CNDE: A Comprehensive Research Facility

Researchers at Iowa State University work closely with industry to advance the field of nondestructive evaluation

BY MARY RUTH JOHNSEN

The heart of nondestructive evaluation (NDE) research in the United States lies in America's heartland, close to its geographical center, at Iowa State University in Ames. While NDE research is also certainly conducted elsewhere in the United States, the Iowa State Center for Nondestructive Evaluation (CNDE) is a comprehensive facility consisting of an interdisciplinary group of scientists, students, and support staff who work in close cooperation with industry.

Objectives of the Center are as follows:

- ◆ Lead basic and applied research that is industrially relevant and defines the principles that underlie NDE technology
- ◆ Transfer technology to industry in Iowa, the United States, and throughout the world
- ◆ Integrate NDE with other disciplines in order to enhance a component's reliability throughout its life cycle
- ◆ Extend its core measurement techniques to other areas such as agriculture, animal science, and medicine (This objective is part of Iowa State's responsibilities as one of the nation's first land grant colleges. Land grant colleges/universities are charged with three main functions: open higher education to everyone, teach practical classes, and share knowledge beyond the campus borders.)
- ◆ Work to improve NDE education at all levels (K–12, community college, university undergraduate, and graduate).

Jon Friedl (front, right) discusses ultrasonic phased array inspection of a titanium engine disk with industrial visitors as part of the Engine Titanium Consortium project. Then a graduate student at CNDE, Friedl is now an employee of Pratt & Whitney. A close-up shows the phased array transducer positioned above the disk.

How CNDE Developed

CNDE's current director is Dr. R. Bruce Thompson. Besides heading CNDE, Thompson is director of the Ames Laboratory Applied NDE Program, and a distinguished professor of engineering at Iowa State University (ISU). He explained the genesis for a center of this type occurred in the late 1960s, early 1970s when fracture mechanics was developed.

"With the use of fracture mechanics," Thompson explained, "damage tolerance strategies were developed that allowed the use of structures if flaw size could be bounded. There was a new demand for inspection. It wasn't just that we needed to find any flaw, but we needed to find a flaw greater than a certain size."

Two industries of great concern in the mid-seventies were nuclear power generation and aviation/aerospace. The Electric Power Research Institute (EPRI), which focused on nuclear power, established and NDE center in Charlotte, N.C., and the Defense Advanced Projects Agency/Air Force Materials Laboratory Interdisciplinary Program in Quantitative Nondestructive Evaluation, which was managed by the Rockwell International Science Center, was established in 1974. "The government philosophy was to develop a science base. What was being asked was 'How did these inspection techniques work?'" Thompson said. The program continued for six years at Rockwell International, but over that time it became clear there was a "need to involve more students," he recalled, "but it was not clear how to do that from any corporate entity. Future needs were better served by going to an academic setting." An academic setting not only provided the education of students who would better enable technology transfer, but it provided a neutral environment in which industry could freely interact.

The program first moved to the Department of Energy's Ames Laboratory in 1980, where Thompson was one of four people who made up the group initially. At that time, the U.S. Air Force continued funding a program to develop more quantitative NDE measurement methods for aircraft inspection. ISU was selected because of the presence of the Ames Laboratory and the university's strong engineering program. Donald Thompson, who had headed the program at Rockwell, served the same role in Iowa. In 1984, the National Science Foundation established the Industry/University Cooperative Research Center (IUCRC) in NDE, and a year later the Iowa State Board of Regents approved the CNDE as an official university center.

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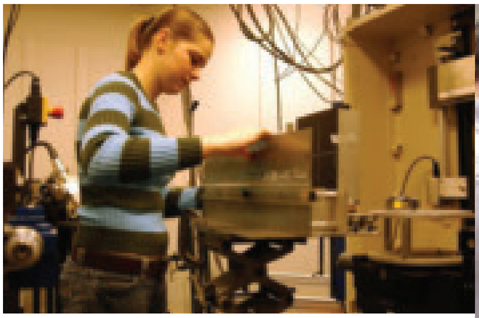
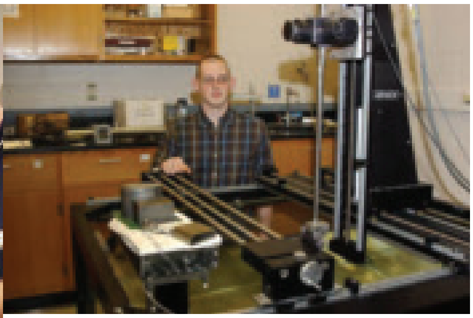


Undergraduate student Mykal Clayton readies a friction stir welding sample for X-ray analysis.

CNDE staff member Brian Larson (left) discusses an interesting sample with students in a graduate student laboratory demonstration.



Undergraduate student Nate Richter is shown setting up one of the center's UT scanning systems for an immersion inspection of a friction stir weld sample.

It is now part of the school's Institute for Physical Research and Technology.

While the IUCRC has been CNDE's core, its existence no longer relies solely on the National Science Foundation funding. As an extension of the IUCRC, the group has performed research for the Department of Energy, Federal Aviation Administration, NASA, and the Air Force. A U.S. Army-funded program is now in its beginning stages. Besides those government entities, member companies of the IUCRC include Honeywell Engines and Systems, Pratt & Whitney, Rolls Royce Corp., Alcoa, Boeing, Korea Gas Safety Co., Areva, and Textron Aircraft.

The CNDE Web site describes the IUCRC work as follows: "This program focuses on generic, industrially relevant research and includes the transfer of those results in industry and the education of the future workforce as central elements of its mission. The IUCRC provides a unique environment in which academic researchers and industry partners can work together on technology issues that affect the broad spectrum of NDE practitioners. Whether it is application of existing NDE methods or development of new approaches, a strong bond has been built between the CNDE research staff and our industry partners. CNDE seeks to serve as a shared, corporate research laboratory in NDE and has developed many supplemental programs focused on the needs of specific clients."

Laboratory Facilities

CNDE is located apart from Iowa State's campus in Buildings II and III of the Applied Sciences Complex. The approximately 52,000-sq-ft facility contains instruments for all the major NDE methods typically used by industry as well as state-of-the-art research instrumentation. Following is a listing of the CNDE labs; the equipment mentioned is only a small part of that available to the researchers.

◆ **Ultrasonics.** Eight laboratories using scanning systems mounted on immersion tanks, as well as portable instruments. Included are both conventional and phased array systems.

◆ **Composite Materials Analysis.** Within the UT Group, a subgroup specializes in analysis of composite materials. The group's facilities include air-coupled ultrasonic instruments, conventional ultrasonic equipment, three ultrasonic immersion tanks and four LeCroy oscilloscopes, two of which can be operated over the Internet. The group develops manual portable scanners and has on hand a number of unique prototypes. It also has an acoustic scope with a 3-MHz source and a 3-in. liquid crystal acousto-optic detector for inspecting small parts with complex shapes in real time.

◆ **Eddy Current and Related Electromagnetic NDE.** Electromagnetic NDE research is performed in eight laboratories at the center. Five contain motion-controlled eddy current stations. Various types of data-acquisition instruments are available, including impedance analyzers, commercial EC instruments, and other proprietary instrumentation.

◆ **Magnetic Inspection.** The magnetics laboratories are shared between programs at CNDE and the Ames National Laboratory. Equipment is available for measuring magnetic hysteresis loops, for detecting Barkhausen effect signals, and for imaging magnetic properties using a scanning system.

◆ **X-Ray Inspection.** The five X-ray inspection laboratories are equipped with three microfocus tubes and three standard X-ray tubes. A high-resolution computed tomography (CT) facility allows both high-resolution digital radiography and 3-D CT. Real-time radiography can be accomplished using three different image intensifier-based systems. Access to a real-time stereographic imaging system composed of two 200-kV X-ray tubes and two 16-in.-diameter image intensifiers is available through collaboration with the ISU Dept. of Mechanical Engineering.

◆ **Thermographic Inspection.** A thermographic NDE lab that will focus on SonicIR measurement is in the startup phase. Major equipment includes an infrared camera, laser vibrometer, broadband 1–100 kHz, 1-kW power amplifier, and data-acquisition computer. Integration of a motion control system and a high-power sonic/ultrasonic actuator system will enable SonicIR inspection capabilities.

◆ **Visual and Mechanical Testing.** Portable and stationary liquid and magnetic particle testing devices are available including a wet horizontal MPI unit. The lab contains a variety of microscopes with white light illumination and CCD cameras. All microscopes are connected to image-acquisition and analysis software. Also available are borescopes, a fiberscope, and a hand-held video inspection unit; servo-hydraulic mechanical test unit; 3-axis electrodischarge machining unit; salt fog corrosion chamber; Rockwell, Leeb's, and durometer hardness testers; and commercial alloy analyzer to perform XRF-type measurements.

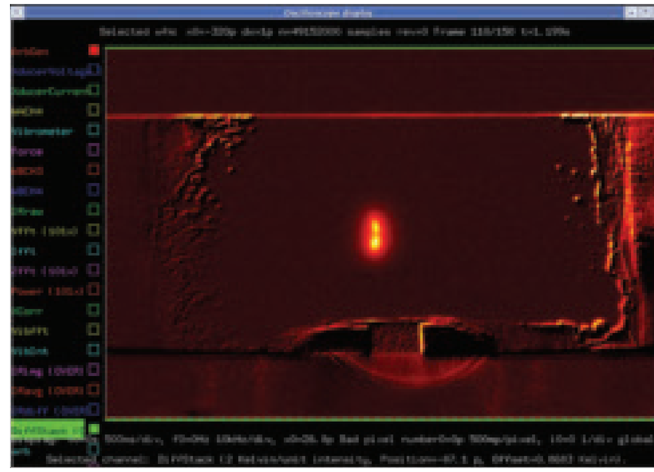
◆ **Machine Shop.** Also available is a basic machine shop containing a mill, lathe, bandsaws, and drill presses for fabrication of custom components. Facilities at ISU or Ames Lab handle larger design or machining jobs.

The Center's Role in NDE Education

In cooperation with the ISU education mission, CNDE works to further NDE education at all levels. The aim of the work at the kindergarten through twelfth-grade levels is to encourage an interest in science and technology. CNDE staff has developed interactive computer programs that use NDE to illustrate the physical principles behind the inspection technologies. "NDE is easy for kids to understand," explained Thompson. "This gives them an incentive to learn the underlying principles."

Since much inspection work is at the hands-on level, most NDE educational programs are at community colleges. CNDE collaborates with institutions such as Ridgewater College in Hutchinson, Minn., Southeast Community College in Milford, Neb., and Salt Lake Community College in Salt Lake City, Utah, to develop improved course materials and provide support for NDE instructors. The NDT Resource Center at *www.nde-ed.org* or *www.ndt-ed.org*, while designed as a comprehensive source of information for NDE technicians and educators, also offers resources for junior and senior high school students, parents, guidance counselors, and NDE professionals.

The Center's staff also develops continuing education materials for groups outside of academia such as Federal Aviation Administration safety inspectors.



An image of a crack indication obtained by vibrothermography is shown. With this technique, the part is vibrated, generating frictional heat. Radiation emitted from the crack can then be detected with an infrared camera, as shown. This is a dark field technique since the crack only "lights up" during the vibration.

Undergraduate Education

Iowa State now offers a minor in nondestructive evaluation — believed to be the first program of its kind in the United States — that is open to undergraduate students enrolled in any of the school's engineering disciplines. Currently, 25 to 30 students are enrolled in the program.

The multidisciplinary minor requires 16 credit hours (9 beyond the regular degree requirements). Students take two required courses, Principles of Nondestructive Testing and Nondestructive Testing Laboratory; must choose two out of four possible NDE-specific classes; and take two other supporting courses. Of the NDE-specific courses, one allows for independent study, an option many of the students select. "Employers like it because it gives the students practical training, not just classroom," Thompson said.

In addition to the NDE minor, undergraduate students work alongside the center's scientists, gaining valuable research experience. Others participate in industrial internships.

Outreach

CNDE's strong outreach focus is in keeping with the mission of a land-grant university. CNDE transfers technology to industry and the public in several ways: 1) working with its industry partners as a National Science Foundation Industry/University Cooperative Research Center; 2) organizing and hosting the yearly Review of Progress in Quantitative Nondestructive Evaluation Conference (QNDE); and 3) through participation in the ISU Institute for Physical Research and Technology's (IPRT's) Company Assistance Team.

Through IPRT Company Assistance (*www.iprt.iastate.edu*), Iowa manufacturers can receive up to 40 hours of NDE support at no cost. The program is aimed particularly at small- to medium-sized companies whose resources may be limited. According to IPRT figures, from 2004 to 2007, almost 60% of the manufacturers it assisted had 99 or fewer employees. The whole IRPT company assistance program over the past five years had an estimated economic impact of $17.3 million on increased and retained sales, cost savings, and investments.

The NDE Group works on about 50 projects a year, according to Rick Lopez, a CNDE metallurgical engineer. Getting word out about the program and then assisting companies is part of Lopez's job at CNDE. "A lot of the projects here are just to provide information," he said. "There is a knowledge base here at CNDE that can be tapped." Lopez started out as an ASME-certified welder and quality control technician at a firm in Dubuque, Iowa, after earning an AAS degree in nondestructive testing at Eastern Iowa Community College. His first work with CNDE was as an undergraduate assistant while working on his bachelor's degree. Upon graduation, he took a job with Mercury Marine in Fond du Lac, Wis., but returned to CNDE in May 2000. He is also working on a master's degree.

Many Iowa firms don't realize assistance is available, Lopez said, so getting word out about the program is critical. He helps operate a booth at trade shows, serves as a speaker at local industry groups such as AWS Section meetings, and even offers an up to 4-hour-long "Intro to NDE" seminar. "We even bring commerical equipment along and let attendees try it out," he said. "The goal is not to give them enough information so they'll try to to it themselves, but plant the seed for us to come to them."

A typical question from the companies he helps is "I made this item, how do I inspect it?" Lopez can go to the company's site, view their manufacturing processes, do feasibility studies, and make recommendations on what NDE process or processes to use. One thing especially helpful to him is that the center contains up-to-date, commercially relevant equipment similar to what a local manufacturer likely would own or could purchase for its inspection program. He can help a company set up an NDE program and decide what equipment it needs to purchase.

Although many of the welding-related questions go to the university's materials group, because of his background, Lopez also fields a lot of welding questions. Many of the problems that NDE reveals result from such issues as selection of filler metals and shielding gases or need for additional training for welders, issues that Lopez can help a company handle.

Weld Inspection

Tim Gray describes himself as "an ultrasonics guy." He is a senior engineer and group leader for Ultrasonic Applications at CNDE, who joined the center in 1981. His research focuses on computer modeling of ultrasonic inspectability, especially develoment of methods and codes for estimating probability of detection (POD) of flaws in components, and development of ultrasonic inspection and signal processing techniques. Gray describes the benefits of simulating UT inspections in the simplest of terms: "It is cheap and easy to run a model a bunch of times, but it is expensive to develop samples with flaws that need to be inspected."

Weld-related work includes NDE of girth welds in pipelines and inspection of friction stir welds. The girth weld project occurred during the late 1990s and was driven by the oil companies' need to drill offshore in ever-increasing depths, Gray explained. Deeper waters place greater pressure on the steel

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catenary risers made of girth welded seamless tubes and call for the use of higher-strength steels. The bottom of a riser is located at the seabed; a flexible connection attaches it to a floating platform.

The safe life of the risers was questioned because the oil companies were worried about crack initiation and propagation. They were interested in CNDE determing the "probability of detection that we'd been involved with in aerospace," Gray recalled. Samples of girth welded pipes containing perfect welds were shipped to the center. "We developed empirical noise data and coupled that with flaw predictions," he said.

More recently, Gray and Terry Jensen, a CNDE physicist whose research interests include development of new X-ray detection techniques and computer modeling of X-ray imaging processes, have done some work with friction stir welds. The South Dakota School of Mines and Technology has a National Science Foundation IUCRC concerned with friction stir welding R&D. "The National Science Foundation likes to have synergistic relationships between the centers," Gray said. "We were looking at the applicability and reliability of NDE for friction stir welds. The idea was they would decide on the different types of defects common in friction stir welded butt joints in aluminum plates and we'd develop a POD for finding those flaws."

The two types of flaws studied were wormholes and incomplete penetration. Gray's job was to determine the capabilities of ultrasonic testing for inspecting those flaws, while Jensen studied using radiography for the same job. Because of the relatively low funding, most of the work concentrated on wormholes.

"Both (inspection techniques) could find the defect fairly well," Jensen said. With X-ray, however, the friction stir welding pin tool ridges could sometimes hide defects that UT could discover because the UT instrument could come in at different angles.

The goal, Jensen explained, is "to have a part strong enough to have a reasonable lifetime and to set up an inspection process that can determine how long that life is." To do that, you need a lot of statistics, but there were not enough FSW panels involved and the project did not go far enough to generate the amount of statistics needed. Some of the work was designed to demonstrate what could be done once additional funding is established.

What's Next

Nondestructive evaluation began at Iowa State with work funded by the Air Force, and initially U.S. defense was the driving influence. However, in the late 1980s the Cold War ended, defense work lessened but the nation became concerned about aging aircraft following the Aloha Airlines accident near Maui, Hawaii, in April 1988, and the United Airlines disaster in Sioux City, Iowa, in July 1989. Aviation and aerospace became the center's key industries.

At one time, metals were all important. Today, there's a need for understanding more about composite materials. In addition, the I-35W bridge collapse in Minnesota in August 2007 has turned attention to the country's aging infrastructure. CNDE's work evolves as the nation's needs and industry demands change.❖