

Non Destructive Testing Evaluation Methods

ASME Standards Technology, LLC

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Project #: MFP4

Acknowledgment

This is a collaborate effort between:

ASME Standards Technology, LLC

Digital Wave Corporation

Lincoln Composites, Inc

TransCanada CG Technologies

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Overview

- **Timeline**

- Start:4/06
- Finish:04/08
- 95% complete

- **Budget**

- Total Project Budget \$668K
 - NCMS Funding \$327K; \$297K spent to date
 - ASME ST-LLC matching in-kind

Objectives

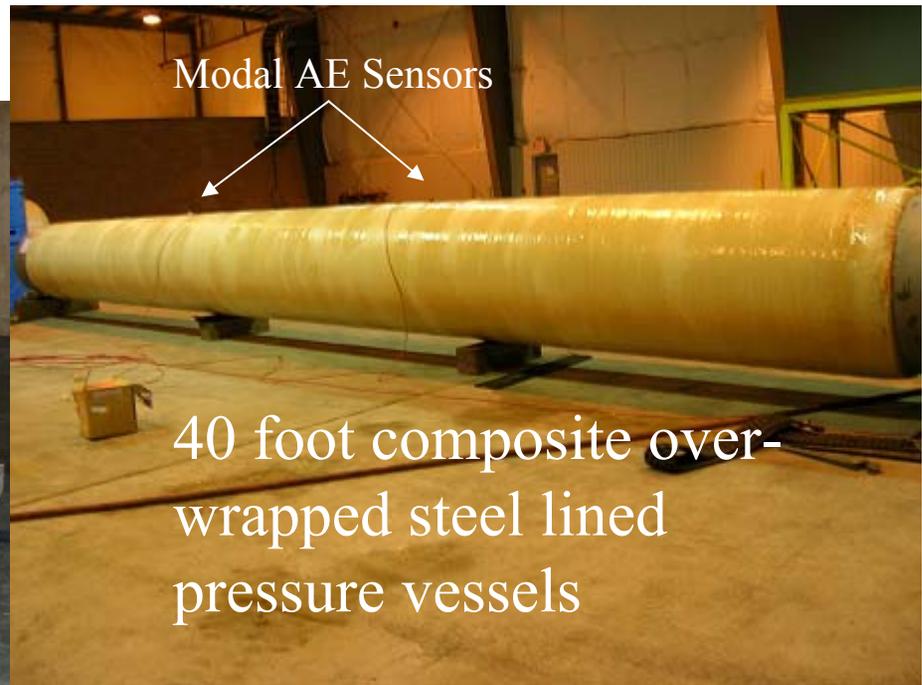
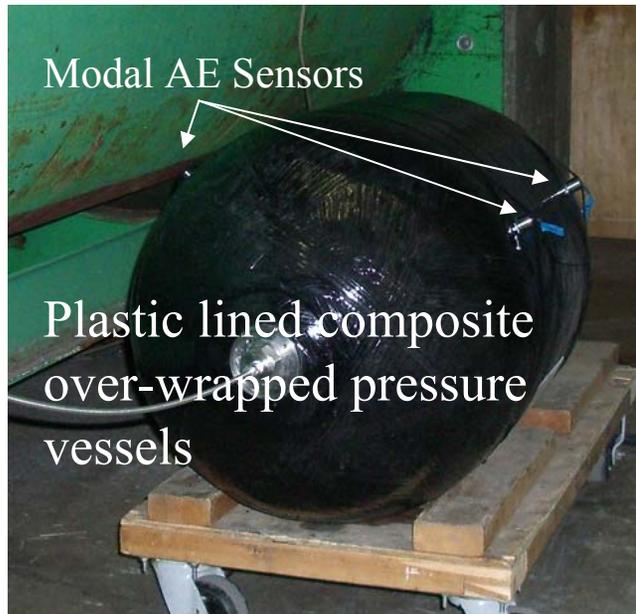
- To investigate the feasibility of using NDE methods in the evaluation of composite pressure vessels
- Determine if NDE methods can be a suitable substitute to existing destructive testing currently used to determine pressure vessel integrity
- Investigate use of stacked piezoelectric transducers in Modal Acoustic Emission (MAE) phased arrays for composite tank monitoring.

Accomplishments

- Determined that Modal Acoustic Emission (MAE) can be used to predict based on source/receiver relationship, source type, and source orientation the possible area of failure
- Prediction of flaws in carbon fiber tanks using MAE phased arrays is possible
- Completed, first in its kind, testing of 42” diameter by 40’ long pressure composite vessels at TransCanada New Brunswick facility
- Implemented stacked piezoelectric transducers into modal acoustic emission phased arrays and testing
- Controlled manufacturing processes yielding consistent products will permit MAE to reduce burst test to a minimum
- Looked at other NDE methods for alternatives of destructive testing

High Pressure Composite Gas Pressure Vessels

These types of vessels are hard to inspect with ultrasound and x-ray due to the materials used in construction



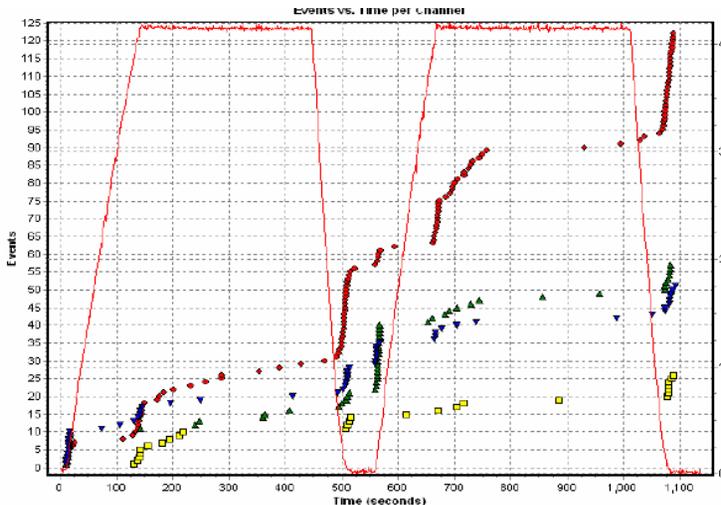
Monitoring of Liner and Over-wrap

Burst test of composite over-wrapped
steel lined pressure vessel



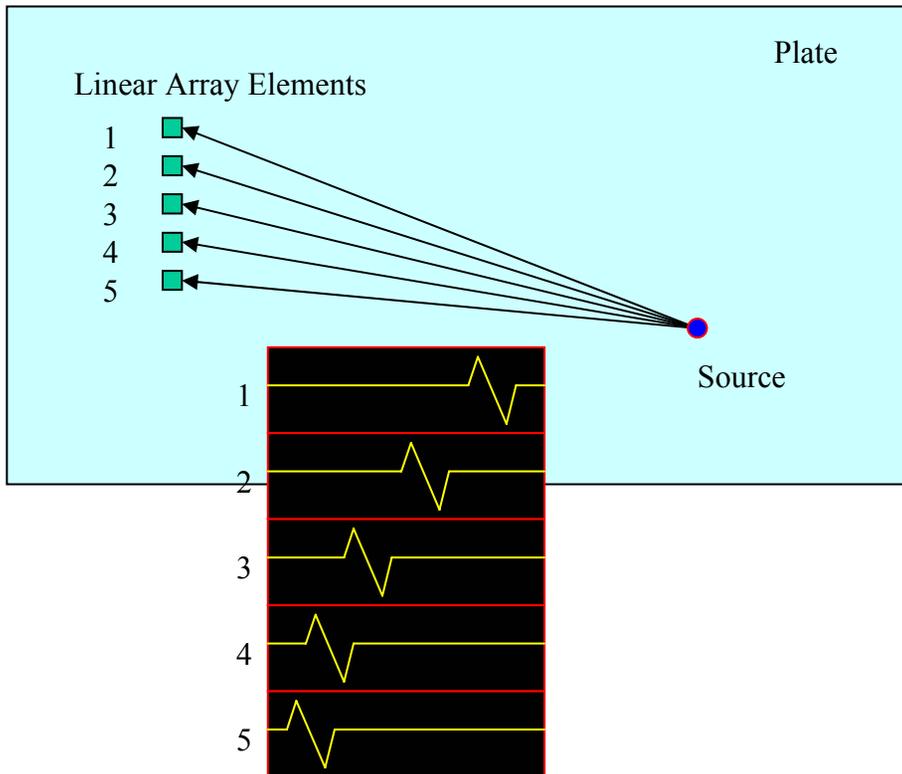
- MAE source locations were correlated to flaw growth failure locations
- Crack growth in the composite over-wrap could be separated from crack growth in the steel liner
- Modal AE was able to detect and locate growing flaws in the steel liner during fatigue cycling and burst tests with 8 sensors on 40 foot vessel

6' Drop Test with MAE



- Events vs. Time and pressure at high gain after 6 ft drop impact. S2 events (red diamonds) show most activity, as expected from the sensor's nearest proximity to the damage.

Phased Array MAE Sensor Development



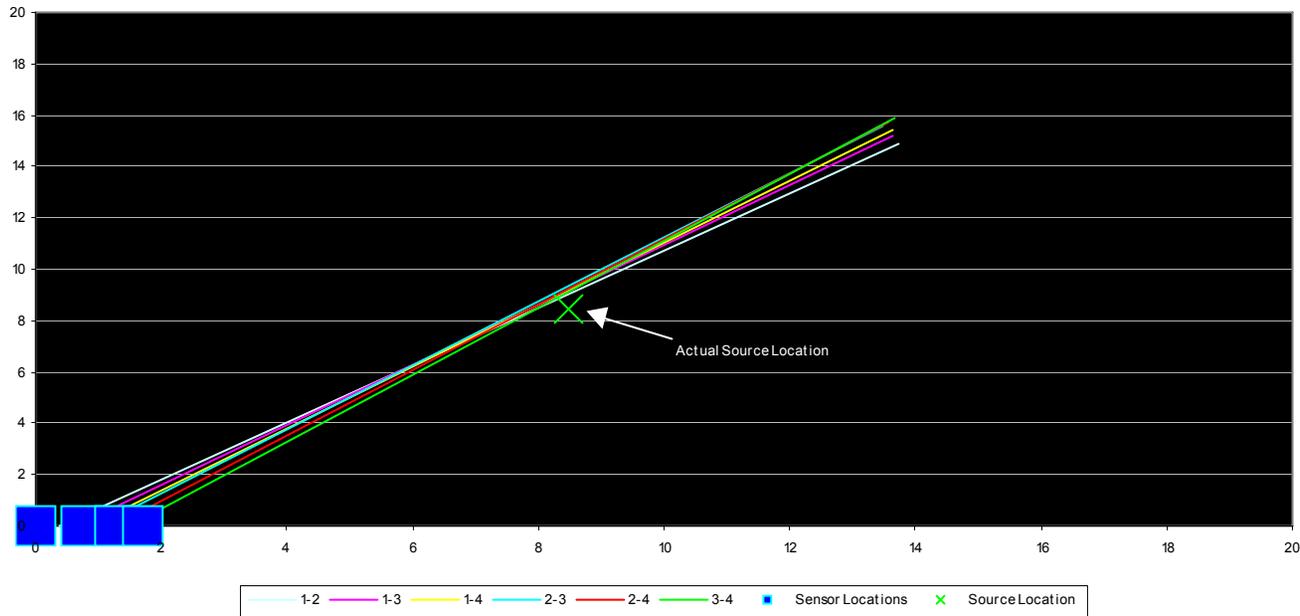
Signal arrival times at the transducers

- Sensor array attached to part
- Polyvinylidene film (PVDF) sensors used
- Wave from source detected by transducers
- Signals are digitized and stored
- Waves phased aligned
- Time differences used to determine source direction
- Intersection of rays from transducer pairs used to determine source location

Why Phased Array MAE?

- Signal-to-noise ratio can be digitally increased – better sensitivity
- Fewer sensor locations will still result in high location accuracy – less setup time
- PVDF piezoelectric film for sensor is inexpensive, mechanically rugged, low profile and easily attached

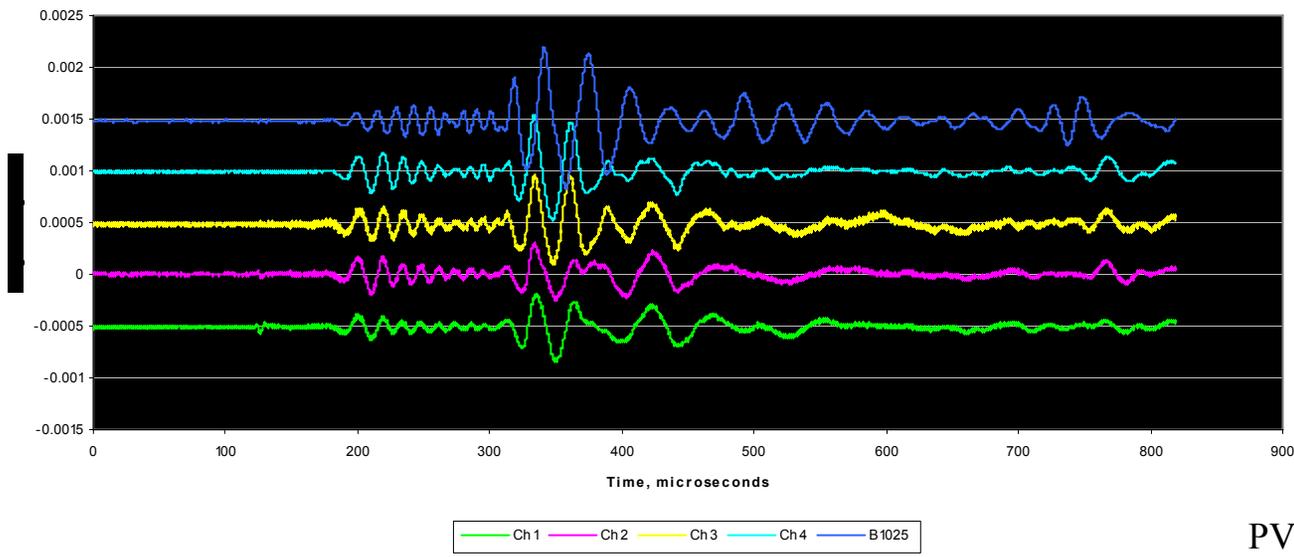
Phased Array Location



Plot showing directional arrays calculated for each time difference between sensor pairs. Intersection of rays is the approximate source location, the X shows the actual location.

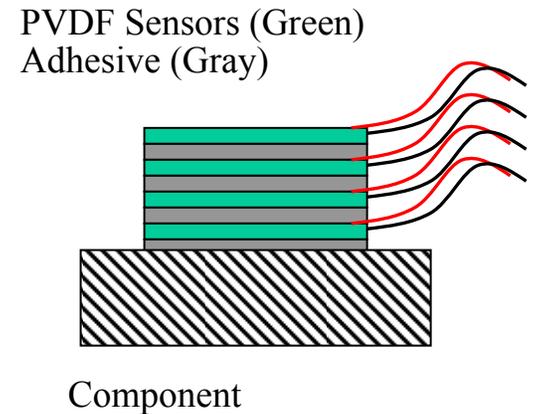
Sensor Stacking for Increased Detection Sensitivity

PVDF vs B1025 Response - 45 Degrees



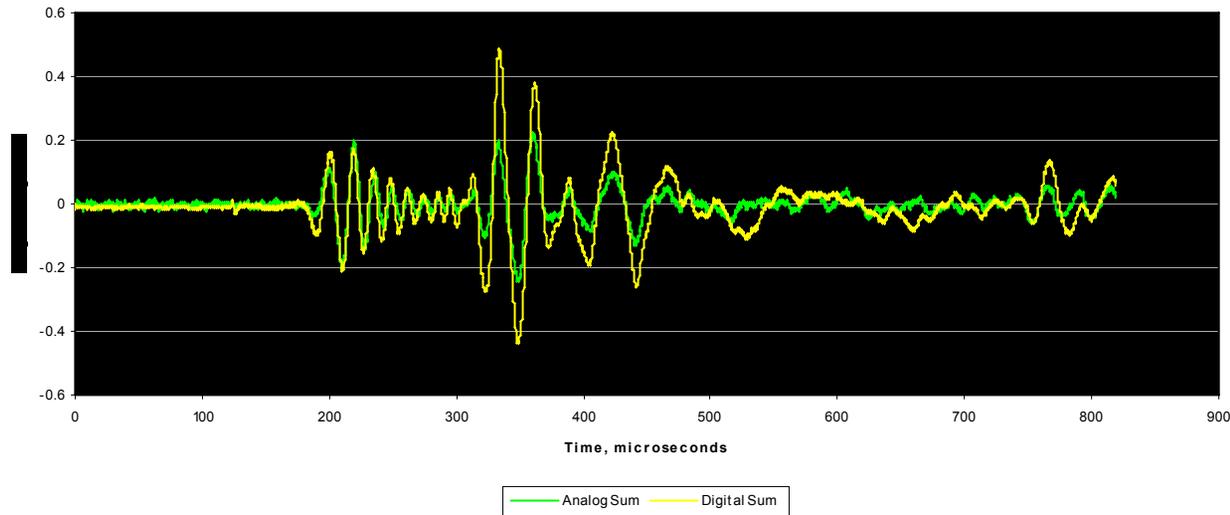
PVDF sensors are less sensitive than conventional composite piezoelectric crystals – However, they are much less expensive, and mechanically more rugged

- Four PVDF sensors were stacked on top of each other and adhesively coupled
- Signals from individual sensors were digitized for analysis to ensure that all sensors were responding similarly
- Signals from PVDF sensors were compared to piezoelectric sensor output (dark blue trace)



Digital and Analog Analysis

Analog vs Digital Sum - 45 Degrees



- PVDF sensors were serially connected, and analog summation was digitized for analysis
- Yellow trace is the digital summation of all four PVDF sensors
- Green trace is the analog summation of the four PVDF sensors
- Both approaches gave a 12 dB (x4) gain in sensitivity over single sensor
- Sensor response (fidelity) was not compromised
- Inexpensive approach to increased sensitivity
- Coupled with phased array configuration, PVDF sensors can have required sensitivity capabilities beyond piezoelectric sensors

Investigate Hydrostatic Test Requirements

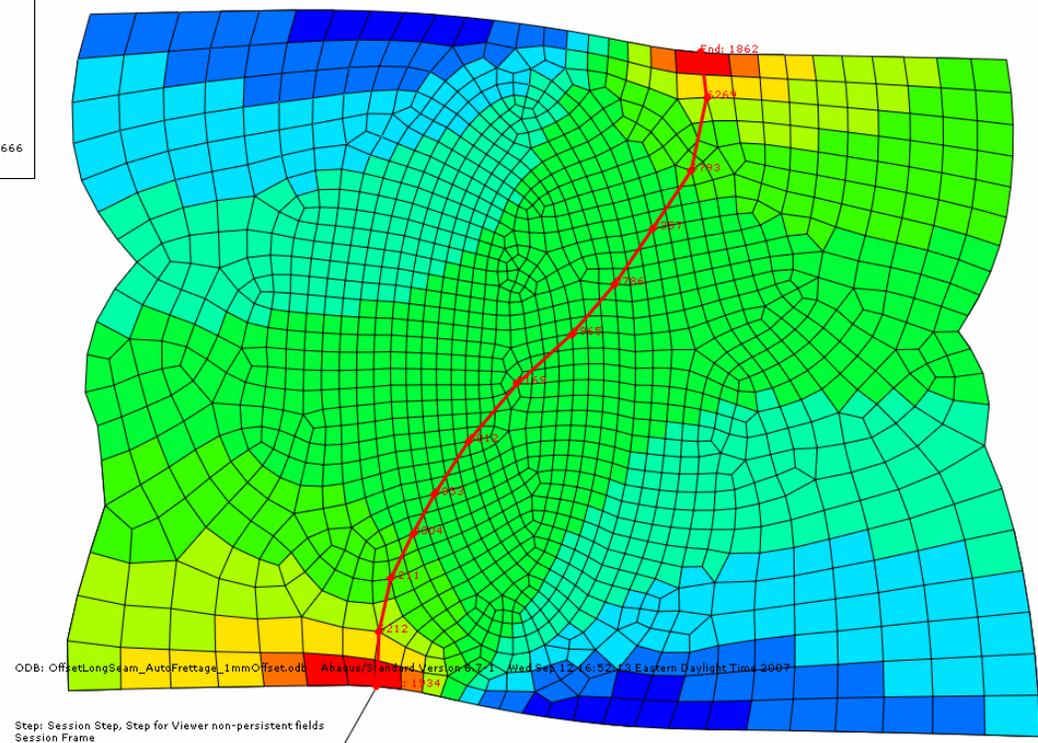
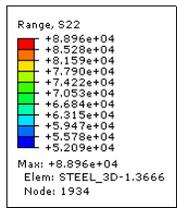
Some standards:

- Require only a pressure test, reflecting a high confidence in the basic design and the level of process control
- Other require only a pressure test, reflects a high confidence in the basic design and the level of process control
- Some require an upper limit on permanent expansion, demonstrating that yielding is limited
- While other require a limit on elastic expansion, demonstrating that the proper amount of composite material was wound on the pressure vessel

Finite Element Analysis (FEA)

- Completed FEA analysis and fracture mechanics analysis on composite reinforced pressure vessels.
- The stresses in the vessel from the FEA were examined to determine the stress distributions at critical locations for the fracture mechanics analysis.
- The stress distribution at each of the “fatigue-sensitive points” from the finite element analysis was used to calculate a fatigue life using the approach described in ASME Boiler and Pressure Vessel Code, Section VIII, Division 3, Article KD-4.
- The results of the FEA and fracture analysis indicated that the most likely fatigue path failures would occur at either the site of an offset long seam weld in the vessel shell or at an offset shell to head weld.
- Burst test of vessels in by TransCanada verified the two failure modes.

Finite Element Analysis (FEA)



ODB: OffsetLongSeam_AutoFretage_1mmOffset.odb Abaqus/Standard Version 6.2.1 Wed Sep 12 16:52:13 Eastern Daylight Time 2007



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Session Frame
Primary Var: Range, S22 Max: +8.896e+004
Deformed Var: not set Deformation Scale Factor: not set

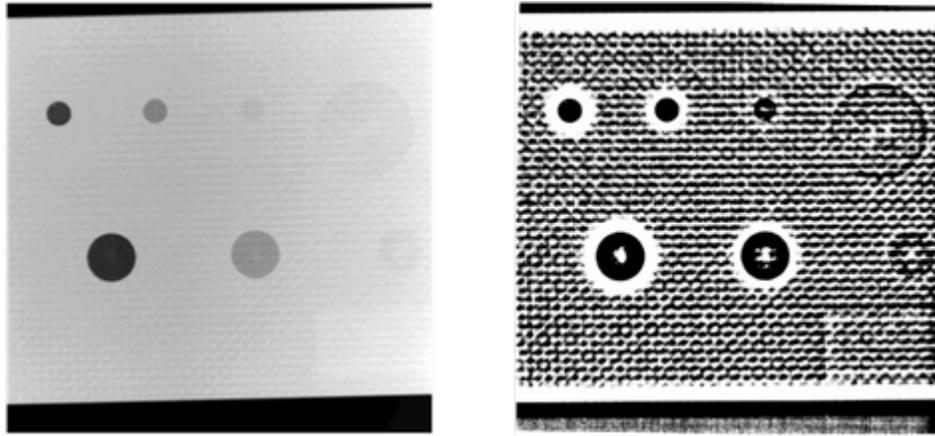
Photon Induced Positron Annihilation (PIPA)

- The technology formerly known as PIPA is now known as induced positron analysis (IPA)
- IPA is a non-destructive evaluation process that can accurately assess material damage at the near-molecular level, and, by looking into the crystal structure, see its future
- IPA can detect a wide variety of damage types in a wide variety of materials including metals, polymers, ceramics, and composites. Because IPA examines materials at the atomic level, it can detect damage at its earliest stage, from initial manufacture through failure. The technology can also determine the remaining useful life of a component and detect damage in 2nd layer materials.
- IPA has a limited range of defect detection. It is limited to detecting nano-fractures or smaller. Also the volumetric version requires a linear accelerator and is therefore limited to a specialized service center and is not portable.

Phase Contrast Analysis (PCA)

- PCA produces a pulsed, tunable monochromatic X-Ray beam. The normal X-Ray you are used to is polychromatic.
- PCA can be tuned for any material, and to almost any depth so can “see into” machines, such as an aircraft and look at just the nickel-alloy parts for example, even without removing the skin.
- PCA has a broader range of defect detection than IPA. PCA can detect defects from the molecular lever to micro-cracks. PCA should be investigated further for composite pressure vessels.

Phase Contrast Analysis (PCA)



- Above are two pictures of an advanced aviation composite material that has some fasteners in it. The left picture was taken using current X-Ray technology and the rightmost picture was taken using PCA

Summary

- Modal AE identified Flaw types in composite pressure vessels
- This allows either proof test and real-time monitoring of high pressure vessels for increased safety
- Phased array technology will allow flaw location with minimal sensor attachments – this means less setup time and lower cost
- PVDF film is an inexpensive transducer for detection, and is easily configured for detection sensitivity requirements