SIU Southern Illinois University CARBONDALE

Nondestructive Evaluation of Aerospace Composites

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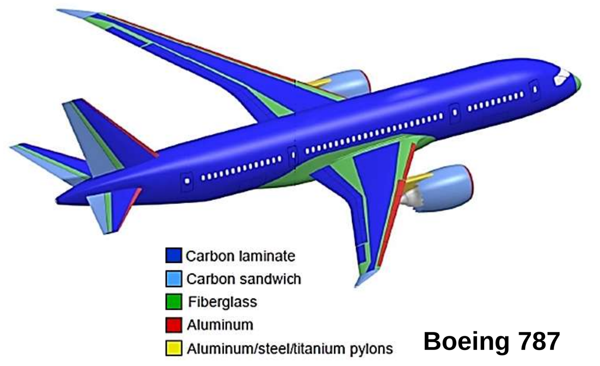
Abstract

Advanced composites such as Carbon/Carbon composite, carbon-fiber-reinforced polymer (CFRP), and honeycomb sandwich structures are often used today for the aerospace applications. The use of advanced composites in aerospace structures brings increased strength and stiffness, better shear properties, high impact resistance, high damage tolerance, and low density. However, composites are prone to different damage mechanisms which can occur either during manufacturing processes or in day-to-day in-service operations. Composite structures are routinely inspected by using various nondestructive evaluation (NDE) methods to ensure structural integrity, safety, and reliability. Our work focuses on the development of intelligent ultrasonic and infrared thermography techniques to automatically identify, classify, and characterize different types of defects found in composite structures.

This novel approach integrates several intelligent methodologies (artificial neural networks, fuzzy logics, genetic algorithm, parametric and non-parametric statistical classifiers based on Bayesian, k-Nearest-Neighbor, Nearest-Mean, and rule based classifiers) with expert knowledge to detect damaging events; characterize the nature, size/extent, and seriousness of the damage; and then respond intelligently on required timescale to mitigate the effects of the damage or its repair. In addition, this technique will have a user friendly interface where knowledge engineers, NDE experts, and NDE technicians can communicate and continuously update the system with new knowledge. We believe this developed technique will be a much faster, more efficient, and more effective process compared to traditional NDE systems. Finally, the trained system for one data set may be reused to classify other data sets with similar characteristics.

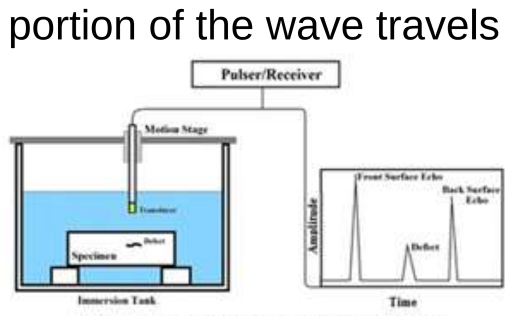


Boeing 787

Ultrasonic Testing

Principle

Ultrasonic Testing (UT) is based on emission of an acoustic wave and recording of the signal after passing through the material under test. The acoustic wave travels through the material from the transducer, hits the surface of the sample and a portion of the wave travels back to the original transducer and another portion travels through the sample before returning back to the transducer. The difference in time for the acoustic sound to travel to both the front and back of the sample is the front and back wall echoes. If there is any variation from the front and back wall echo this could signify a defect. Information is obtained from ultrasonic waves as below:



Pulse-echo configuration for immersion UT

1. the acoustic intensity and frequency
2. the time of flight measurements (allows detection of flaws)

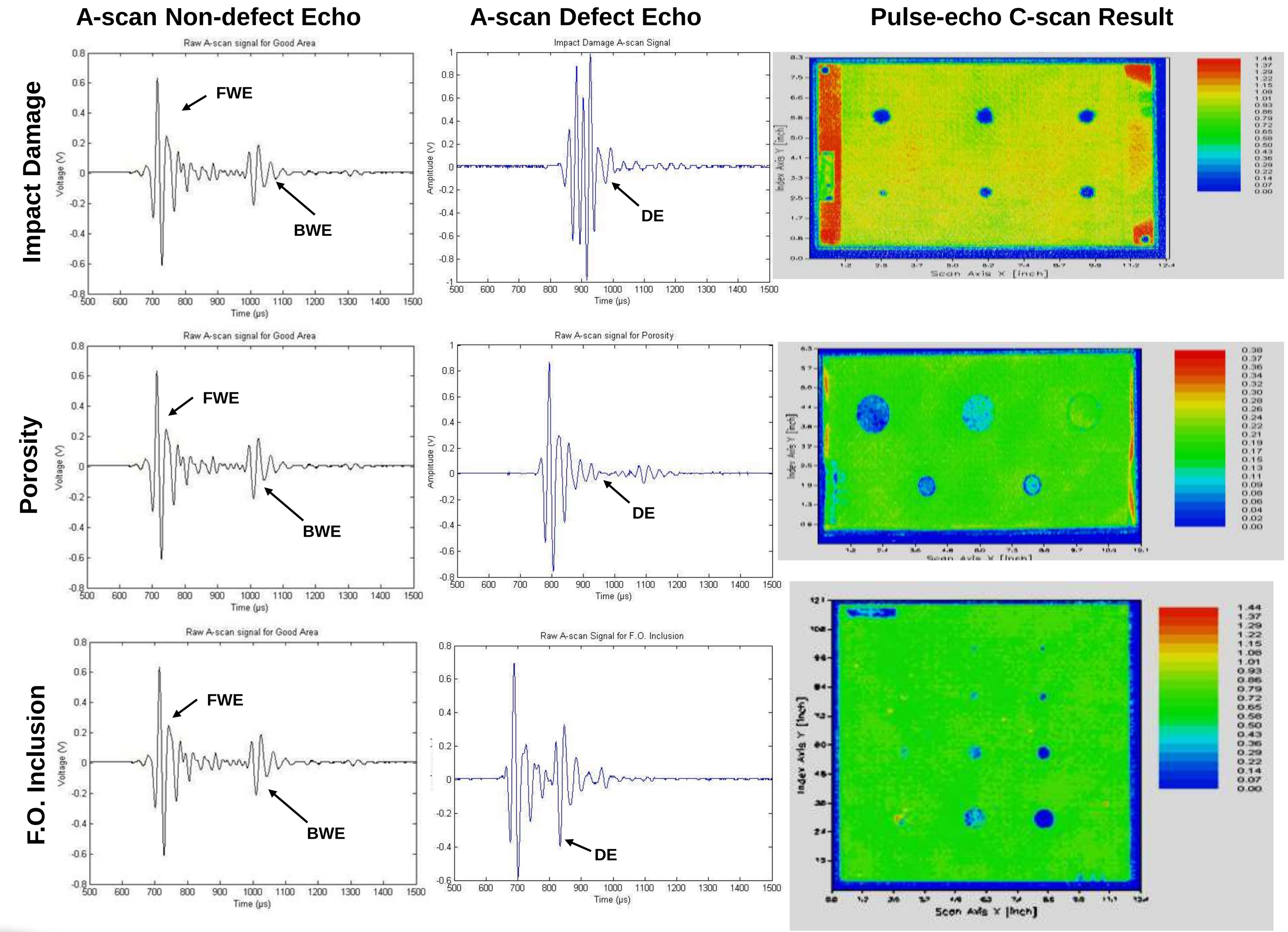
Methods

UT can be performed in various configurations depending upon the application. Some of the common methods include pulse-echo, through-transmission, shear wave, pseudo-pulse echo, plate wave methods.


IMEL Immersion C-scan UT System

Immersion UT Transducers

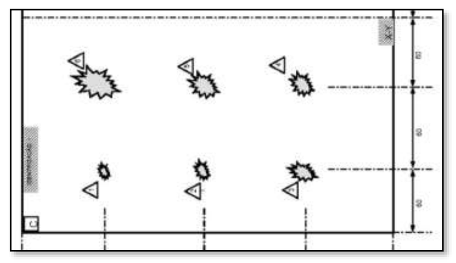
Results

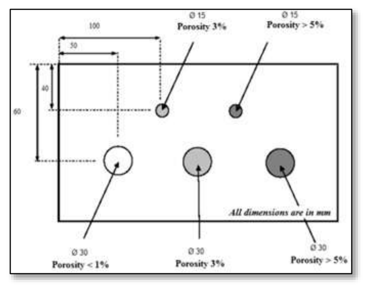


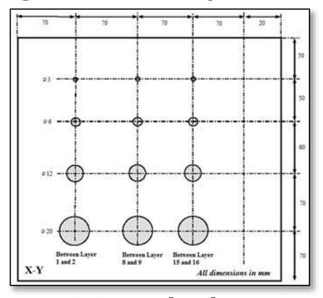
Material Description

CFRP panels with simulated impact damage, porosity, and foreign object (F.O.) inclusion defects were considered. All panels consisted of 16 plies of woven carbon fiber $[[0/45/0/45]_2]_S$ with a total panel thickness of 3.36 mm.

- Impact damage were created by impact with known energy.
- F.O. Inclusion simulated by inserting foreign materials in different layers.
- Porosity simulated by controlling the pressure exerted during the cure process.


Impact Damage

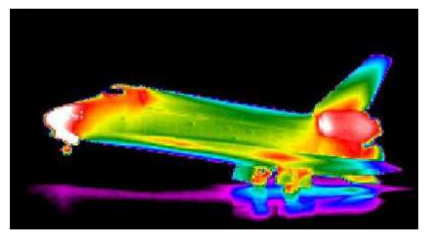

Porosity

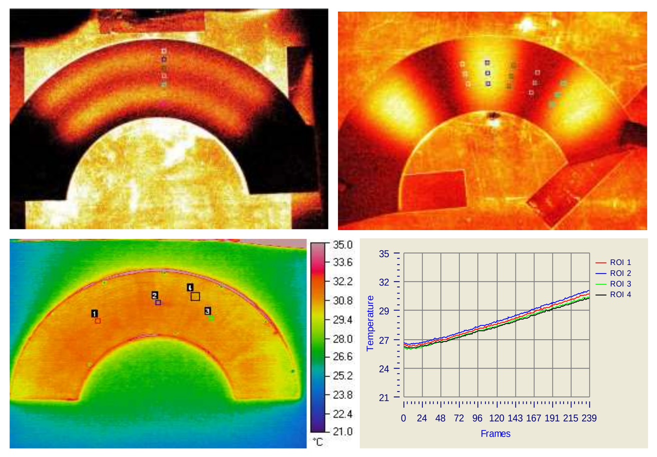

F.O. Inclusion

Infrared Thermography

Principle

Infrared thermography (IRT) is based on recording images of the thermal radiation which is emitted by the surface of a sample. A defect (such as delamination, inclusions, or porosity) will be revealed by a change in the thermal radiation associated with that region, as the formation of a hot or cold spot.

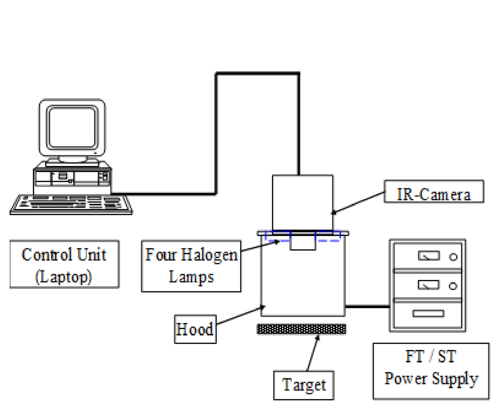

IR image of Space Shuttle


IR images of Carbon/Carbon Aircraft Brake Disks

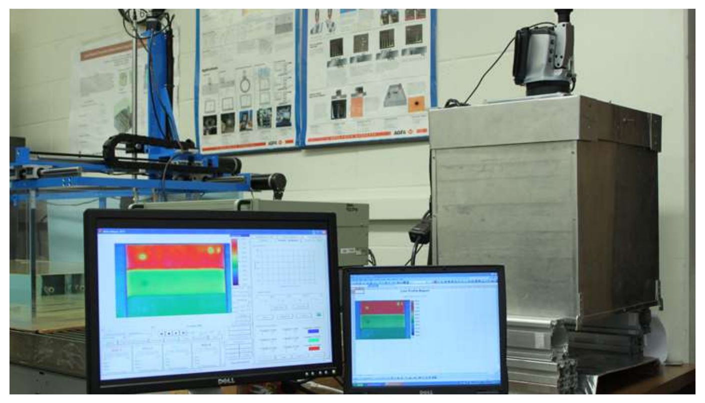
Methods

There are numerous methods within the infrared thermography technique that are used to determine defects in composites and friction materials. These methods include: Pulsed Thermography (PT) also known as flash heating method, Step Heating (SH), Lock-in Thermography (LT), and Vibro-Thermography (VT).

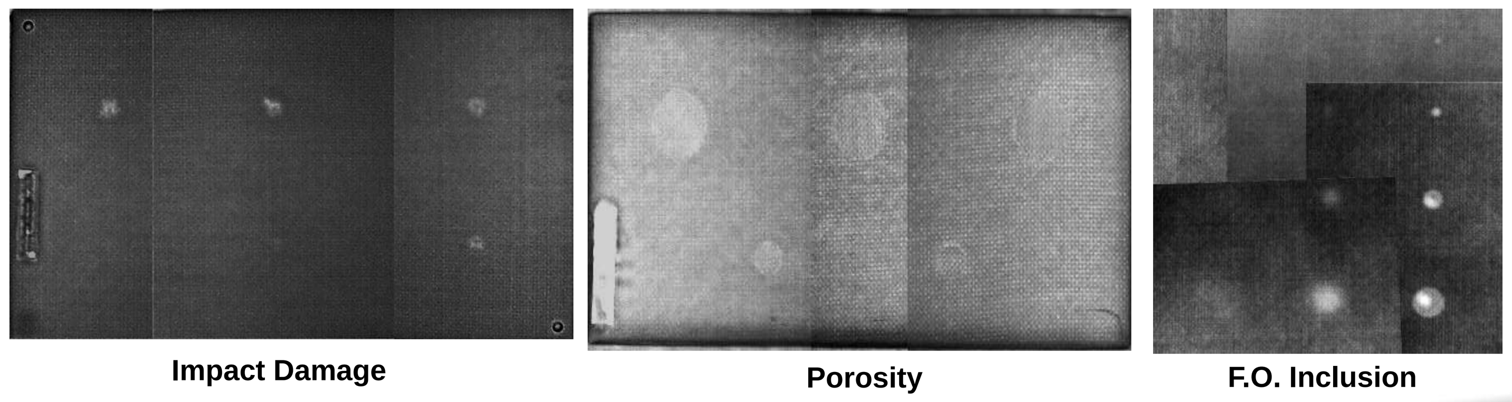

Infrared Camera



Flash Heating Setup


IMEL IRT System

Results

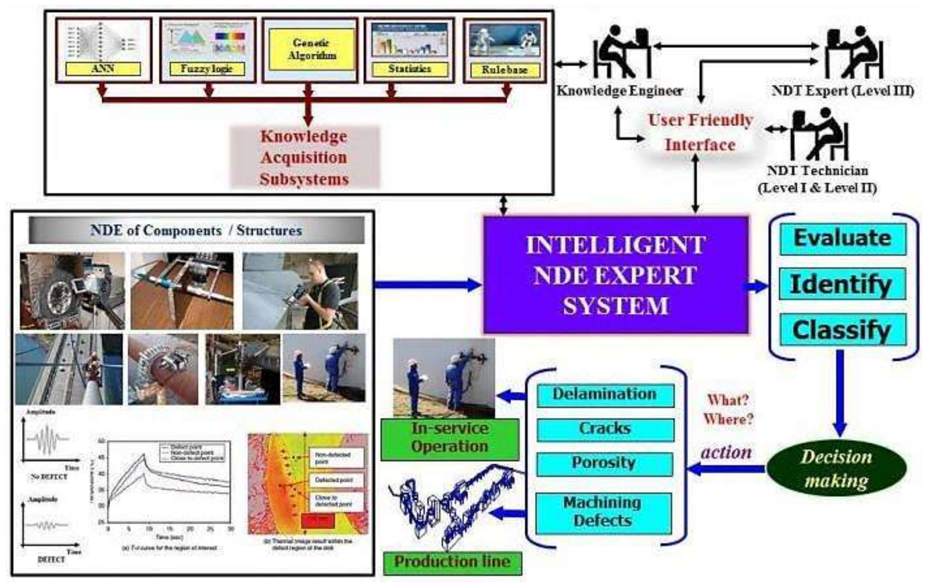

Impact Damage
Porosity
F.O. Inclusion

Flash Heating Infrared Thermographic Images

Intelligent NDE Technique

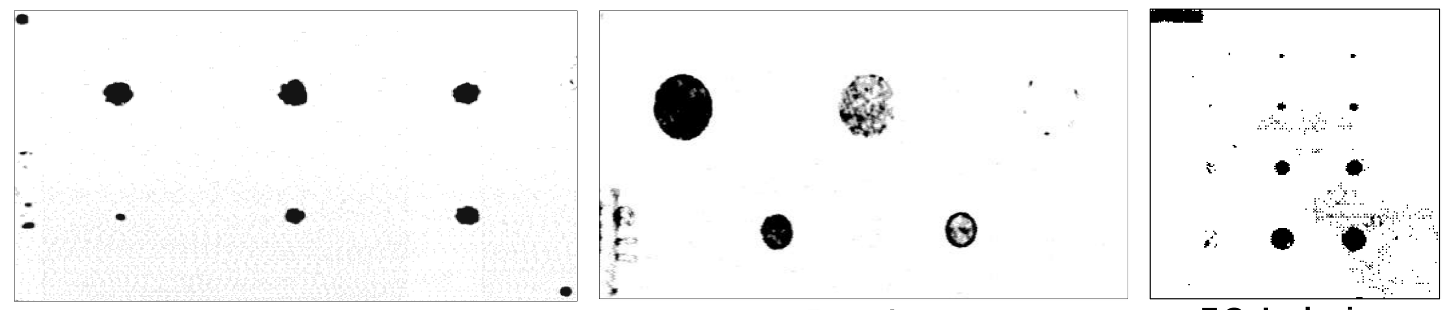
Background

An intelligent system (IS) is composed of a knowledge base, an inference engine, a working memory, a user interface, and an explanation based subsystems. IS can think and act rationally like humans to provide reasoned judgments to decision makers as a basis for action. It helps to solve important problems, obtain consistent and reasonable results, and predict reason for failure.

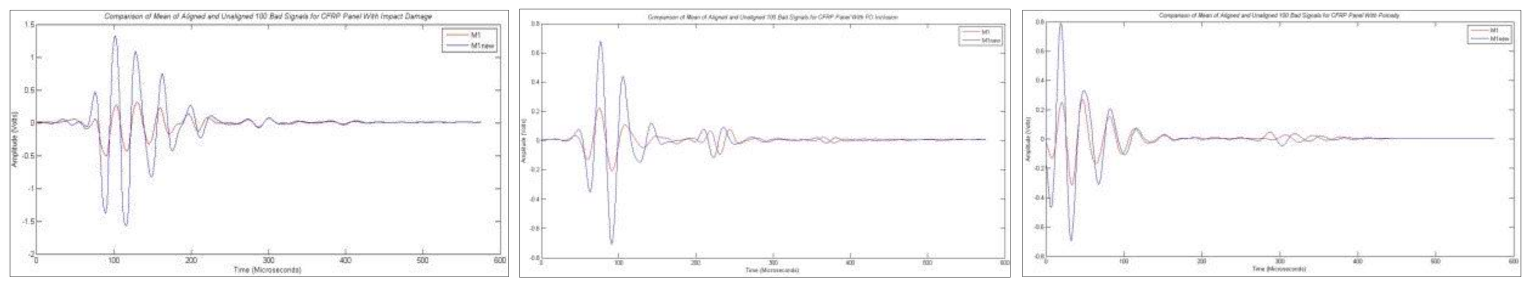


Intelligent Nondestructive Evaluation Expert System Architecture

Results


Impact Damage
Porosity
F.O. Inclusion

Fuzzy Logic Output using mean of maximum (MOM) Defuzzification method and 25 Fuzzy Rules


Impact Damage
Porosity
F.O. Inclusion

A-Scan Signal Alignments Prior to Classification Using Cross-Correlation Coefficients

Confusion Matrix showing the classification accuracy for the 4-class problem using nearest mean classifier

	Good	Impact Damage	F.O. Inclusion	Porosity	Classification Accuracy
Good	1	0	0	0	99.0%
Impact Damage	0	0.96	0.02	0.02	
F.O. Inclusion	0	0	1	0	
Porosity	0	0	0	1	

Classification accuracies exceeding 99% are possible!

Summary

- Various NDE methods are often applied to inspect aerospace composite structures to ensure their structural integrity, safety, and reliability.
- The use of intelligent techniques for automated defect detection, classification, and characterization not only makes an inspection job an easy process, but also makes it much faster, efficient, and effective.
- Overall, it reduces the chances of human error!

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