

Image Cover Sheet

CLASSIFICATION

SYSTEM NUMBER

510350

UNCLASSIFIED



TITLE

NDE FOR THICK SECTION COMPOSITE LAMINATES

System Number:

Patron Number:

Requester:

Notes: Paper #7 contained in Parent Sysnum #510343

DSIS Use only:

Deliver to: DK

1. The first part of the document discusses the importance of maintaining accurate records of all transactions and activities. It emphasizes that this is crucial for ensuring transparency and accountability in the organization's operations.

2. The second part of the document outlines the various methods and tools used to collect and analyze data. It highlights the need for consistent and reliable data collection processes to support effective decision-making and strategic planning.

3. The third part of the document focuses on the role of technology in data management and analysis. It discusses how modern software solutions can streamline data collection, storage, and analysis, leading to more efficient and accurate results.

4. The fourth part of the document addresses the challenges associated with data management, such as data quality, security, and privacy. It provides strategies and best practices to overcome these challenges and ensure the integrity and confidentiality of the organization's data.

5. The fifth part of the document discusses the importance of data governance and the role of leadership in establishing a strong data management framework. It emphasizes the need for clear policies, procedures, and roles to ensure effective data management across the organization.

6. The sixth part of the document explores the benefits of data-driven decision-making and how it can lead to improved performance, innovation, and competitive advantage. It provides examples and case studies to illustrate the impact of data on organizational success.

7. The seventh part of the document discusses the future of data management and the emerging trends in the field. It highlights the importance of staying up-to-date with the latest technologies and practices to remain competitive in a data-driven world.

8. The eighth part of the document provides a summary of the key points discussed throughout the document. It reiterates the importance of data management and the need for a comprehensive and integrated approach to ensure the organization's long-term success.

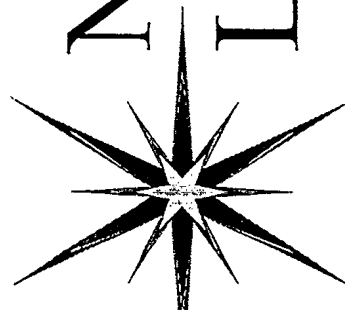
9. The final part of the document includes a list of references and resources for further reading. It provides a comprehensive list of books, articles, and online resources that can help readers gain a deeper understanding of data management and its applications in various industries.

NDE for Thick Section Composite Laminates

by Carol Lebowitz

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Annapolis, Maryland

ABSTRACT



NDE of Thick Section, Laminated Composites

“The application of fiber-reinforced polymer matrix composites to U.S. Navy surface ships systems offers the potential for significant weight, cost and signature reductions.”

Gagorik, Corrodo, and Kornbau

Proceedings of the 36th International SAMPE

Symposium, April 1991



NDE of Thick Section, Laminated Composites

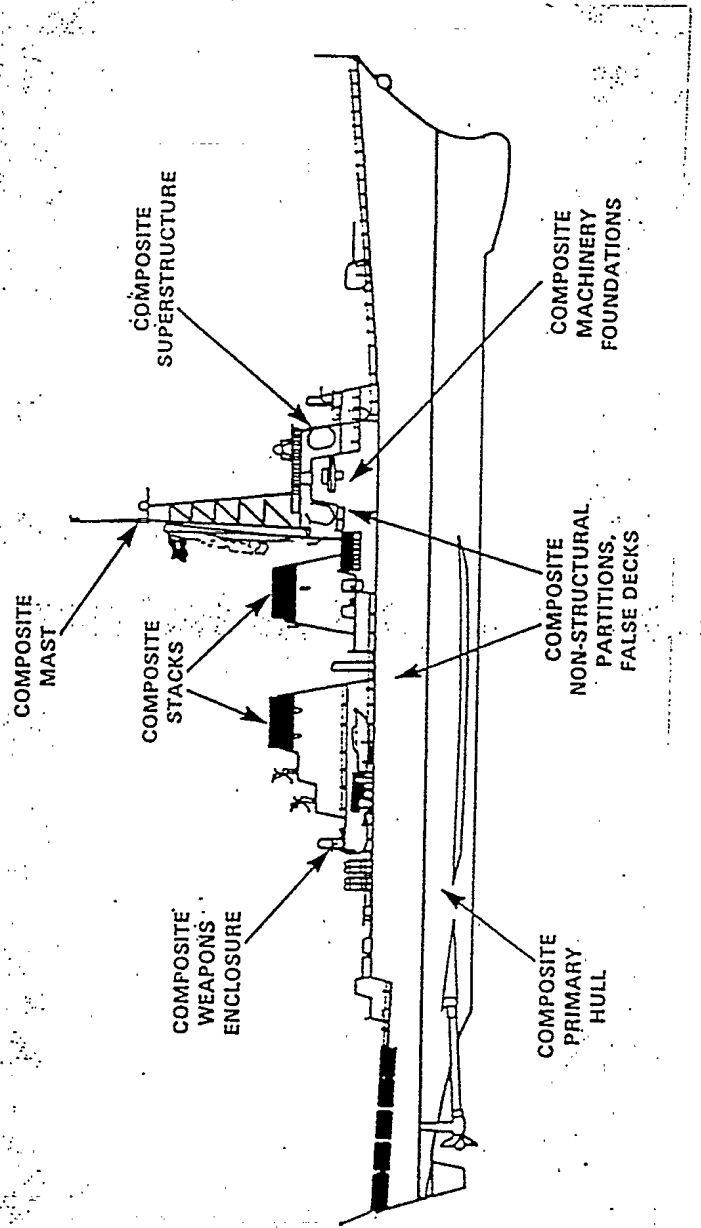
- Current applications for composites on
submarines and surface ships
- submarine bow sonar domes
 - towed array fairings
 - sonar windows
 - minehunter hulls
 - other applications like seawater piping,
pumps and ventilation ducting



NDE of Thick Section, Laminated Composites

Potential Composite Ship Structures

Gagorik, Corrodo and Korbau, SAMPE 1991





NDE of Thick Section, Laminated Composites

Challenges:

- anisotropic, inhomogeneous material
- many potential defect types (i.e., voids, delaminations, inclusions, resin variations, fiber breakage & wrinkles, etc.)
- no predominant failure mode
- presence of “acceptable flaws”
- manufacturing vs. service-induced defects
- large structures
- lack of defect and calibration standards



NDE of Thick Section, Laminated Composites

Classification of Defects in Thick Section Graphite Epoxy Test Blocks

- **Objective:** To demonstrate the feasibility of using neural networks to classify defect types in thick section gr/ep material
- **Approach:**
 - construct thick section gr/ep test blocks with known defects at midply and near front surface
 - signal acquisition using immersion UT system
 - select features from power spectrum
 - defect classification using an artificial neural network



NDE of Thick Section, Laminated Composites

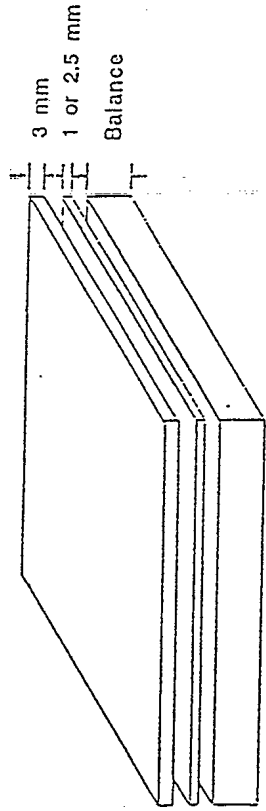
Classification of Defects in Thick Section Graphite

Epoxy Test Blocks

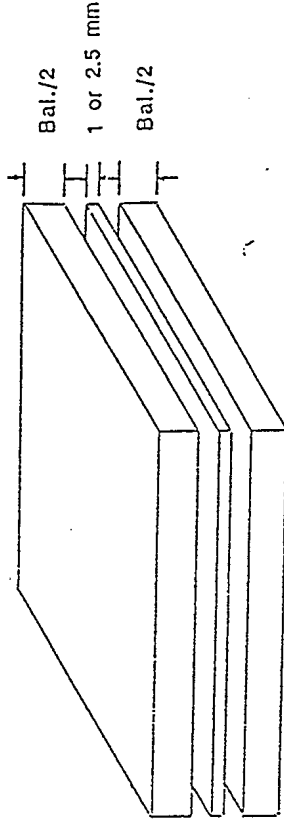
- Status:
- 8 specimens examined
- 6 features from power spectrum selected
- back propagation neural network analysis resulted in 91% classification accuracy for both training and test sets

COMPOSITE DEFECT CLASSIFICATION

CONSTRUCTION -



1/8 THICKNESS



MIDPLANE

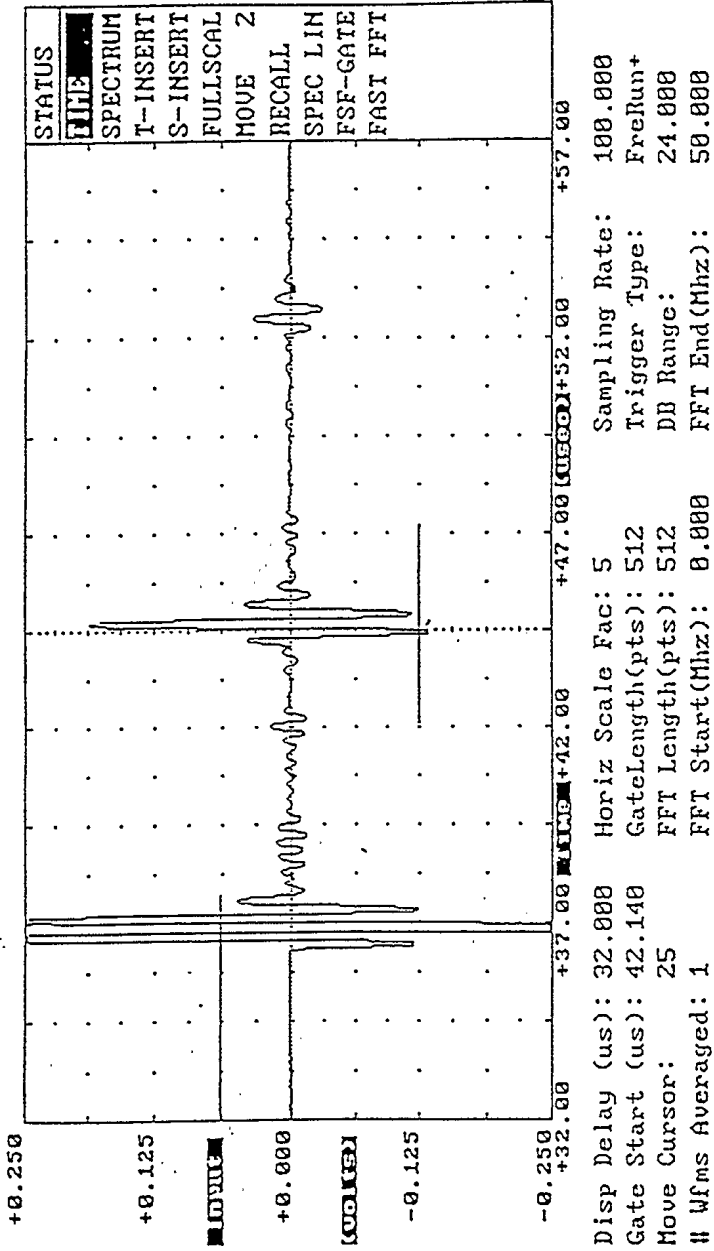
<u>ID</u>	<u>PANEL DESCRIPTION</u>	<u>SUB-PANEL THICKNESS</u>	<u>SUB-PANEL PLACEMENT</u>
A1	REFERENCE	NONE	MIDPLANE, PLYS 92-99
A2	REFERENCE	8-PLY	1/8 THICKNESS, PLYS 24-31
B1	DELAMINATION	8-PLY	MIDPLANE, PLYS 92-99
B2	DELAMINATION	8-PLY	1/8 THICKNESS, PLYS 24-44
D1	POROSITY ¹	20-PLY	MIDPLANE, PLYS 87-106
D2	POROSITY	20-PLY	1/8 THICKNESS, PLYS 24-31
F1	CONTAMINATION ²	8-PLY	MIDPLANE, PLYS 92-99
F2	CONTAMINATION	8-PLY	

¹Air

²Peel Ply

COMPOSITE DEFECT CLASSIFICATION

RESULTS - SAMPLE RF WAVEFORM

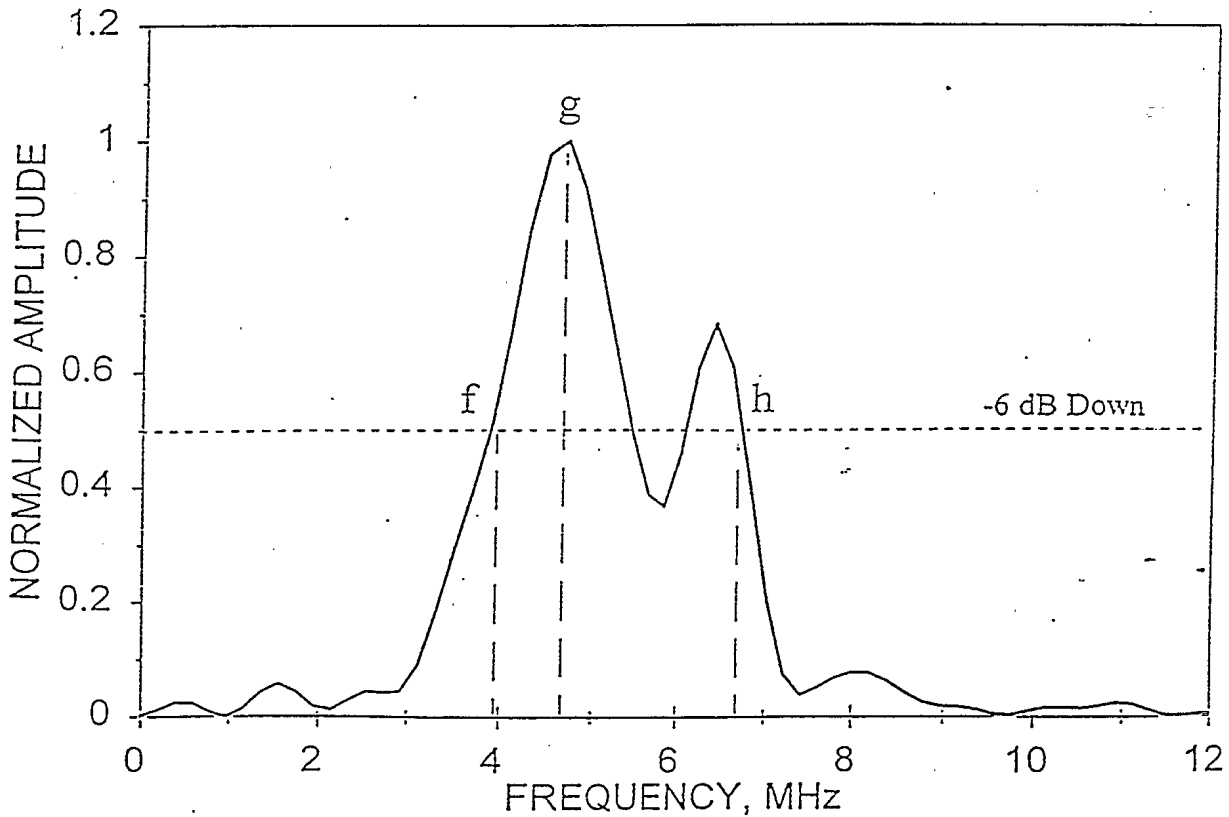


COMPOSITE DEFECT CLASSIFICATION

RESULTS - SELECTED FEATURES

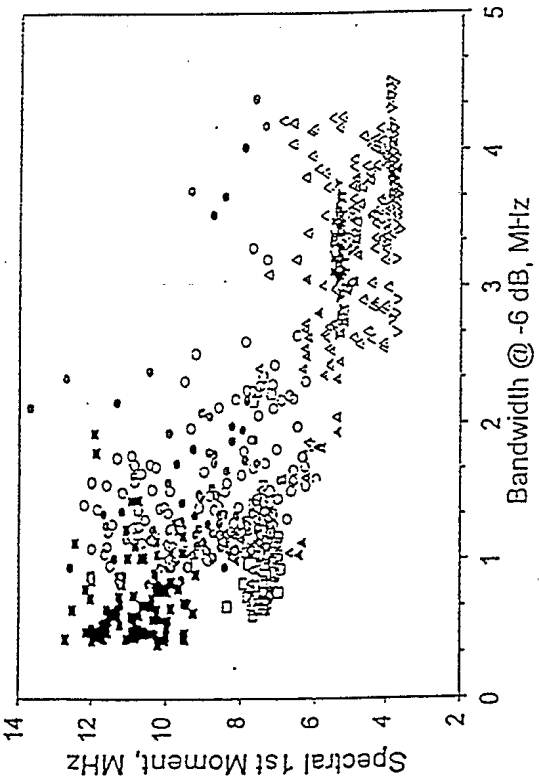
- PEAK FREQUENCY, MHz (g)
- BANDWIDTH @ -6dB DOWN (h-f)
- SPECTRAL SKEW @ -6dB DOWN $(h-g)/(g-f)$
- SPECTRAL ENERGY @ 1.95 MHz
- SPECTRAL FIRST MOMENT, MHz
- SPECTRAL SECOND MOMENT, MHz

POWER SPECTRUM



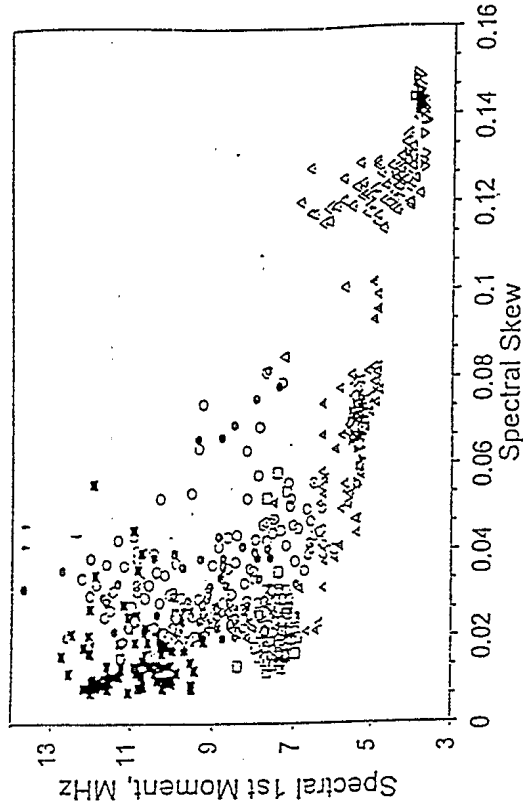
RESULTS - POWER SPECTRA FEATURES

FEATURE SCATTER DIAGRAM



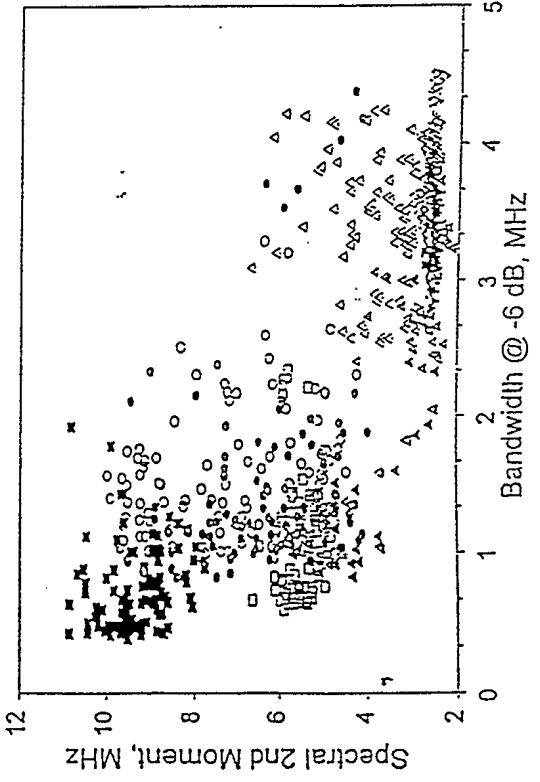
■ A1 □ A2 ▾ B1 ▽ B2 • D1 ◊ D2 ▲ F1 ▼ F2

FEATURE SCATTER DIAGRAM



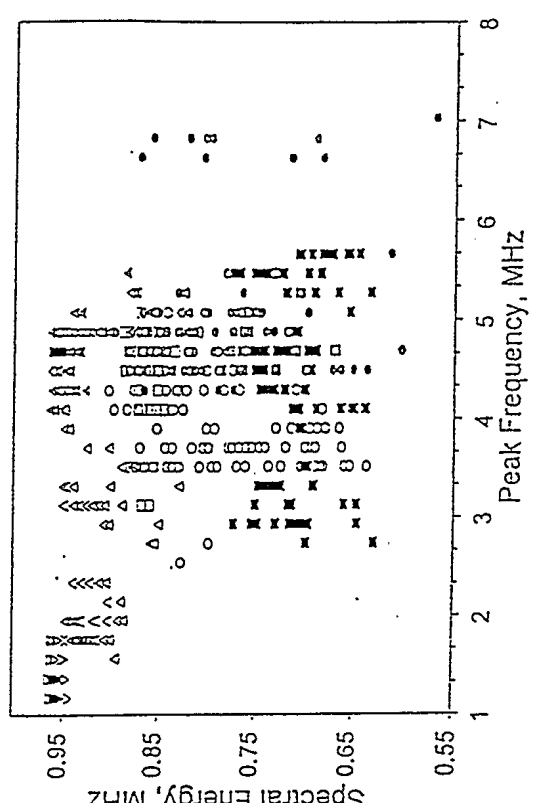
■ A1 □ A2 ▾ B1 ▽ B2 • D1 ◊ D2 ▲ F1 ▼ F2

FEATURE SCATTER DIAGRAM



■ A1 □ A2 ▾ B1 ▽ B2 • D1 ◊ D2 ▲ F1 ▼ F2

FEATURE SCATTER DIAGRAM



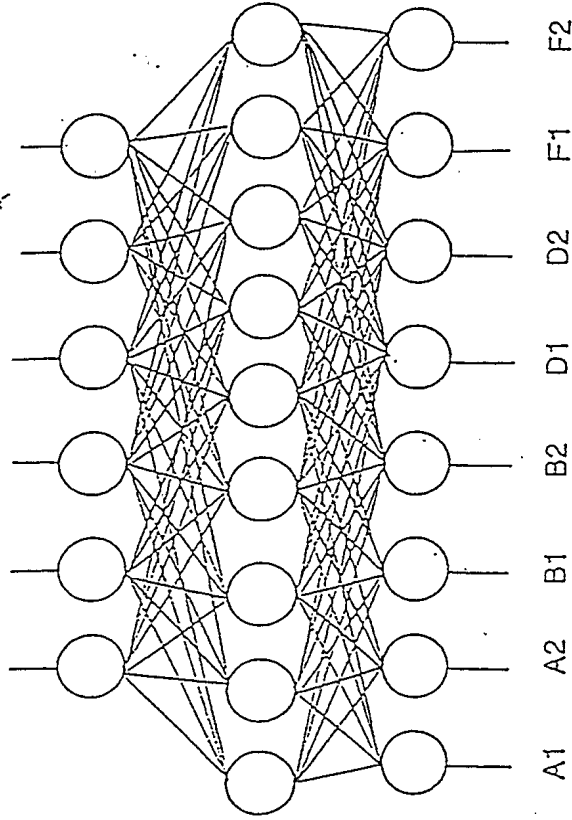
■ A1 □ A2 ▾ B1 ▽ B2 • D1 ◊ D2 ▲ F1 ▼ F2

COMPOSITE DEFECT CLASSIFICATION

ARTIFICIAL NEURAL NETWORK

- BACK PROPAGATION PARADIGM (NEURALWORKS PROFESSIONAL II)
- NORMALIZED CUMULATIVE DELTA LEARNING RULE
- HYPERBOLIC TANGENT TRANSFER FUNCTION
- 6 INPUT NEURONS, 9 NEURONS IN HIDDEN LAYER
- OBSERVATIONS IN CLASSIFICATION DATA (TEST SET RANDOMLY SELECTED BEFORE TRAINING)

POWER SPECTRUM
INPUT FEATURES



DEFECT CLASSIFICATION

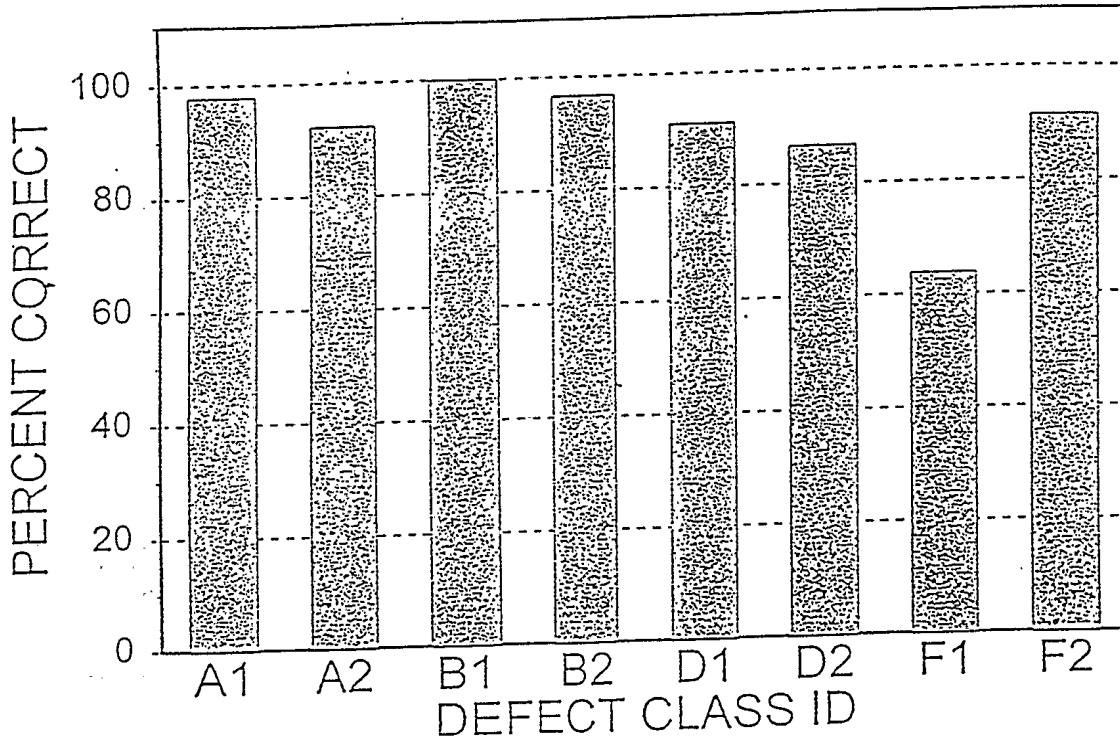
CLASS	TRAIN	TEST
A1	90	10
A2	90	10
B1	90	10
B2	90	10
D1	90	10
D2	90	10
F1	69	9
F2	81	9
TOTAL	690	78

• TRAINING ITERATIONS: 82,807

COMPOSITE DEFECT CLASSIFICATION

CLASSIFICATION RESULTS - TRAINING DATA

COMPOSITE DEFECT CLASSIFICATION
TRAINING DATA



NEURAL NETWORK CLASSIFICATION*

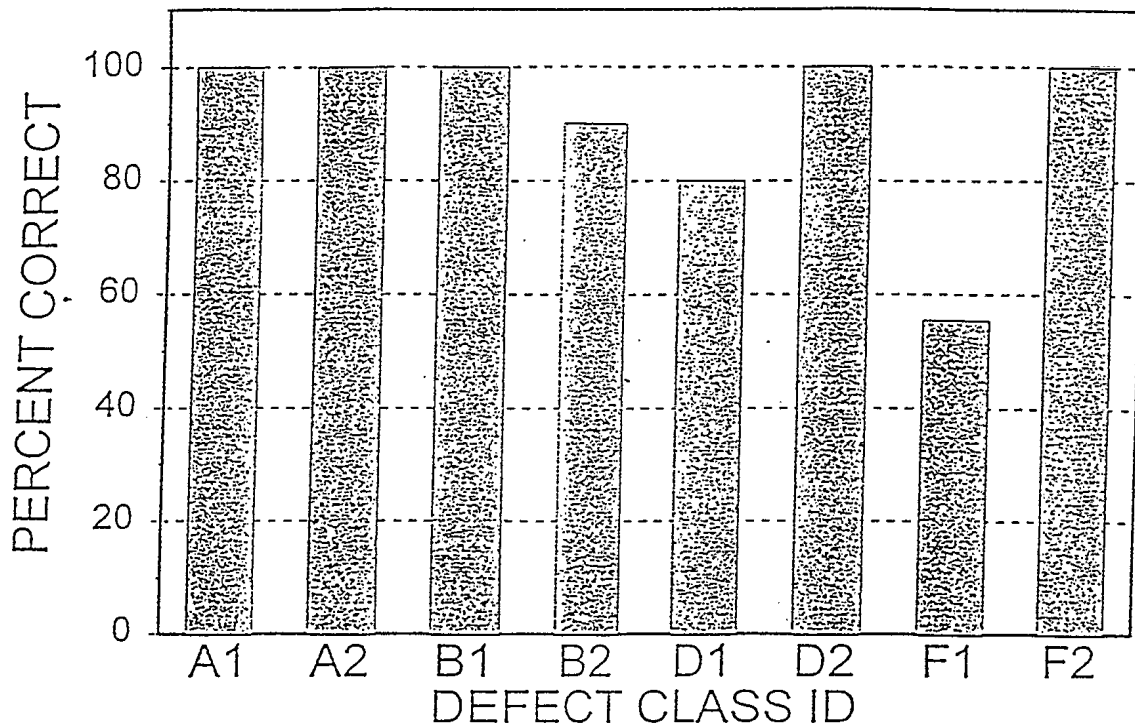
	A1	A2	B1	B2	D1	D2	F1	F2	N	NOT CORRECT	CORRECT	PERCENT CORRECT
A1	88	0	0	0	0	0	0	0	90	2	88	97.8
A2	0	83	0	0	0	3	0	0	90	7	83	92.2
B1	0	0	90	0	0	0	0	0	90	0	90	100.0
B2	0	0	0	87	0	0	0	0	90	3	87	96.7
D1	0	0	0	0	82	0	3	0	90	8	82	91.1
D2	0	0	0	0	0	78	0	0	90	12	78	86.7
F1	0	2	0	0	4	0	44	0	69	25	44	63.8
F2	1	0	0	0	1	0	0	74	81	7	74	91.4
TOTAL									690	64	626	90.72

*Class assignment for neuron output > 0.6.

COMPOSITE DEFECT CLASSIFICATION

CLASSIFICATION RESULTS - TEST DATA

COMPOSITE DEFECT CLASSIFICATION
TEST DATA



NEURAL NETWORK CLASSIFICATION*

	A1	A2	B1	B2	D1	D2	F1	F2	N	NOT CORRECT	CORRECT	PERCENT CORRECT
A1	10	0	0	0	0	0	0	0	10	0	10	100.0
A2	0	10	0	0	0	0	0	0	10	0	10	100.0
B1	0	0	10	0	0	0	0	0	10	0	10	100.0
B2	0	0	0	9	0	0	0	0	10	1	9	90.0
D1	0	0	0	0	8	0	0	0	10	2	8	80.0
D2	0	0	0	0	0	10	0	0	10	0	10	100.0
F1	0	0	1	0	0	0	5	0	9	4	5	55.6
F2	0	0	0	0	0	0	0	9	9	0	9	100.0

TOTAL: 78 7 71 91.03

*Class assignment for neuron output > 0.6.



NDE of Thick Section, Laminated Composites

Thickness Gaging on a GRP Frame Structure

- **Objective:** To perform thickness gaging at approximately 175 locations on a GRP machinery cradle.
- **Approach:**
 - used Krautkramer Branson USD-10 with KB-Aerotech 1” diameter, 500 kHz delay line transducer
 - calibrations performed using:
 - for thicknesses up to 1”, step wedge cut from cradle material
 - for thicknesses from 1” to 2”, used accessible section of known “good” cradle material
 - variety of couplants used - Sonotech High Viscosity Soundclear was selected for this application



NDE of Thick Section, Laminated Composites

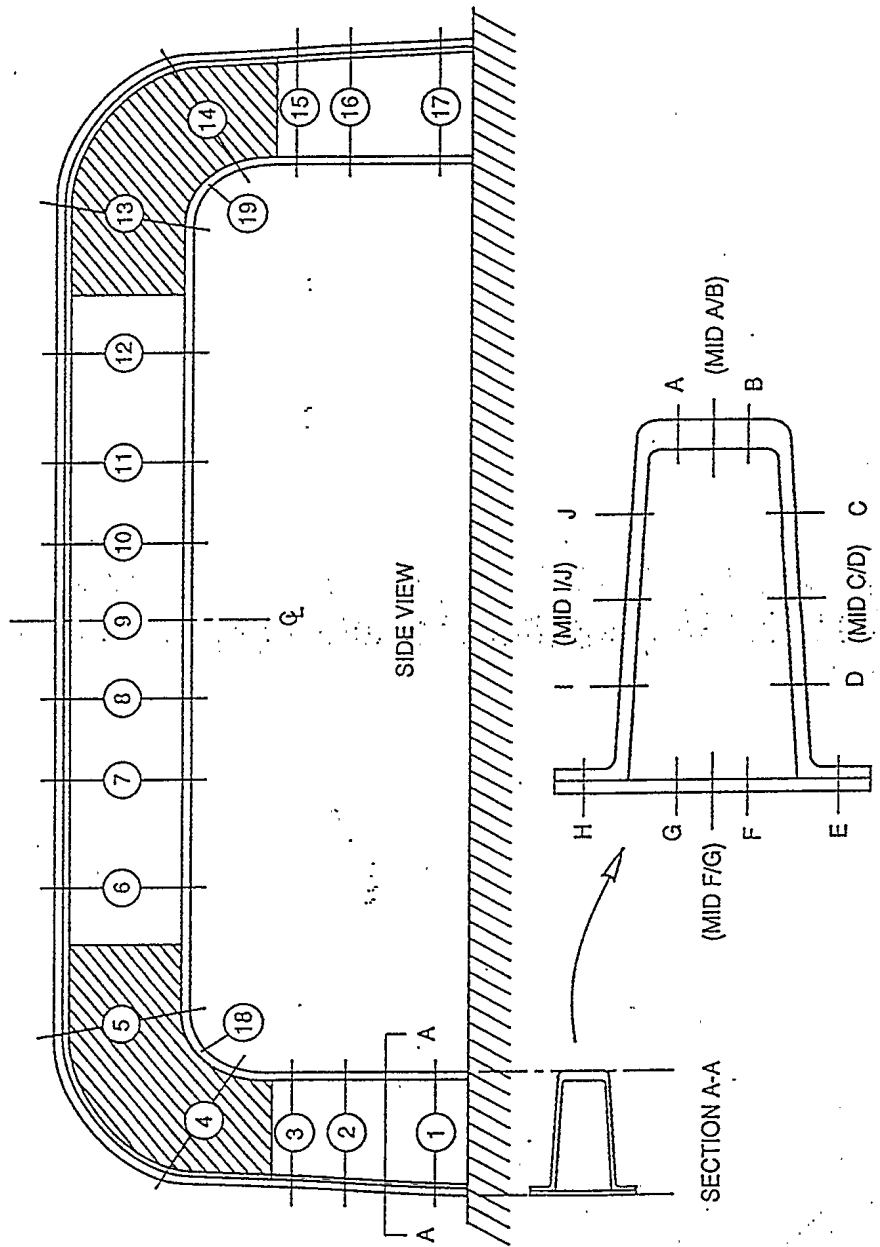
Thickness Gaging on a GRP Frame Structure

- Results:
- at most locations, a backwall was readily discernable, thus permitting thickness measurement
- A-scans contained obvious evidence of the layered nature of material
- required approximately 10dB more gain to penetrate the 2” material (vs. 1” material)
- inspection accuracy approximately +/- 1 mm
- Lessons Learned?????



NDE of Thick Section, Laminated Composites

Thickness Gaging on a GRP Frame Structure





NDE of Thick Section, Laminated Composites

Inspection of a Large GRP Structure

- Objective: NDE of a very thick section (up to 8”), large area, GRP structure
- Approach:
 - identify specific locations to be monitored
 - for UT inspection:
 - independent measure of longitudinal velocity
 - transducer and equipment evaluation
 - calibration standard requirements & design
 - identify limitations of inspection
 - Identify other potential inspection methods such as visual & microwave



NDE of Thick Section, Laminated Composites

Inspection of a Large GRP Structure

- Independent measure of longitudinal velocity:
 - measurements using point-source/point receiver (PS/PR) ultrasonic technique.
 - two samples evaluated: a plate-like specimen measuring 1" in thickness, and a semi-circular "cut-out" measuring 5.5" thick.
 - resulting measured longitudinal velocities:
 - for 1" sample, $V_L = 2.77$ mm/us
 - for 5.5" sample, $V_L = 2.66$ mm/us
 - amplitude of signal greatly influenced by thickness



NDE of Thick Section, Laminated Composites

Inspection of a Large GRP Structure

- independent measure of longitudinal velocity
- longitudinal wave, pulse echo techniques used to measure time of flight through a 1" thick block of GRP material
- mechanical thickness measurements made at same locations with a micrometer
- longitudinal velocity calculated to be 2.66 ± 0.40 Km/s.



NDE of Thick Section, Laminated Composites

Inspection of a Large GRP Structure

- transducer and equipment evaluation
- evaluation of the wave penetration capability and influence of transducer frequency and diameter for a thick section of the GRP material (13 cm thick)
 - frequencies of 0.5 MHz or lower have better penetration capability
 - large diameter transducers (0.75" - 1") are more efficient and powerful for generating and receiving ultrasonic signals
 - dual element transducers provided higher SNR



NDE of Thick Section, Laminated Composites

Inspection of a Large GRP Structure

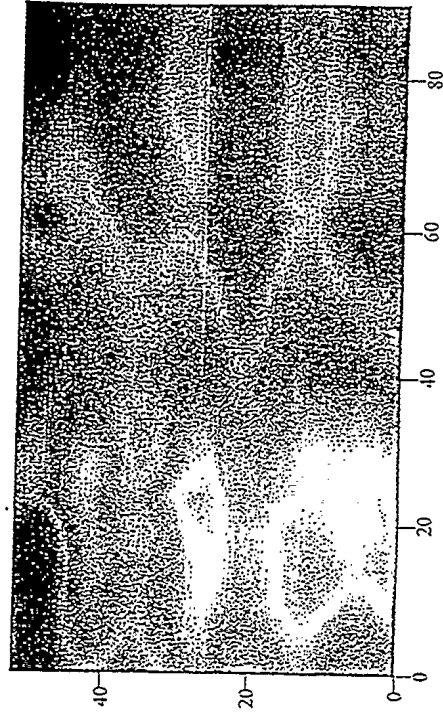
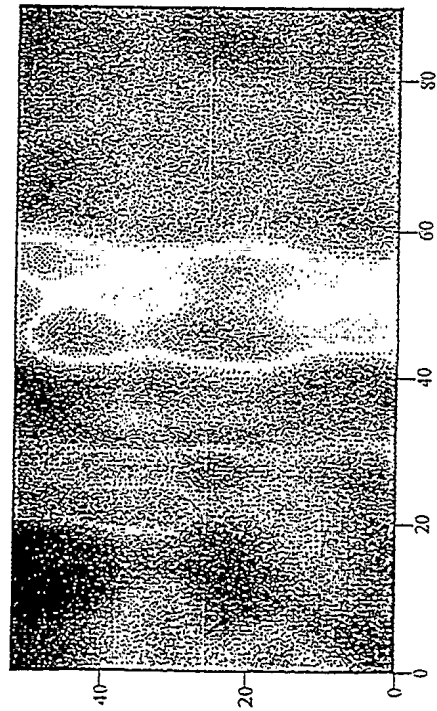
- transducer and equipment evaluation (cont.)
 - 3 types of UT instruments tried on actual structure with selected transducer
 - analog instrument - penetration depth ~ 0.5”
 - “older” digital instrument - penetration depth ~ 1-1/2”
 - “state-of-the-art” digital instrument - penetration depth ~ 3”

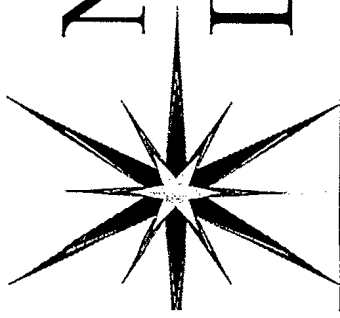


NDE of Thick Section, Laminated Composites

Microwave Inspection

Example: 10 GHz scan of 90 x 53 mm area with defect on a GRP panel. Left image obtained w/ standoff of 1.6 mm, right image w/ standoff of 14.25 mm. Left image shows inclusion; right shows variations in sample thickness.





NDE of Thick Section, Laminated Composites

Summary

- Composite usage increasing/many advantages to using composites for shipboard structures
- Many challenges associated with inspecting thick section composites
- Variety of techniques in NDE Toolbox
- Near-term requirement for inspecting a large GRP structure