NDE Research Update
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Research and Development Efforts Help Nondestructive Evaluation Pay Off for Today's and Tomorrow's Air Force

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The Air Force has been involved with the development and application of nondestructive evaluation (NDE) ever since the Army Air Service used X-ray radiography to explore internal defects in materials back in 1926. Today, our work spans the entire spectrum of applications.

On one hand, the NDE Branch works directly with engineers and scientists in the research and development community as they look at new materials and processes development. We also deal with new and emerging weapon systems to ensure effective NDE methods are in place for new systems before they go into service. Finally, we provide vital inspection technologies to allow safe life extension of the Air Force's aging aircraft fleet.

Also, we are heavily involved with the whole area of sustainment of the fielded and aging systems in the Air Force fleet. In fact, the lion's share of our work is focused on how we provide the R&D base that supports those elements of the Materials and Manufacturing Directorate engaged in solving problems for weapon systems in the field.

The Directorate's NDE effort has an R&D focus as well as a systems support focus. Our NDE R&D activities cut across both of these critical areas. If there are immediate problems in the field, the Directorate already has in place a systems support organization to provide direct field support. If that part of the Directorate needs further technical assistance, the NDE R&D organization becomes involved. So we have a role in offering R&D support to our people who are helping to solve field problems.

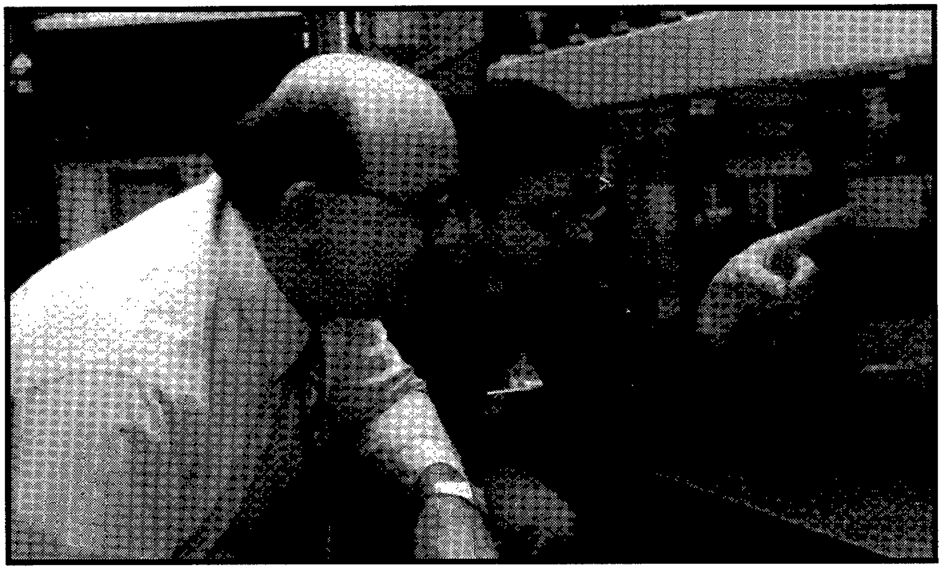
Our Current Focus

We are responsible for developing and addressing the NDE R&D needs of Air Force customers in depots and in the field. A key element for R&D program development is responding to the needs of Air Force Air Logistics Centers (ALCs) and Major Commands (MAJCOMs); and to the requests from the Integrated Product Teams (IPTs) which have been formed all across the Air Force to deal with individual systems. We focus on the needs of our customers to help us prioritize what new R&D efforts are needed. This focus also helps to ensure effective transition of the technology after completion of the various phases of R&D.

At the same time we work through all these issues very closely with the Air Force Nondestructive Inspection Program Office (NDI PO) – also part of the Directorate, currently located at the San Antonio ALC. We coordinate our programs very closely with them because they are directly involved with NDI personnel in the field and at the ALCs, and therefore are instrumental in helping to set program priorities.

A quarterly NDI IPT meeting, chaired by the NDI PO involves the entire community of engineers and scientists conducting NDI research, development and application. These IPT meetings are attended by the Air Force NDE R&D community, Headquarters AFMC, the MAJCOMs, and all the ALCs. Another opportunity to interface with the people in the field results from actively participating in the annual worldwide Air Force NDI managers meeting. We take advantage of these opportunities to maintain a meaningful dialogue with depot and field personnel, as well as learn of new NDI needs coming through the NDI PO Air Force solicitation process.

The role of NDE R&D is to develop technologies with a goal of implementation to meet customers' future needs. To meet the full spectrum of our responsibility, about 25 percent of our organization's developmental activities are focused on the near-term (0 to 3 years to application); about 50 percent are mid-term (3 to 7 years out),



Tobey Cordell and Mark Blodgett examine a scan-in-progress of a titanium alloy sample on the High Precision Scanning Acoustic Microscope.

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New Ultrasonic Technique Enables NDE for Process Sensing of Components at High Temperatures

A nondestructive evaluation technique which can be used during the production process to verify the integrity of critical aerospace structural components has been developed by scientists at the University of Dayton Research Institute and the Air Force Research Laboratory's Materials and Manufacturing Directorate. Their ultrasonic sensor technology allows real-time process monitoring at operating temperatures up to 1100°C (2012°F). Further development of this technology will allow optimized processing for critical components of advanced Air Force weapon systems and result in shorter production cycles and increased product yield.

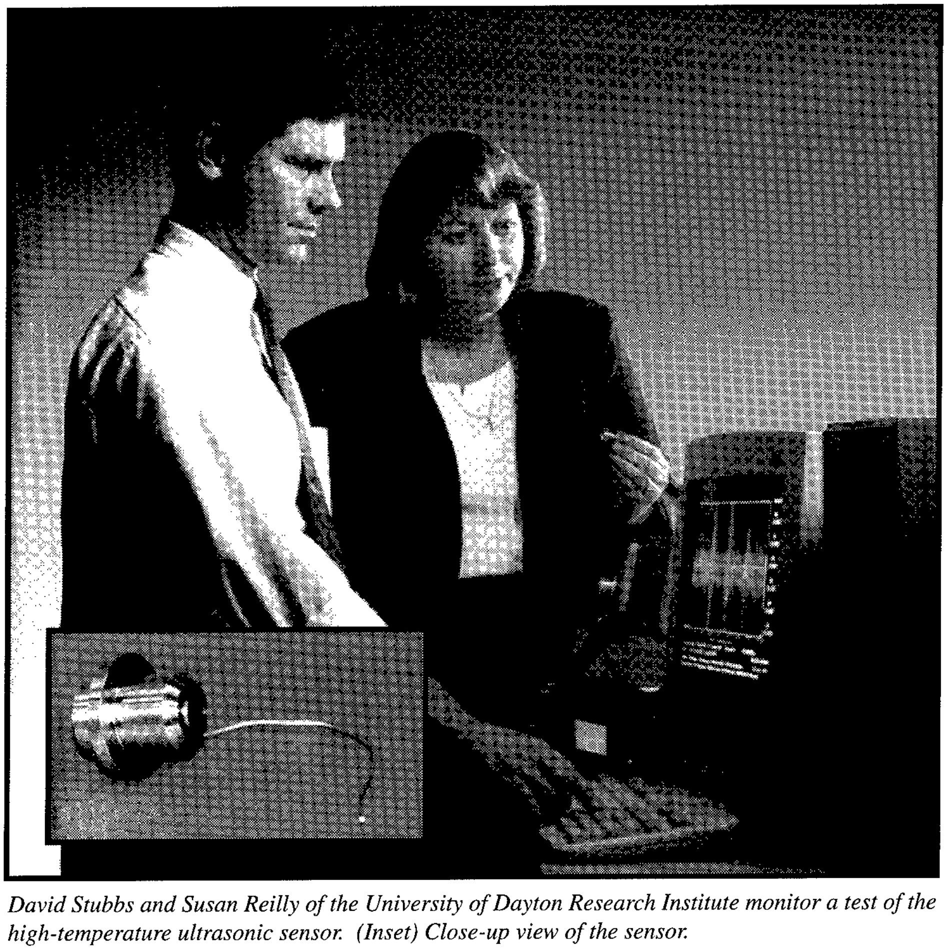
Many components for Air Force weapon systems such as castings for jet engines, nickel-base superalloy turbine blades, and parts made of ceramic and metal matrix composites must withstand high-temperature operating conditions and severe environments. To assure the precision component structure necessary for dependable operation, reliable monitoring during the manufacturing process is required. Hot isostatic pressing (HIP) is a case in point.

During HIP, the workpiece is heated above 900° C (1650° F) in a sealed container pressurized with argon gas up to 140 MPa (20,300 psi) to densify the material and eliminate porosity in the component. Since traditional monitoring sensors usually cannot withstand the required high temperatures, components must be held in the HIP vessel for several extra hours at maximum rated pressure and high processing temperature to assure full densification, even though a part actually may be completely densified in only a fraction of this time. Besides unwanted changes in workpiece microstructure, extra processing time can add as much as $10,000 to the cost of a single complex component.

To meet high temperature monitoring requirements, a team of researchers from the University of Dayton Research Institute worked under contract with scientists from the Air Force Research Laboratory's Materials and Manufacturing Directorate. They developed an ultrasonic transducer capable of precision operation in a high temperature environment and demonstrated the feasibility of using ultrasound to acquire metrology data in severe operating conditions. A prototype sensor was successfully tested to 1100°C (2012°F) and 150 MPa (22,000 psi) without sustaining damage.

Several possibilities are under consideration to develop this sensor for use in other high temperature applications such as optoelectronic crystal production, real-time monitoring of casting processes, or the monitoring of component shape changes during turbine engine operation.

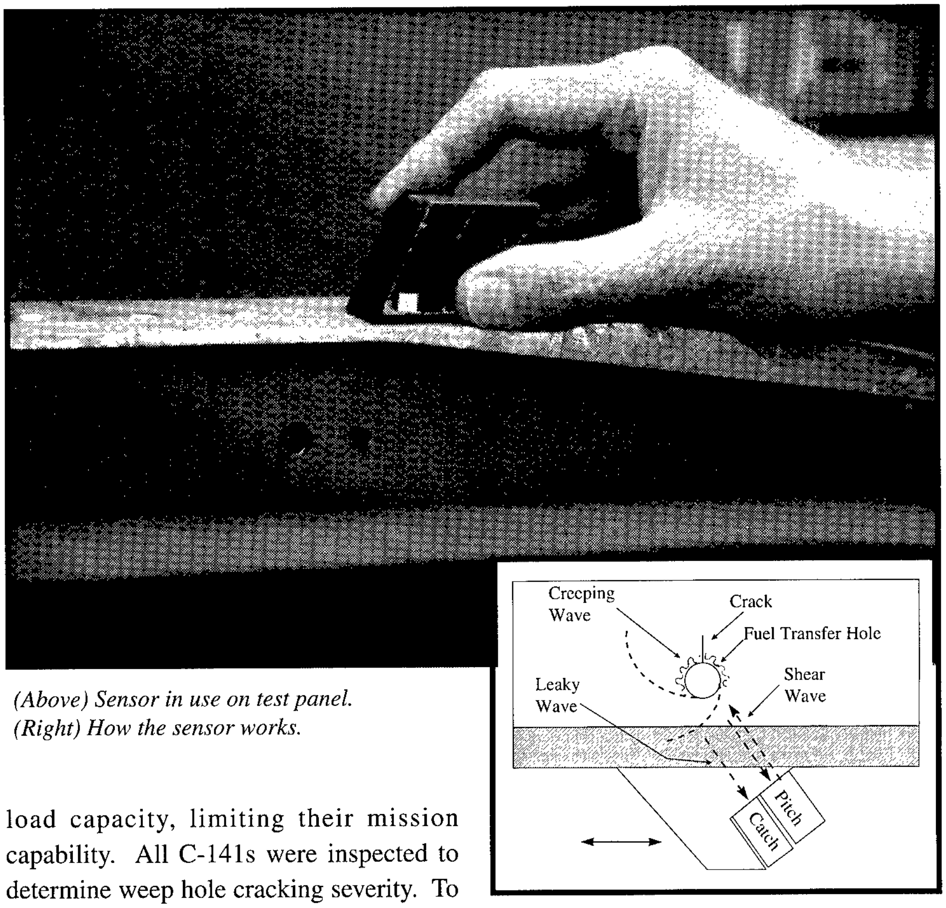
The ultrasonic transducer shows promise for high temperature monitoring of materials and components at temperatures significantly higher than current sensors will allow. This can help produce shorter production cycles and maximized product yield for Air Force weapon system components.



David Stubbs and Susan Reilly of the University of Dayton Research Institute monitor a test of the high-temperature ultrasonic sensor. (Inset) Close-up view of the sensor.

For more information, contact the NDE Technology Transfer Center at (937) 255-2818 or e-mail ndedata@ml.wpafb.af.mil. Refer to 97-671.

New Creeping Wave Ultrasonic Technique Improves Inspection of Aircraft Internal Wing Fuel Tank Structure



(Above) Sensor in use on test panel.
(Right) How the sensor works.

A nondestructive evaluation technique has been developed for detecting fatigue-induced cracks on internal wing fuel tank structures equipped with fuel transfer holes, also called weep holes. Scientists at the Air Force Research Laboratory Materials and Manufacturing Directorate have developed a split-aperture circumferential ultrasonic sensor technology technique for external inspection of the area around internal weep holes of fuel tank baffles on aircraft. This technique promises to be quicker and safer than conventional visual inspections. Further development of this technology will permit more efficient inspections to maintain the mission readiness of "wet wing" aircraft.

Several Air Force weapon systems are built with internal wing structures called wet wings, used as fuel tanks. Inside the wing, a series of vertical risers at right angles to the wing's leading edge serve as stiffeners. To provide balanced fuel flow and distribution during flight, quarter-inch weep holes are drilled through each of the stiffeners. Weep holes become sites where fatigue cracks tend to originate, primarily growing upward over time to weaken the stiffener and diminish wing integrity. While downward cracks also occur and are fairly easy to detect, cracks on the upper part of the weep hole are not readily detectable.

Weep hole cracks in C-141 Starlifter aircraft wings are a case in point. Excessive weep hole fatigue cracks caused the grounding of 45 C-141s in August 1993 while 116 more C-141s were prohibited from in-flight refueling. Earlier in 1993 all C-141s were held to 74 percent of normal load capacity, limiting their mission capability. All C-141s were inspected to determine weep hole cracking severity. To accomplish this, the fuel tanks had to be emptied and purged so that an operator could crawl inside each wing section and do a manual inspection using a special eddy current bore-hole transducer — a time-consuming, potentially hazardous operation. Other Air Force weapon systems with wet wings include the A-10 Thunderbolt II, the F-15 Eagle, and the F-4 Phantom II (used today for drone duty).

Engineers in the Nondestructive Evaluation Branch at the Air Force Research Laboratory Materials and Manufacturing Directorate worked with researchers from the University of Cincinnati, University of Dayton Research Institute of Dayton, Ohio and Advanced Quality Concepts of Columbus, Ohio, to find a faster, safer, more effective and convenient technique to locate weep hole cracking. At the outset the use of conventional ultrasonics was investigated, but it was found to be very difficult to detect cracks radiating upward from weep holes.

To overcome this problem a dual element, split-aperture circumferential creeping ultrasonic transducer inspection system was developed. With it, when an ultrasonic signal encounters a weep hole it travels around it. If no signal comes back the hole is crack-free, but if some of the signal travels completely around the hole and a partial-travel echo comes back the presence of a crack is indicated.

This can make the inspection process much more efficient by previewing all holes from outside the wing. Only those holes with indicated cracks must be inspected from inside the wing, so overall inspection time can be substantially reduced. Further work is now proceeding to achieve system viability for in-field use.

For more information, contact the NDE Technology Transfer Center at (937) 255-2818 or e-mail ndedata@ml.wpafb.af.mil. Refer to 97-603.

X-Ray Three-Dimensional Computed Tomography Enables Nondestructive Evaluation of Large Solid Rocket Motors

Engineers at the Air Force Research Laboratory Materials and Manufacturing Directorate, working with a research team led by Perceptics Corporation of Sandy, Utah, have developed a method for highly accurate nondestructive evaluation (NDE) of large solid rocket motors. For the first time, flaws in inaccessible motor areas such as bondlines can be clearly detected and quantified. Their high resolution, X-ray 3D computed tomography system has shown improved imaging accuracy and detection sensitivity for finding bondline flaws.

Large solid rocket motors (SRMs) used for heavy-lift expendable launch vehicles are vital for lifting heavy payloads into space for Air Force and U.S. national security needs. SRMs are typically built with an outer casing, internal insulation and solid propellant, all separated by bondlines with adhesives and barrier coats. These must be accurately applied to assure correct operation and prevent flaws or gas paths to bondlines which can lead rapidly to catastrophic failure of the SRM during vehicle launch. A major problem is to correctly and precisely detect and quantify bondline defects.

NDE is used to inspect SRMs for component integrity, with computed tomography (CT) and radiography as the most common methods. However, these traditional technologies have serious limitations. Radiography through the entire SRM cross-section results in low resolution at the bondline, an area where it was suspected that flaws and problems could occur. CT does not have the spatial resolution to recognize bondline separations as small as 10 mils.

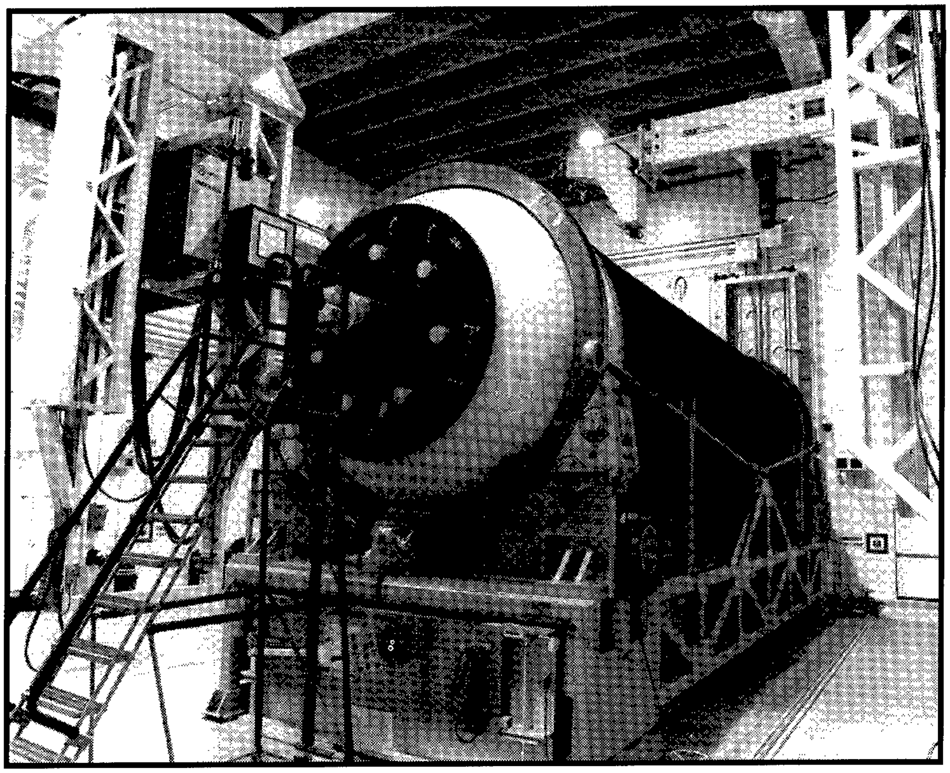
Working under contract to the NDE Branch of the Air Force Research Laboratory Materials and Manufacturing Directorate, a team composed of Perceptics Corporation of Sandy, Utah, Skiametrics Inc. of Winchester, Mass, Alliant Techsystems, Inc. of Magna, Utah, Lockheed Martin Missile Systems of Palo Alto, Cal., and Tufts University of Boston, Mass., successfully developed a novel solution: high-resolution 3-dimensional computed tomography (HR3DCT).

This solution is based on the recognition that bondline anomalies in SRMs are oriented along tangential directions of the SRM case. Imaging the important features of the bondline requires good spatial resolution in the radial direction only, which can be easily captured while the SRM is rotated in a tangential radiography fixture.

The large interior of the SRM, typically inspected using CT, need not be irradiated or reconstructed. To gain good radial spatial resolution in examining large rocket motors, a high-energy digital area imaging detector such as is used for real-time radiography is utilized.

The new technology is expected to require only minimal changes to imaging sources and handling equipment. In use, the partial angle CT reconstruction yields a 3-D volume image of a region concentrated near the periphery of the motor. This image is displayed as a linear CT slice at a fixed radius corresponding to the bondline. It effectively unwinds the periphery of the motor and results in a high resolution true HR3DCT image that clearly identifies features, flaws and problems along the bondlines.

For more information, contact the NDE Technology Transfer Center at (937) 255-2818 or e-mail ndedata@ml.wpafb.af.mil. Refer to 97-629.



120-inch diameter solid rocket motor mounted on a rotary inspection stand for bondline inspection.

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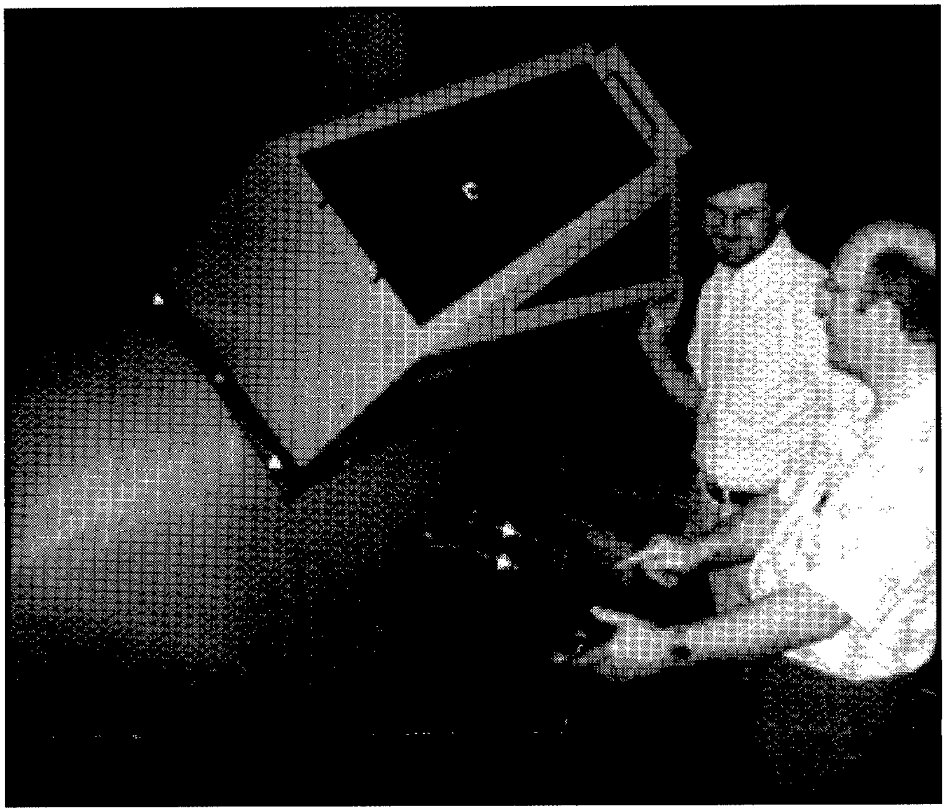
New Inspection System for Aircraft Surfaces Improves Capability to Detect Hidden Damage

Engineers from Diffracto Ltd. of Windsor, Canada and the National Research Council of Ottawa, Canada, have developed a highly efficient technique for detecting material defects in large metal and composite aircraft components. This effort was sponsored and supervised by the Air Force Research Laboratory's Materials and Manufacturing Directorate.

Their new D-Sight Aircraft Inspection System (DAIS) evaluates large surface areas on composite aircraft parts to locate subsurface problems such as impact damage and delaminations, with time savings ranging from 60 percent to over 90 percent. The portable system includes a user-friendly computer interface to manage high quantities of data.

Fiber reinforced composite structures have been used on Air Force weapon systems ever since fiberglass-reinforced polyester became available in the 1970s for secondary aircraft structures such as fairings, cowlings, landing gear doors, movable control surfaces and fixed surfaces of wing trailing edges. Advanced materials developed in the early 1980s such as graphite/epoxy extended composite usage into primary aircraft structures such as vertical or horizontal stabilizers. Today the B-2, F-117 and F-22 all have composite primary structural elements while the F-15, F-16, C-17, EC-135 and E-4 have composite secondary structures.

Composite structure damage due to impact by hard objects, lightning strikes, fire, and other causes, as well as hidden corrosion in metal parts, can combine with factors such as high loads, fatigue, and wind erosion to result in major part failures. Visual examination is the primary method to inspect aircraft weapon systems surfaces, since damaged subsurface areas are often indicated by localized changes in surface shape. While the U.S. Air Force Damage Tolerance Design Guide regards an impact indentation of 0.1 inch (2.5 mm) as the minimum visibility threshold, residual impact indentations of less than this may also be accompanied by considerable internal damage. Once a surface area of concern has been visually identified, nondestructive ultrasonic or radiographic testing can determine the extent of damage hidden beneath the surface.



Inspection of a EC-135 aircraft radome.

Engineers at the Nondestructive Evaluation Branch of the Air Force Research Laboratory's Materials and Manufacturing Directorate, with researchers from Diffracto Ltd. of Windsor, Canada, and the National Research Council of Ottawa, Canada, worked to develop a cost-effective technique to detect non- or barely-visible damage on composite and metal structures.

They developed a new system called D Sight Aircraft Inspection System (DAIS) for fast, efficient inspection of large areas of aircraft surfaces to highlight prob-lems such as damaged, corroded, delaminated or disbonded areas. The DAIS system uses a charge coupled device camera, a white light source mounted slightly beneath the camera lens, glass mirrors, and a retroreflective screen which returns light falling on its surface in the same direction as the incident light, all contained in a single portable unit. The aircraft surface must be reflective, or be made reflective with a thin film of highlighter. When the aircraft surface is illuminated by the white light source, local surface curvature variations focus or disperse the light onto the retroreflective screen, showing up as bright and dark gray scale variations for later analysis.

For more information, contact the NDE Technology Transfer Center at (937) 255-2818 or e-mail ndedata@ml.wpafb.af.mil. Refer to 97-606.

NDE Research and Development Efforts, *continued from page 1.*

and 25 percent are long-term (7+ years out). These activities span the entire spectrum of current NDE methods, as well as development of new methods, such as laser based ultrasound, that may offer a new approach, or a more rapid or reliable method of inspecting parts on a large scale.

We deal with the development of NDE methods and systems for the entire spectrum of Air Force weapon systems.

- Aircraft involvement includes NDE for airframes such as rapid methods for reliably locating corrosion on KC-135s, as well as for aeropropulsion in enhanced automated turbine engine disk inspection.
- As low observables are applied to more and more aircraft systems we are developing point inspection NDE methods that can verify the electromagnetic integrity of those components.
- For space systems, we are involved principally in space launch systems – solid as well as liquid rocket propulsion systems.
- For satellite systems, we're looking at novel methods of NDE for very lightweight materials that need inspection but can't tolerate fluids on their surfaces. We're also involved in what is called vehicle health management, where we plan to directly monitor changes in the structure of a vehicle without having to come back and conduct additional inspection operations.

Life extension of the ICBM fleet is another area of investigation — the Minuteman III missiles in silos as well as Peacekeeper missiles. There are vital issues here in terms of NDE. Very large, complex computed tomography systems are currently being used by the Ogden ALC at Hill AFB to inspect the Minuteman III and Peacekeeper systems. We are directly involved in terms of providing new X-ray technology that can be used by the ALC inspection system.

Transitioning NDE Programs to Customers

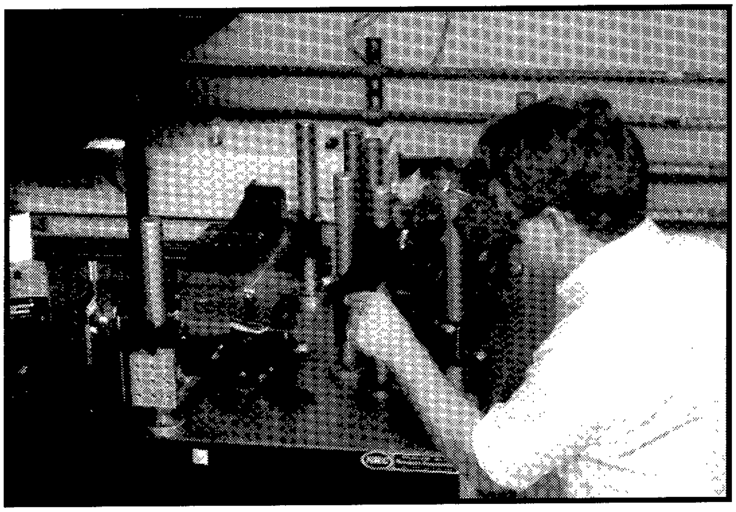
Our NDE R&D work spans the spectrum of funding types as well as the points at which this work might be applied. For example:

- In 6.1 basic research projects we work very closely with the Air Force Office of Scientific Research (AFOSR). Currently, most of those efforts are focused on advanced methods for corrosion detection.
- A significant number of 6.2 applied research programs are underway. These include efforts ranging from detection of corrosion and cracking to looking at novel optical methods, as well as applying shearography to inspect composite structures, etc.
- Several 6.3 advanced development programs are being worked to translate 6.2 programs into engineering prototypes. The reliability of these prototypes will then be validated, and they will be put to work operating in field or depot environments.

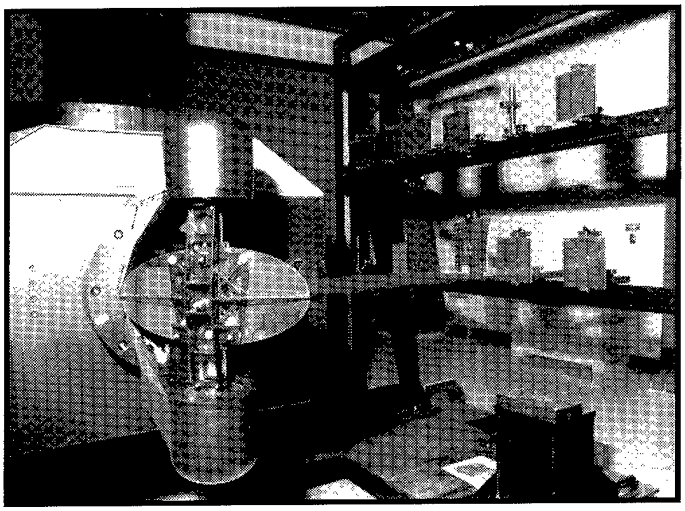
Each of these programs, and especially the 6.3 activities, are closely coordinated with our ALC and SPO customers. When R&D programs reach the 6.3 stage, the objective is to provide in-the-field assessment of engineering prototypes to learn just how they will perform in actual service, and determine whether additional development is necessary.

Follow-up activities are conducted in close coordination with our Manufacturing Technology counterparts in the Directorate. These activities also require involvement with 6.5 Engineering Development work, sponsored by Aeronautical Systems Center's Subsystems SPO.

A good example of program flow is the Mobile Automated Scanner (MAUS) system. Original development was done during a 6.2 program with McDonnell Douglas (now Boeing) in St. Louis. As part of subsequent 6.3 efforts and with the assistance of Air Force NDI Program Office funding, we were able to put these units into every Air Force ALC for evaluation, as well as getting some units into the Navy at Patuxent River NAS and Cherry Point NAS. Latest versions of the MAUS are now being used in Manufacturing Technology efforts at Oklahoma City ALC, on KC-135 tankers.



Extensive laboratory work on the development of novel laser-based ultrasonics for advanced inspection systems pays off . . .



. . . in laser ultrasonic inspection systems for complex and composite aircraft parts, capable of reducing inspection time by over 90 percent.

NDE developmental efforts are closely coordinated among a network of key people, from scientists in AFOSR and those doing 6.1 basic research to the 6.5 personnel in ASC who work to apply field-ready NDE methods and systems directly with System Program Offices.

Equally important, in-house research is under way that reaches across several key activities. An excellent example involves research in scanning acoustic microscopy which is being used to characterize advanced fiber-reinforced composite materials, and is also being assessed for application to examination of high cycle fatigue of turbine engine components.

In some cases, in-house research is under way to ensure that we have people who are smart buyers of advanced technology for the Air Force. One good example of this is our work in laser-based ultrasound (LBU). The principal scientist working on this area has in-house research under way in an advanced laser-based ultrasound system. He also provided extensive technical support to Sacramento ALC as they acquired the first production LBU inspection system. In-house research helped develop a smart buyer for the Air Force in terms of interfacing advanced technical knowledge with the NDE needs of the field.

Our in-house research scientists are directly involved with their counterparts in the field or in the ALCs. By redirecting our program to make it more clearly customer-focused, we are now structured to look at NDE in support of materials and process development, focused on our R&D customers; NDE for low observable and space systems, primarily for our SPO customers; and NDE for fielded and aging Air Force weapon systems, closely coordinated with our systems support counterparts, and our ALC and SPO customers.

Technology Transition and Transfer

Technology transition and technology transfer are important for NDE R&D. Technology transition involves moving developed NDE technologies into the hands of Air Force depot and field customers, with technologies such as the MAUS. Another key example of technology transition involves the development of advanced digital X-ray detection methods. Here, technology from the industrial and medical communities will be applied to develop enhanced solid-state X-ray detectors for Air Force use.

The Mobile Automated Scanner (MAUS) system, developed for NDE work on Air Force weapon systems (left), has been demonstrated on commercial applications such as composite chassis components for racing cars (right).

Technology transfer involves moving Air Force NDE technologies into the commercial sector. This is effective when dual-use opportunities exist for technologies originally developed for Air Force use. By making advanced NDE technologies available for commercial applications, sales volume increases significantly and per-unit costs drop. This helps to reduce overall costs to the Air Force to implement these NDE technologies.

The MAUS scanner system has been extensively demonstrated to the automobile and power boat racing industries in the hope of stirring interest in these key markets. This could lead to reducing the overall cost of acquisition of this system for the Air Force. We have also worked very closely with our counterparts in the civil aviation industry, where the MAUS has been extensively demonstrated on commercial airline aircraft. A significant part of our technology transfer effort is our continuing interface with our NDE counterparts in the FAA and NASA, which includes close coordination of developmental efforts. At the same time we maintain close contact with the international NDE community, particularly in the areas of corrosion detection with British, French and German counterparts. Ongoing activities with Australian and Canadian NDE experts also help to increase our effectiveness in NDE R&D.

Extending NDE Capabilities

We provide national leadership in new areas of importance to NDE. For example, right now we feel it is very important to work not only the area of nondestructive inspection of systems in the field, but also to extend the capabilities of NDE into earlier phases of the product development and manufacturing spectrum. Our objective is to provide NDE systems to engineers who are processing either metallic or composite material into products, to improve production effectiveness.

We're also working to develop NDE methodologies that can be used even earlier in the development process, to characterize properties of materials while they are in development. Thus, NDE is becoming a full-spectrum activity, one intended to pay off for the Air Force at every stage of product development and application.

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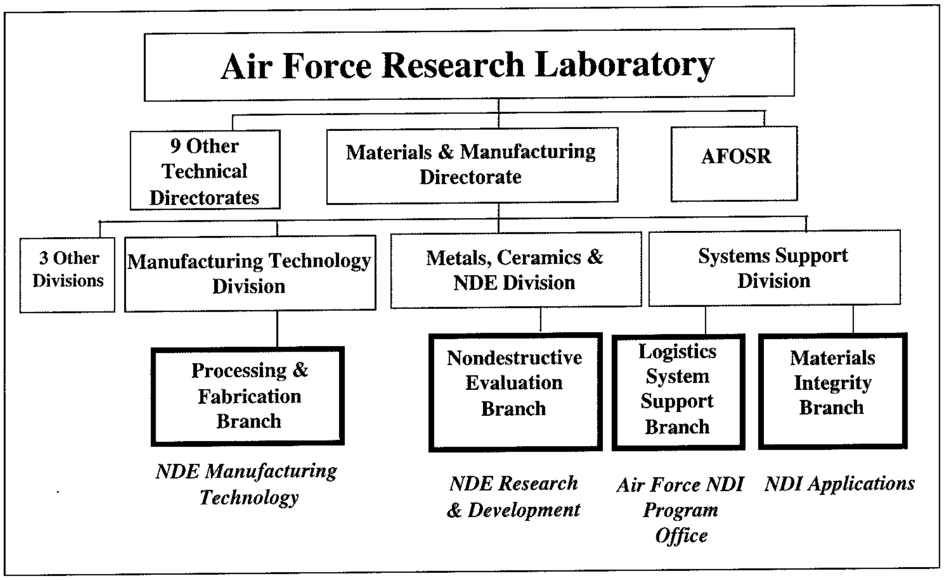
How nondestructive evaluation efforts fit into the Air Force Research Laboratory system.



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