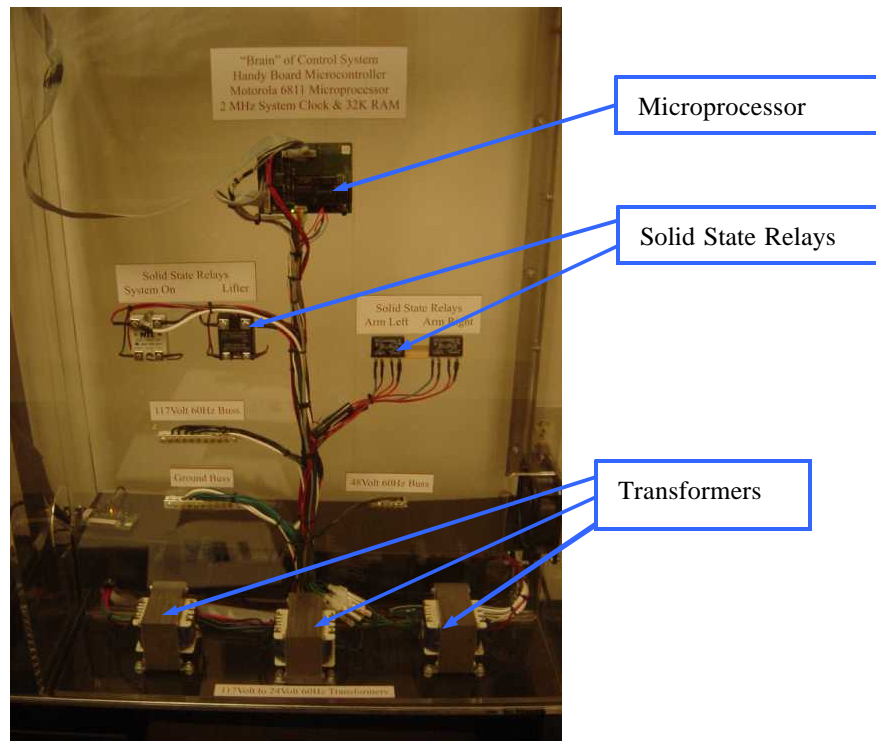


FIGURE 9  
ELECTRICAL COMPARTMENT PANEL



FIGURE 10  
CONTROL PANEL

## CONCLUSIONS

Two sets of interactive experiences/displays have been designed, fabricated and tested. These projects were two of the 23 completed in the three-department capstone design course in the Cullen College of Engineering at the University of Houston

in the spring of 2003. The two, multi-disciplinary projects were completed by two multi-disciplinary teams of student from the Departments of Mechanical Engineering and the Electrical and Computer Engineering. Both projects required the design teams to consider a range of engineering issues including strength, dynamics, heat transfer, fluid mechanics, electronics, electrical power, controls, sensors, microprocessors, safety, ergonomics, manufacturing, economics, and materials while providing an interactive demonstration of the emerging technologies of magneto-rheological fluids and shape memory alloys.

Economic:	The projects were supported by the client and funds were raised by the students. There was a budget that was adhered to.
Environmental:	All projects have some environmental impact. The MRF project used a hydrocarbon based fluid so care was taken to assure that no leaks would occur.
Manufacturability:	Both of these projects had significant manufacturing issues. The demonstrations were designed to be taken apart and modified. There were many materials including, iron, steel, copper, aluminum, and plastics that had to be machined, welded, and/or otherwise shaped and attached. Each demonstration was controlled and run by an independent system of electronics, power supplies and actuators.
Health and Safety:	Both projects were designed to be used by the public and their safety was a paramount concern.
Codes and Standards:	These had mostly to do with the standards for safety regarding electrical systems.

TABLE 3  
The primary ABET Criterion 4 Issues Addressed in the MRF and SMA Projects

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