

Integrated Laboratory for Manufacturing Education*

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The Integrated Laboratory for Manufacturing Education (ILME) at Christian Brothers University creates a laboratory environment that integrates undergraduate instructions in modern design method, agile manufacturing, and automated assembly. The approach of this manufacturing education combines the traditional computer-aided design drafting technique with parametric design and 3-D modeling using Pro/ENGINEER[®] as well as hands-on experiences on traditional machining, state-of-the-art computerized numerical controlled machining and robotic assembly. Creation of machining code and simulation of machining sequences are completed through Pro/MANUFACTURING while thermal and stress analysis are performed through Pro/MECHANICA[®]. As a result, the ILME creates a small scale of industrial environment in modern manufacturing.

INTRODUCTION

THE ILME Integrated Laboratory for Manufacturing Education at Christian Brothers University (CBU) was established in 1995 with support from the National Science Foundation (NSF) through the Instrumentation for Laboratory Improvement Program (ILI) [1]. The objective of this project was to develop an integrated laboratory to facilitate undergraduate instruction in the complete design through manufacturing process. The laboratory consists of three subsystems. The design subsystem is composed of workstations and software that support Computer-Aided Design and Manufacturing (CADM) instruction at the advanced undergraduate level. The manufacturing subsystem includes computer numerical control (CNC) machining and robotic assembly stations. The integration subsystem consists of a workstation server with network connection to the design and manufacturing subsystems as well as to existing Computer-Aided Engineering (CAE) and Controls laboratory resources.

Undergraduate student instruction is enhanced in a number of ways. Modern engineering graphics, including 3-D modeling, is introduced in the freshman year. Hands-on experience with CNC machining and robotic assembly is included in the Manufacturing Processes class in the sophomore year. After exposure to CAD drafting techniques and familiarization with different machining tools, students can apply enhanced skills to projects in higher level classes. As part of the NSF-ILI grant activity, two new undergraduate courses that utilize assets of the ILME were developed. The first course, ME 435 (Intermediate

Manufacturing), focuses on utilizing the leading-edge 3-D modeling package, Pro/ENGINEER[™], for designing and creating manufacturing models for CNC machining. The second course, ME 445 (Concurrent Engineering), introduces the concept of concurrent engineering through in-class projects. Students apply concurrency concepts and utilize CADM facilities to complete projects that include design, analysis, and manufacturing. Other courses in the Mechanical Engineering curriculum such as Kinematics, Design of Mechanisms, Dynamics of Machines, and senior projects also benefit from the ILME.

Regarding interdisciplinary curriculum, the ILME also supports Electrical Engineering classes related to Digital Control Systems, Robotics and Senior Projects. The ILME enhances the undergraduate engineering curriculum by providing substantial improvements in graphical, computational, and manufacturing capability including hands-on experience. It creates a laboratory environment that reinforces and integrates undergraduate instruction in modern design methods, agile manufacturing, and automated assembly.

SYSTEM CONFIGURATIONS AND INTEGRATION

The configuration of the physical systems is shown in Fig. 1. The physical components of the ILME are organized in three subsystems.

A. Manufacturing Subsystem: The manufacturing subsystem includes a laboratory containing a Fadal[®] VMC-15 Vertical Machining Center (VMC) with 4th axis pre-wired, a Serpent 4-axis robot, a Gryphon 5-axis robot, and three 1.5-meter conveyor belts. The VMC-15

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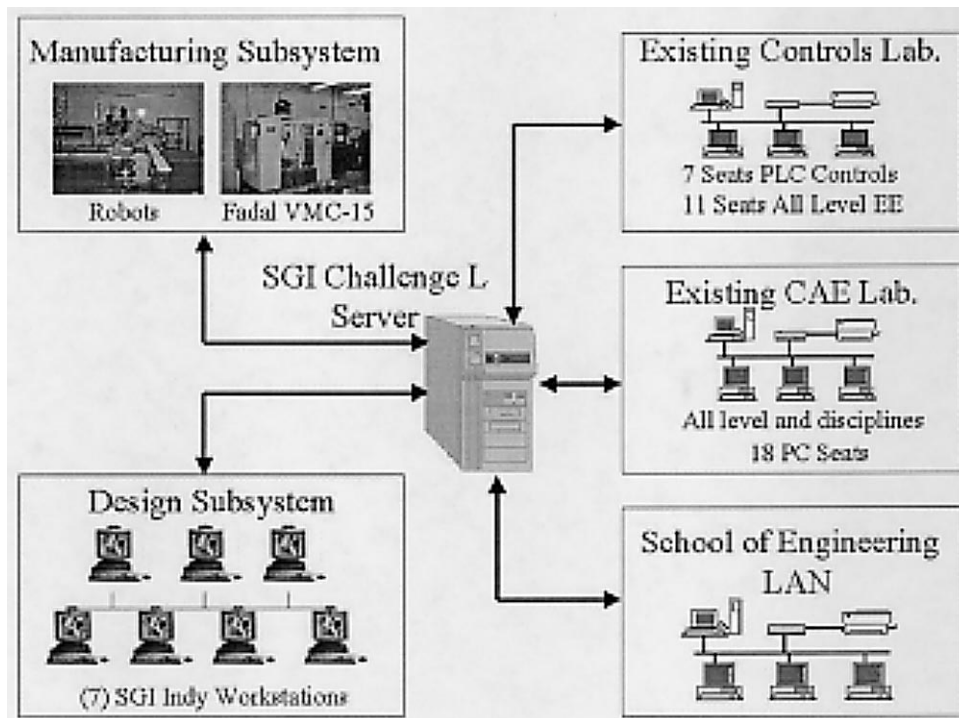


Fig. 1. Integrated laboratory layout.

includes 21-tool storage and a maximum spindle rate of 7500rpm with a 10 horsepower motor. A Gateway 486DX33 personal computer (PC) is dedicated to the CNC machine for network communications. Direct Numerical Control (DNC) of CNC equipment allows the NC code to be executed as it is received through an RS-232 port from the PC. Another 486DX33 computer is dedicated to two robots and the conveyor systems. Other than this, two Pentium II 266 computers running Windows NT workstation were set up at the site and served as workstations for Pro/ENGINEER[™].

- B. **Design Subsystem:** The design subsystem is composed of seven Silicon Graphics (SGI) Indy workstations together with parametric design software. Each workstation is equipped with a 133 MHz MIPS 4600 CPU, 64 MB RAM, and 1 GB HDD with 400 MB swap partition as well as external CD-ROM and 4mm DAT for installation and backup. Twenty-one-inch monitors provide excellent graphical resolution and each workstation includes a digital camera and sound system.
- C. **Integration Subsystem:** The integration subsystem includes a Silicon Graphics Challenge L server equipped with two 150 MHz MIPS 4400 CPUs and 128 MB RAM as well as two 4 GB HDD, CD-ROM, and 8 mm tape drive. The server is available for numerically intensive applications such as structural analysis of complex parts.

The local area network (LAN) at CBU is configured to support the network file system (NFS) standard. The Challenge server handles network

access to the design software and connections to the manufacturing and design subsystems as well as to existing personal computers in the CAE and Controls laboratories. In addition, the server provides both interlaboratory communication and a shared platform for workstation applications in component design and analysis. Pro/ENGINEER[™], a leading-edge parametric design software system, was selected as the tool for design and analysis of components. All modules of Pro/ENGINEER[™], together with Pro/MECHANICA[™] and Pro/MANUFACTURING[™], were installed. Pro/MECHANICA[™] is used for structural and thermal analysis and Pro/MANUFACTURING[™] is used to generate tool paths and CNC code that can be transferred to the CNC machine. Students design parts on the Indy workstations and perform analysis or assembly using Pro/MECHANICA[™] and Pro/ASSEMBLY[™]. After part creation, the Pro/MANUFACTURING[™] module can be used to create tool path and cutting sequences as well as NC code.

On-screen simulation of actual cutting can be done using NC-CHECK. This is followed by NC code creation using the NC-POST postprocessor. This NC code file is then transferred to the computer in the manufacturing subsystem via the campus network. Students can modify the NC code manually as needed or load the code to the CNC machine for operation. The VMC-15 in the manufacturing subsystem currently contains 32 KB memory that is sufficient for most manually written NC code for simple parts. However, the NC code generated by the Pro/MANUFACTURING[™] module will be greater than 32 KB in most cases and direct numerical control (DNC) mode must be used for

continuous transfer to the CNC machine. In this case, tool path simulation on the control panel of the CNC machine will not be available. Accordingly, tool path and cutting simulation on the Indy workstations in the Design Subsystem is vital for preventing tool breakage.

The CADM laboratory also communicates with the existing CAE and Controls Laboratories providing file transfer capability. The Windows NT or Windows 95 version of Pro/ENGINEER[™] can also be run on faculty's office computer by using a floating license from the network server. The ILME configuration links existing laboratories and also provides hands-on experience for students in complete design, analysis, simulation, and manufacturing.

INTEGRATED MANUFACTURING CURRICULUM

The ILME forms an integrated curriculum in manufacturing. Connections within the Mechanical Engineering (ME) curriculum are described as follows:

Freshman year

Students take an Engineering Graphics course that covers the fundamentals of engineering drafting as well as 3D modeling using MicroStation 95. The Engineering Graphics class is a prerequisite for Manufacturing Processes.

Sophomore year

All ME Students are required to take Manufacturing Processes (ME 201). This class includes four parts: concepts and theory, field trips, hands-on projects, and knowledge bowl. In the concepts and theory portion, different manufacturing processes and material properties are introduced. Students learn to use different kinds of traditional machining tools such as a lathe, mill, drill, bend saw, power shear, etc. Oxyfuel and MIG welding are also a part of practice projects. In the second half of the semester, CNC machining is introduced to students as well as NC programming and robotic assembly. Students learn to write NC code manually and machine parts on the CNC machine. In addition, approximately six field trips to local industry are taken. Students learn from engineers in industry and actually view machining processes. Projects corresponding to course material utilize machine tools in the ME Development Shop at CBU. Some projects utilize the VMC-15 vertical machining center shown in Figs 2 and 3. The capabilities of Pro/ENGINEER[™] are also introduced with NC programming.

The highlight of the class is the Manufacturing Bowl at the end of the semester. Students are divided into four groups for competition in general knowledge in manufacturing. The competition is conducted with multimedia presentation using Microsoft PowerPoint. The instructor will serve



Fig. 2. Truck and trailer.

as the judge of this competition. This class provides general knowledge of manufacturing processes and prepares students for other projects and experiments in higher level classes and advanced manufacturing electives.

Junior and senior year

In the junior year, several classes benefit from the ILME. Evidence of the impact on these classes is shown below.

- ME 317 (Kinematics): The class project in ME 317 requires use of the Serpent and Gryphon robots for position analysis. The objective of this project is to find the optimal path/sequence of robot arms that will move an object from one conveyor to another without collisions.
- ME 302 (Energy System Laboratory): Students apply skills learned in manufacturing processes to build systems for experimental studies.
- ME 401 (Mechanical Systems Laboratory): Students manufacture testing specimens and build test equipment using machining tools including the VMC-15.
- ME 408 (Senior Project): In 1996, a senior project entitled 'Design of Robotic Assembly Processes' utilized the Serpent and Gryphon robots to study the automatic assembly of parts [2]. The two robots were programmed to acquire nuts and bolts from two separate conveyors and assemble them before sending to the



Fig. 3. Basic machining projects.



Fig. 4. Assembly of chair mechanism.

next conveyor line. In 1997, a senior project entitled 'Chair Mechanism Design' utilized Pro/ENGINEER[™] and Pro/ASSEMBLY[™] to design and assemble parts of office chair mechanisms [3]. An example of assembled mechanisms is shown in Fig. 4. The Pro/MECHANICA[™] structure module was utilized for stress analysis of the assembled mechanism. Another project entitled 'CNC Code Checking System' was developed for NC codes syntax and tool speed checking. Both 16-bit and 32-bit code checking programs were developed using Microsoft Visual Basic 4.0 [4]. This program is suitable for class instructional purposes and it reduces tool breakage rate. Currently, this program is used as an aid in ME 201 (Manufacturing Processes) to check hand-written machining codes. 'Design of a Load Sensor for a DRS Wrist Fixator' project also utilized Pro/ENGINEER[™] and Fadal[®] CNC machine for building prototype.

- ME 435 (Intermediate Manufacturing): ME 435 is organized to exploit the facilities of ILME. Students are first introduced to parametric design methodology, including part and assembly creation and parameterization using Pro/ENGINEER[™]. The manufacturing module is then introduced in which students create a manufacturing model, build operation sequences, and manufacture a complex part. Students also learn how to perform structure and thermal analysis using Pro/MECHANICA[™]. Design projects are assigned to student groups in different stages of the class. A final project allows students to apply all techniques including design, analysis, manufacturing, and machining codes. Figure 5 shows an example gear-type

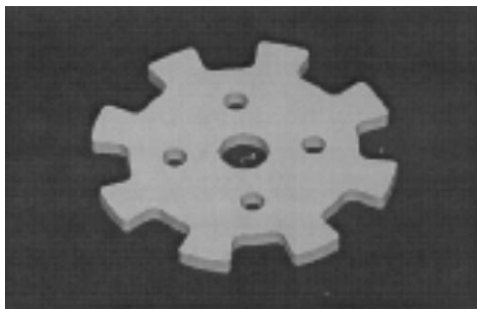


Fig. 5. Example gear part.

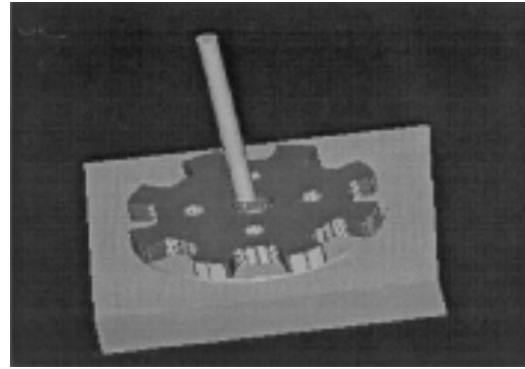


Fig. 6. Cutting simulation.

part. Figure 6 shows the cutting simulation of the manufacturing model for gear-type part, and Fig. 7 shows the actual machined gear-type part [5].

- ME 445 (Concurrent Engineering): The concepts of concurrent engineering are introduced to students. Students are divided into groups to complete the same project. The design group develops an idea for a part and utilizes Pro/ENGINEER[™] to design the part. The analysis group utilizes Pro/MECHANICA[™] to perform stress and thermal analysis on the part. The manufacturing group creates a manufacturing model of the part and NC sequences as well as on-screen simulation of cutting sequences. After manufacturing of the part, all groups discuss the outcome of the manufactured part and test it. During the process of design, analysis, and manufacturing, all groups meet constantly to discuss the progress of the project. Figure 8 shows a heat sink design, Fig. 9 shows an air cylinder design, and Fig. 10 is the design of an air cylinder actuator. An example thermal analysis is also shown in Fig. 11.
- ME 446 (Design of Mechanisms): A Microsoft Visual Basic 4.0 program was developed for designing disk cams with reciprocating followers [6]. The program not only displays the displacement, velocity, acceleration, and jerk diagram of the cam but also creates NC codes that can be transferred to the VMC-15 for machining the cam. More details about this program can be



Fig. 7. Machined gear part.

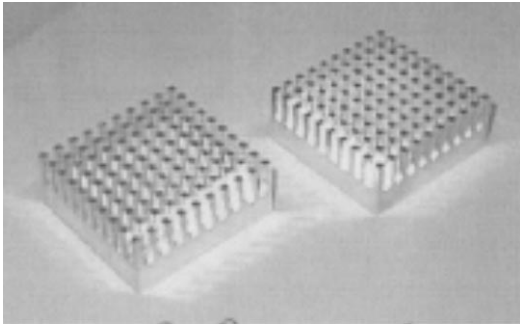


Fig. 8. Heat sink design.

retrieved from the Web at '<http://www.cbu.edu/~pshiue/Cam20.htm>'. In the future, motion simulation with Pro/MECHANICA[™] can be included in the class as an aid for mechanism design.

SUPPORTS TO INTERDISCIPLINARY CURRICULUM

The ILME contributed to the restructuring of several courses in the electrical engineering department. In addition, faculty uses more computationally intensive projects. This has increased the number of senior electives that the electrical engineering faculty can give. So far, the CADM laboratory has been utilized in six electrical engineering courses and two more are under restructuring in an effort to incorporate the usage of this laboratory equipment. The courses that have been impacted by the facility since inception are as follows:

- EE 405 (Electromagnetic fields): A topic that is usually abstract to the student is now made more comprehensive with the use of MAXWELL, a finite element package used to simulate Electromagnetic and radiating systems.
- EE 409 /EE 410 (Senior Project I and II): Over the past two years, four projects used this laboratory facility to complete these two courses that are required by all seniors to fulfill graduation requirements.

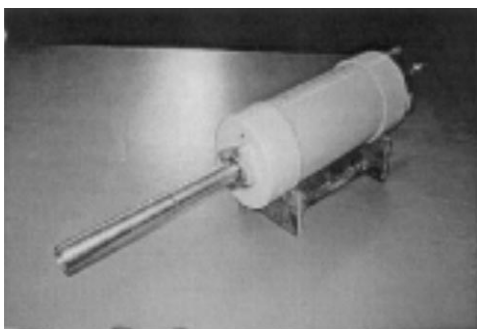


Fig. 9. Air cylinder design.

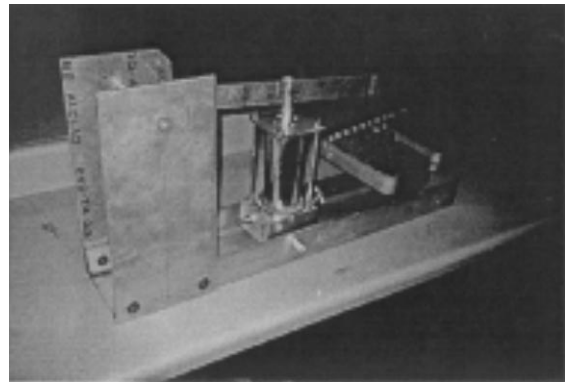


Fig. 10. Actuator design.

- EE 423 (Computer Graphics): Students use the laboratory's high-end computer workstations to program graphic-intensive algorithms for static and animated graphics using C or C++ language.
- EE 452 (Advanced Computer Software): The facility is used for its computational power to write systems-level code and object-oriented design and applications.
- EE 475 (Digital Telephony): The students use the audio and video interfaces on the Silicon Graphics workstations to design and test adaptive filters for applications such as echo cancelers.
- EE 480 (Unix and the Internet): Students use the Unix environment to program Java and Internet applications as well as gain experience with system administrator. Two more courses will incorporate this laboratory facility in the next two years. The first is EE 454, Computer Hardware, which will use Pro/ENGINEER to do schematic capturing and board layout design in its projects. The second is EE 415, Data Communications, which will use the laboratory for projects to broadcast real time audio and video.

The presence of this laboratory gives the electrical engineering department a great computer infrastructure to develop a new NSF supported telecommunications laboratory.

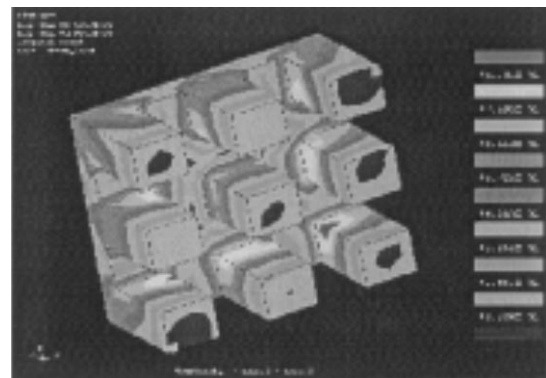


Fig. 11. Example of thermal analysis.

EVALUATION AND ASSESSMENT

Students of Mechanical Engineering and Electrical Engineering Departments all benefit from the ILME. Some evidence can be seen from the feedback of graduates as follows:

- ‘This process that I was exposed to by way of the ILME can dramatically decrease the costs associated with getting a product on the market and/or improve an existing product.’
- ‘The curriculum is very good overall. It’s also nice to be able to put ‘Pro/ENGINEER: 3+ years experience or 1000+ hours’ on a resume after graduation.’
- ‘It is one of the most important assets a student can have. The machine shop and CNC machine are excellent. I noticed that having CNC machining experience as well as CNC tool path programming experience has really gotten the attention of potential employers.’
- ‘Yes, I am about to take a new job. I will be the CNC expert at the site. I will be in charge of evaluating, purchasing, and integrating new capital equipment. I will also be a secondary Pro/E administrator. The classes are the closest experience you get to real-world applications. The push to gain new technology is a big plus. Integrating design to manufacturing with Pro/E and the CNC is very impressive.’

Total number of students in all courses impacted by ILME is listed in the table.

Courses	1996–97	1997–98	1998 Fall
ME 201 (Manufacturing Processes)	20	17	17
ME 317	16	17	15
ME 302	11	14	Offer in Spring
ME 401	16	7	15
ME 407/408	14	11	13
ME 435	14	9	6
ME 445	Not offered	10	Offer in Spring
ME 446	6	Not offered	Not offered
EE 405	12	19	16
EE 409/410	15	16	17
EE 423	13	19	Not offered
EE 475	4	Not offered	5
EE 480	8	Not offered	Not offered

CONCLUSION

The original Development Shop at CBU consisted of different kinds of machining tools similar to those in the traditional machining shop such as lathes, drills, mills, bend saw, etc. The Development Shop supported the basic undergraduate instructions in manufacturing education with hands-on projects. However, it did not meet the need of industry with advanced manufacturing technologies. By integrating the CNC machine, workstations, and leading-edge 3D modeling and analysis software into the original manufacturing curriculum, students will be better prepared to meet the future challenge in industry. The ILME project has effectively integrated the components of manufacturing education, including design, analysis, and production, within the Mechanical Engineering curriculum at CBU. The Engineering Graphics class in the freshman year builds a basic foundation of drafting techniques. The Manufacturing Processes class in the sophomore year provides hands-on machining experience as well as knowledge related to the capability and operation of different machines. In the junior and senior years, several classes benefit from the ILME project. Students in higher level classes utilize ILME facilities as described above to plan and fabricate project designs or experimental devices. The Intermediate Manufacturing and Concurrent Engineering classes introduce students to state-of-the-art parametric design methodology. Computer simulations of the manufacturing model and stress/thermal analysis of machined components provide better visualization and understanding of the manufacturing process. Tool path simulation and NC-Check in the Pro/MANUFACTURING[®] module are especially useful for previewing the outcome of cutting sequences.

The ILME also supports the Electrical Engineering curriculum in several areas such as Digital Control Systems, Senior Project, and Advanced Computer Software. As a result, the ILME project creates a new environment for manufacturing education. Students learn not only traditional machining processes, but also modern manufacturing processes with parametric design and analysis. Therefore, the ILME project better prepares students for productive careers in industry.

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Yeu-Sheng Shiue, Associate Professor at Christian Brothers University, received his BS from Tatung Institute of Technology in Taiwan and his MS and Ph.D. degrees from University of Memphis. He is an associate member of the American Society of Mechanical Engineers. His interests include dynamics, control, vibration, machine design, design of mechanisms, and mechanical system simulations. He has performed research related to the determination of the mechanical characteristics of shoe insoles. He is widely published in the area of shock reduction for shoe insole materials. Currently, he is focusing on concurrent engineering and intermediate manufacturing process utilizing Pro/ENGINEER and CNC vertical machining center.

Bernard B. Beard received his Ph.D. in Physics from the Massachusetts Institute of Technology in 1996. He returns to CBU after 4 years spent earning his doctorate. Dr. Beard was a visiting assistant professor in the Mechanical Engineering Department in 1991–92. He came to CBU with a Bachelor's and Master's degree in Mechanical Engineering from MIT, and eleven years' experience in the aerospace industry. At General Dynamics Fort Worth Division, he was the group leader for advanced propulsion systems integration as well as the integration chairman for the F100 and F110 increased performance engines for the F-16 fighter. At Pratt & Whitney's Government Products Division, he was a systems engineer on the F119 advanced tactical fighter engine program. From 1992 to 1996, he pursued his doctorate in physics at the Center for Theoretical Physics at MIT. His research interests are correspondingly broad, ranging from advanced manufacturing and materials technology, to fluid mechanics and advanced propulsion systems, to quantum spin systems and lattice gauge theory. Dr. Beard is also an adjunct faculty member in the CBU Physics Department.

L. Michael Santi received his Ph.D. from Vanderbilt University in 1984. His areas of research interest include design optimization, computational fluid dynamics, and thermal systems design. Dr. Santi is currently active in research associated with Space Shuttle Main Engine performance modeling and prediction. Before coming to CBU, Dr. Santi held a number of responsible positions in industry. He was the Director of Engineering of a division of the Kellogg Company, Engineering Vice-President of a resource development group, and on the board of directors of three corporations. Dr. Santi is currently a member of the American Society of Mechanical Engineers Region XI operating board; he serves as the Student Sections Committee Senior Representative from ASME Region XI.

Joseph E. Beaini is an Associate Professor and chairman of Electrical Engineering at CBU. He is a member of the IEEE communications society. He is the recipient of a National Science Foundation grant and is currently serving on the committee for the development of the Telecommunications Education Research Network (TERN). He serves as the IEEE Tennessee Council Student activities officer, and the IEEE Memphis Section student activities chairman. Mr. Beaini's interests are controls and communications. At CBU, he also serves as the faculty advisor of the engineering honor society, Tau Beta Pi, and the Institute of Electrical and Electronic Engineers Student Branch advisor.