AC 2007-41: THE ENGINEERING INSTITUTE: A COLLABORATIVE GRADUATE EDUCATION AND RESEARCH PROGRAM

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Michael Todd received his B.S.E. (1992), M.S. (1993), and Ph.D. (1996) degrees from Duke University's Department of Mechanical Engineering and Materials Science. From 1996-2003 he served as Research Engineer and later Section Head of the Fiber Optic Smart Structures Section at the U.S. Naval Research Laboratory in Washington, DC. In 2003, he joined the faculty of the Department of Structural Engineering at the University of California, San Diego, where he currently serves as Associate Professor and Co-Director of the Engineering Institute. He conducts research in structural health monitoring strategies, nonlinear time series modeling applications, and fiber optic measurement systems.

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The Engineering Institute – A Collaborative Graduate Education and Research Program

Abstract

Los Alamos National Laboratory (LANL) and the University of California, San Diego (UCSD) have taken the unprecedented step of creating a collaborative, multi-disciplinary graduate education program and associated research agenda called the Engineering Institute. The technology thrust of the Engineering Institute is damage prognosis, a multidisciplinary engineering science concerned with assessing the current condition and predicting the remaining life of a wide variety of structural systems. The mission of the Engineering Institute is to develop a comprehensive approach for conducting LANL mission-driven, multidisciplinary engineering research and to improve recruiting, revitalization and retention of the current and future staff necessary to support LANL's nuclear weapons stockpile stewardship responsibilities. The components of the Engineering Institute to be discussed in this paper are 1) the Los Alamos Dynamic Summer School (LADSS), 2) a joint LANL/UCSD degree program with a unique focus in validated simulations, structural health monitoring, and damage prognosis, 3) joint LANL/UCSD research projects, and 4) industry short courses. This program is a possible model for future industry/government interactions with university partners.

Introduction

Los Alamos National Laboratory (LANL) contributes to national security by ensuring the safely and reliability of the US nuclear stockpile, developing technologies to reduce threats from weapons of mass destruction and by solving problems related to energy, environment, heath, infrastructure and national security. The newly formed Los Alamos Institutes represent a substantial LANL investment dedicated to developing the next generation of scientists and engineers, revitalizing current LANL technical staff and retaining these staff. These Institutes are collaborative efforts with university partners and represent a significant investment of money. When these Institutes are viewed in conjunction with LANL's wide range of existing critical skills development programs that address K-12, undergraduate and graduate student development, it is evident that LANL has been a leading innovator in addressing technical work force development issues for many years.

These Institutes also directly address US economic competitiveness issues raised in the National Academy of Science's recent *Rising Above the Gathering Storm* report[1]. These Institutes are LANL's attempt to take an even more aggressive approach than suggested in this report by working with its university partners to not only increase the number and quality of technical graduates and educators, but to also develop new multidisciplinary curricula based on LANL's strategic technical needs. If the US is to maintain its technology lead, it will not only need more scientist and engineers, but it will also need to train them in evolving curricula that are at the forefront of emerging technology. The new and unique aspect of critical skills development that distinguishes these Institutes from the numerous Centers at LANL and other Department of Energy (DOE) labs is the emphasis on working with the university partners to develop and

jointly deliver novel curricula, and then integrate it into LANL's mission-driven programs. The particular emphasis on multidisciplinary curricula, coupled with the Institutes' collaborative campus research, establishes them as premier educational/research programs that are training the next generation of technology leaders in the US.

Currently, there are five Institutes:

1. The Engineering Institute with the Univ. of California – San Diego
2. The Institute for Multi-Scale Materials Studies with the Univ. of California – Santa Barbara
3. The Materials Design Institute with the Univ. of California – Davis,
4. The Institute for Scalable Scientific Data Management with the Univ. of California – Santa Cruz
5. The Advanced Studies Institute with the Univ. of New Mexico, New Mexico State Univ. and New Mexico Tech.

The Engineering Institute (EI) was the first one developed starting in 2003 and is the topic of this paper.

The Engineering Institute

The Engineering Institute is a collaboration between LANL and the University of California at San Diego (UCSD) Jacobs School of Engineering whose mission is to develop a comprehensive approach for 1) conducting mission-driven, multidisciplinary engineering research and 2) recruiting, revitalization and retention of the current and future staff necessary to support LANL's stockpile stewardship responsibilities. The scientific thrust of the EI is damage prognosis, a multidisciplinary engineering science concerned with assessing the current condition and predicting the remaining life of aerospace, civil, and mechanical engineering infrastructure.

Figure 1. The Engineering Institute's facility in the Los Alamos Research Park

Organization

The EI was established in April, 2003 through a memorandum of understanding signed jointly by the Dean of the UCSD Jacobs School of Engineering and the Associate Director Weapons Engineering and Manufacturing and a subsequent 5-year contract with UCSD. The EI is physically located in the Los Alamos Research Park as shown in Figure 1 and resides administratively in the Principal Associate Director for Science, Technology and Engineering's office. It consists of a full-time director and program administrator with four additional technical staff members spending 20%-50% of their time on EI activities. Two other staff members spend 50%-100% of their time at the institute while they are working on their Ph. D. dissertations. Two students, one working on his MS thesis and another providing computer support are also

assigned to the EI. Through its research and education activities the EI has collaborations with many LANL technical divisions.

Technical Thrust

The technology thrust of the EI is damage prognosis, a multidisciplinary engineering science concerned with assessing the current condition and predicting the remaining life of a wide variety of structural systems. Developing damage prognosis capabilities requires coordinated development of 1) advanced sensing and telemetry hardware, 2) novel signal processing and pattern recognition algorithms, and 3) complex multi-scale, physics-based predictive modeling as shown in Figure 2.

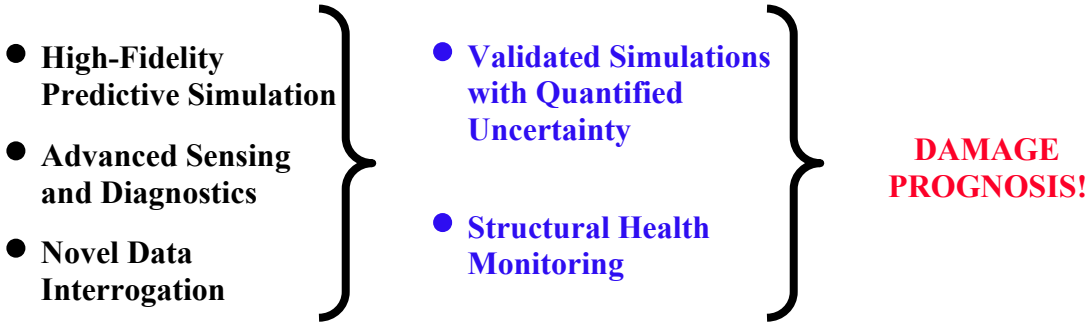


Figure 2. Schematic of the elements required for damage prognosis.

These same three fundamental technology areas are essential to advancing engineering capabilities required for LANL's stockpile stewardship mission, particularly with regards to the validation of the large-scale simulations needed in the absence of nuclear testing. Thus, the technical thrust of the EI is directly aligned with LANL's core mission. Additionally, advances in damage prognosis capabilities offer the potential for significant life-safety and economic benefits to a variety of civilian and conventional defense applications associated with aerospace, mechanical, and civil infrastructure. These societal benefits coupled with the difficulties associated with multidisciplinary research make the development of damage prognosis solutions a "grand challenge" for engineering in the 21st century.

There are four primary components of the EI to be discussed in this paper: 1) the Los Alamos Dynamic Summer School (LADSS), 2) a joint LANL/UCSD degree program with a unique focus in validated simulations, structural health monitoring, and damage prognosis, 3) joint LANL/UCSD research projects, and 4) industry short courses.

The Los Alamos Dynamics Summer School

The LADSS is a very selective 9-week summer school in which top upper-level US-citizen undergraduate students (mean GPA > 3.8/4.0) from universities around the nation participate in summer school activities and work in teams of three with a LANL mentor on research projects related to the EI's technology focus[2]. The summer school activities include four basic elements: lectures on fundamental engineering topics; a distinguished lecturer series on "cutting edge research"; a mini-project consisting of a modal test, finite element analysis, model correlation

and validation of a small test structure; a research project that results in a conference paper and presentation. A picture of two students taking data on a frame structure is shown in Figure 2. The goal of this program is threefold: 1) to encourage these students to attend graduate school and specialize in fields related to the National Nuclear Security Administration's (NNSA) mission, 2) to recruit the top students to return to LANL in following summers as graduate research assistants, and 3) to subsequently hire the best of these students as LANL staff upon completion of their graduate degrees. Over the last seven years, 111 students from 34 academic institutions have participated in the summer school. To date, 107 of these students have entered graduate school, nine staff members have been hired by LANL from this program and 25 students have returned to LANL to work during a subsequent summer.

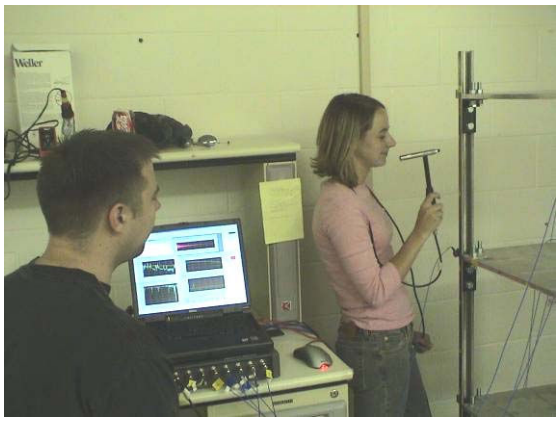


Figure 2. A LADSS student performing a modal test on a frame structure

Students participating in the summer school have also been very successful in obtaining competitive fellowships. Thus far students have received:

- 12 NSF Graduate Fellowships (6 honorable mentions)
- 5 National Defense Science and Engineering Fellowships
- 2 Graduate Education for Minorities (GEM)
- 2 NASA Graduate Fellowships
- 2 National Physical Science Consortium Fellowships

The various elements of the LADSS are continually evaluated. Each year every speaker is assessed and there is a final overall survey. These assessment results are used to improve the overall program and to make modifications to the program. Since the program's inception, the overall rating of the summer school has been **4.73/5.0** and the comments are extremely positive**.** Plus, 100% of the students indicate they would recommend the program to a classmate.

The Joint Degree Program

The second component of the education program is a joint LANL/UCSD multidisciplinary graduate degree program. This multidisciplinary program was designed around LANL's and industry needs for people trained in the areas of structural health monitoring, damage prognosis and validated simulations. This program cuts across traditional engineering department boundaries and involves all but one of the departments in the Jacobs School of Engineering. Consequently, many new courses are being developed, both by UCSD faculty as well as LANL staff who are also adjunct UCSD faculty members. Students are required to take three courses in three primary technical areas: 1) Predictive Simulations, 2) Experimental Diagnostics, and 3) Data Interrogation and one course in Structural Health Monitoring or Model Validation. An example program for an MS student is shown in Figure 3.

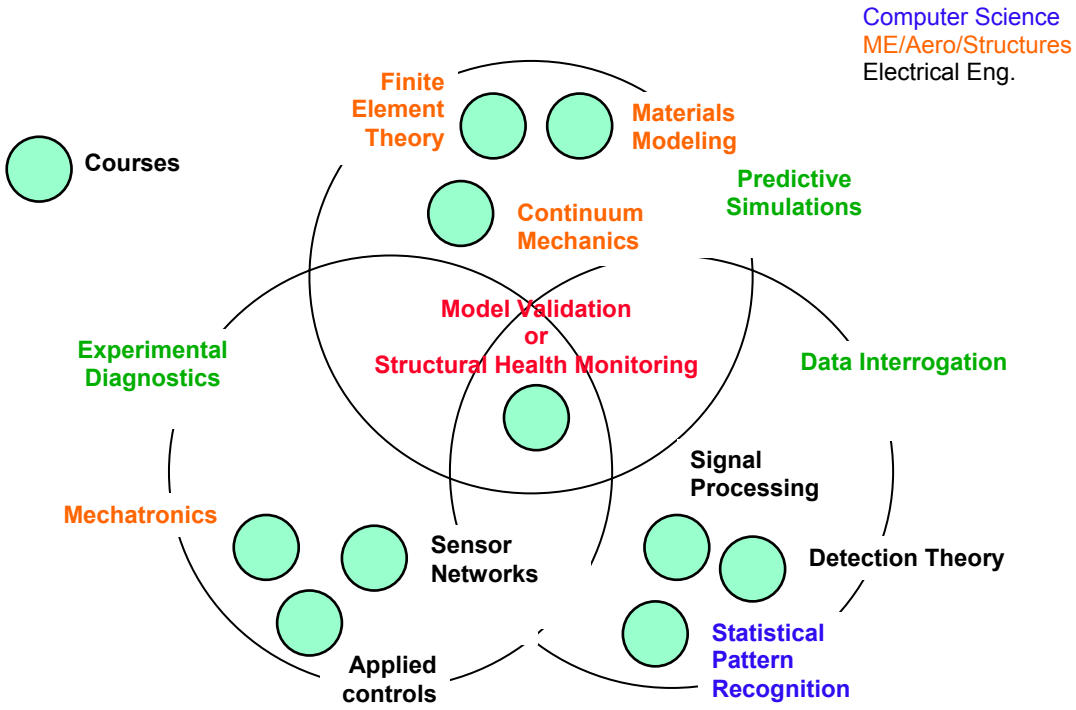
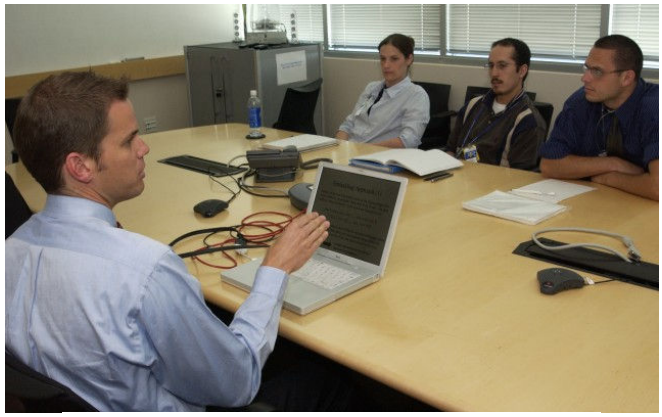


Figure 3. An example of the program for an MS student illustrating courses need to be taken in three primary areas.

Courses are taught at UCSD and transmitted to LANL over the Internet and visa versa. UCSD and LANL distance learning classrooms are shown in Figure 3.

UCSD Distance Learning Classroom



LANL Distance Learning Classroom

Figure 3. Distance learning classrooms at UCSD and LANL

This degree program is targeted at two distinct groups of students. The first group is made up of LANL TSM's pursuing advanced degrees. To date, 26 graduate classes have been offered for the LANL staff either live or through distance learning infrastructure. Seven LANL staff have been accepted into graduate degree program and more than 25 staff member have taken these

courses. One TSM has completed all course work for her Ph. D. and has successfully passed her oral qualifying examination. The second group is made up of traditional full-time graduate students at UCSD, and as such, this program provides a mechanism by which students attending the LADSS as well as other LANL GRA's can stay engaged with LANL throughout their graduate school career.

It is anticipated this continued engagement will greatly enhance the recruiting mission of the EI. Currently, six former LADSS students are enrolled in graduate school at UCSD and they are actively participating in the Institute's collaborative research projects described belwo. The first student to receive a graduate degree in this program, who also was an LADSS participant, completed his MS degree requirements in March, 2006.

The joint degree program addresses training of potential new hires and early-career staff, while also serving to retain mid-career staff members who act as instructors and advisors for the early-career staff.

Joint LANL/UCSD research projects

In addition to meeting mission-driven research needs, the joint research projects also serve as a retention tool for staff at all career levels that collaborate with the UCSD faculty and students on these projects. The new technology development associated with these projects inherently provides the added benefit of a recruiting tool.

Currently, LANL is funding seven graduate student research projects that involve 11 faculty members and more than 15 UCSD graduate students from the structural engineering, mechanical and aerospace engineering, electrical and computer engineering, and computer science departments. With one exception, all the graduate students are US citizens. These projects are needed for the graduate students to complete the research component of their degree program. In an effort to enhance the recruiting aspect of this program, the student spends part of their summers in Los Alamos working with LANL staff members that are collaborating on these projects. All projects have a direct tie to defense programs. Efforts are now underway to solicit research topics relevant to LANL programs so that the students have more direct ties to these programs. It is anticipated that such ties will enhance the subsequent recruitment of these students upon completion of their graduate degrees. An example of a research project involves damage prognosis of an unmanned aerial vehicles as shown in Figure 4 and damage detection in composite-to-steel connections for (DD-X) Navy destroyer as shown in Figure 5.

Figure 4. Collaborative LANL/UCSD research project involving on-board damage detection capabilities for unmanned aerial vehicles

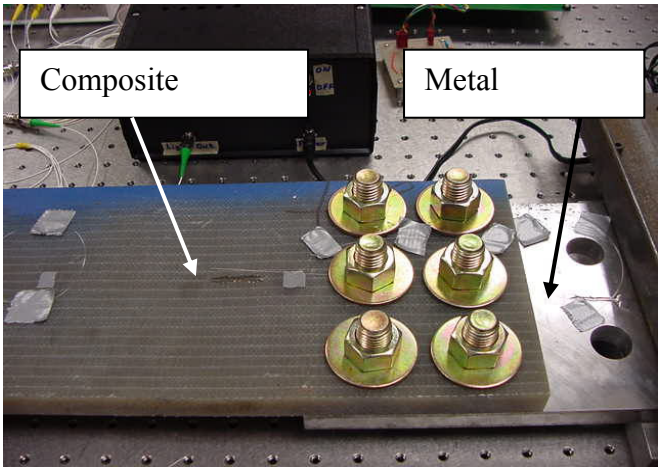


Figure 5. Composite-to-metal lab joint used to study damage detection in composite-to-steel connections

The research portfolio is now expanding as technical staff members working on programmatic activities are beginning to collaborate with UCSD faculty and students on research topics of interest to these programs. In this regard, the EI provides a mechanism to expand the technical expertise addressing defense programs issues at LANL.

Industry Short courses

The final component of the educational program of the EI is the development of industry-focused short courses taught jointly by LANL staff and UCSD faculty in the areas of structural health monitoring (SHM) and model validation and uncertainty quantification. Industry short courses provide an avenue of outreach to the engineering community at large as well as an additional, non-traditional form of peer review. Most recently, the SHM course has been taught at NASA Marshall Space Flight Center, Sandia National Laboratory, and Boeing Inc. (St. Louis). These short courses speed industry adoption of EI research and provide a metric for the relevance of EI research activities. The courses are completely self-sufficient and require no funding from LANL.

Additional Activities

Additional strategic guidance of the EI comes through an annual workshop, with a four-year cycle of recurring themes. Each year, a workshop is organized that focuses on one of the three fundamental technology areas (experimental diagnostics, data interrogation, and predictive simulations), with the fourth year's workshop dedicated to the integration of these three technologies. With this repeating sequence, the evolution of the EI's research in these respective technologies is tracked on a regular basis.

The first such workshop was held during the summer of 2005 and focused on energy harvesting. Energy harvesting is the process of converting ambient thermal or mechanical energy into electrical energy. Particular emphasis was placed on energy harvesting for small embedded sensing systems. The outcome of this workshop was a report (in development) that summarized

the state of the technology in this field. Ideas exchanged in this workshop have also lead to a new research project with UCSD that will make use of robotic devices to deliver energy to embedded sensor networks. In July, 2006 a second workshop was held that was focused on using concepts from nonlinear system identification to extract damage sensitive features from dynamic response measurement.

Achievements to Date

Even though formal EI collaborations began in 2003 and the degree program did not begin officially until 2005, students, UCSD faculty, and LANL technical staff affiliated with EI have flourished under this new model for collaborative activities. A number of student accomplishments with regard to securing highly-competitive extramural fellowships have already been documented above along with the growth in the education program participation and collaborative research activities. In addition, a number of other achievements in the last 3-4 years are listed here:

- Michael Todd wins "Structural Health Monitoring Person-of-the-Year Award", 2005; Francesco Lanza di Scalea finalist, 2006; Gyuhae Park finalist, 2006
- Gyuhae Park named Associate Editor of *Journal of Intelligent Materials, Systems, and Structures*, 2005; Michael Todd named Associate Editor of *Structural Health Monitoring: An International Journal*, 2006; Franceso Lanza di Scalea named to Editorial Board of *Research in Nondestructive Evaluation, 2004*
- François Hemez wins the European Association of Structural Dynamics Junior (Under 40) Research Prize, 2005
- Francesco Lanza di Scalea wins COMETT European Union Award, 2004
- Francesco Lanza di Scalea wins UCSD Hellman Faculty Award 2000, 2002; Michael Todd wins UCSD Hellman Faculty Award, 2004
- Tim Fasel, Colin Olson, Michael Todd, and Gyuhae Park win UCSD Research Expo department prize, 2005
- Joel Conte wins 'UCSD Distinguished Teaching Award', 2006
- Chuck Farrar delivers keynote addresses at three international conferences: IMAC Structural Dynamics, 2005 (Orlando, FL); Int. Symposium on Dynamic Problems of Mechanics, 2006 (Oro Preto, Brazil); 3rd European Workshop on Structural Health Monitoring, 2006 (Granada, Spain)
- At this writing, 25 refereed archival journal articles have been published
- Chuck Farrar (ed.), Gyuhae Park, François Hemez, Matt Bement, Michael Todd, and John Kosmatka contributed to first comprehensive SHM/DP book, *Damage Prognosis for Aerospace, Civil, and Mechanical Systems*, John Wiley and Sons, UK., 2005.

Assessment

It is intended that the EI will ultimately have formal advisory committees for 1) the educational program and 2) the joint research program. The joint degree component of the educational program will establish a balanced selection and advisory committee. This committee will meet semi-annually and will be composed of EI personnel, LANL management, and senior external technical people. Its purpose will be to select LANL staff for institutional support when

pursuing their advanced degrees and to continually assess the quality of the joint LANL/UCSD graduate degree program.

The primary objectives of the research program advisory committee will be to ensure that the nature of the collaborative research projects is well aligned to the LANL's NNSA mission, as well as to provide peer review on the quality of the research. This committee will meet annually and will brief LANL management on the quality and relevance of the Institute's research.

As stated previously, the success of the industry short courses is another non-traditional form of peer review. The fact that industry and other government labs are willing to pay to learn about technology developed through the EI demonstrates the relevance of the EI's research work. Finally, the EI will continue to seek traditional academic metrics of peer review such as refereed journal publications, presentations at national and international technical conferences, and participation in various professional society activities.

Future Plans.
Future plans for the EI fall into four areas of 1) personnel, 2) education, 3) research, and 4) facilities.

Personnel. Personnel plans for the next four years include adding 1) one additional full-time TSM, 2) three half-time staff members, 3) five, rotating, two-year staff positions, 4) two post-doc positions, 5) five additional fellowships for full-time UCSD graduate students, and 6) two, part-time visiting faculty positions. Additionally, adjunct faculty status at UCSD is being sought for the non-rotating TSM positions, for the purpose of teaching courses and advising students.
Education. Develop a senior's honors program where nine UCSD undergraduates spending one quarter at Los Alamos working with LANL staff on a senior project. The intent of this program is to recruit the best UCSD undergraduates into the Institute for their graduate studies.
Research. Research program plans include expanding the portfolio of multidisciplinary joint research projects through collaborations with industry and through competition for third-party government funded research (e.g. DoD and NASA).
Facilities. Facilities plans include securing a dedicated facility with the requisite teaching, office, and laboratory space required to support the educational and research programs and personnel.

Conclusions
LANL's investment in the EI is building a firm foundation for coupled education/research programs that are defining innovative approaches to workforce development. These same programs will directly address economic competitiveness issues through the new education programs and exploratory research being developed with the partner universities. With further investments, these Institutes can expand their education/research portfolio, establish collaborative efforts with additional university partners and government laboratories, increase the technology focus areas, and address a variety of other issues related to developing and educating the United States' current and future technical workforce.

References

1. National Academies Press, *Rising Above The Gathering Storm: Energizing and Employing America for a Brighter Economic Future* (2006)
2. Farrar, C.R. and P.J. Cornwell, "The Los Alamos Dynamics Summer School," *Sound and Vibration Magazine*, April, 2002.