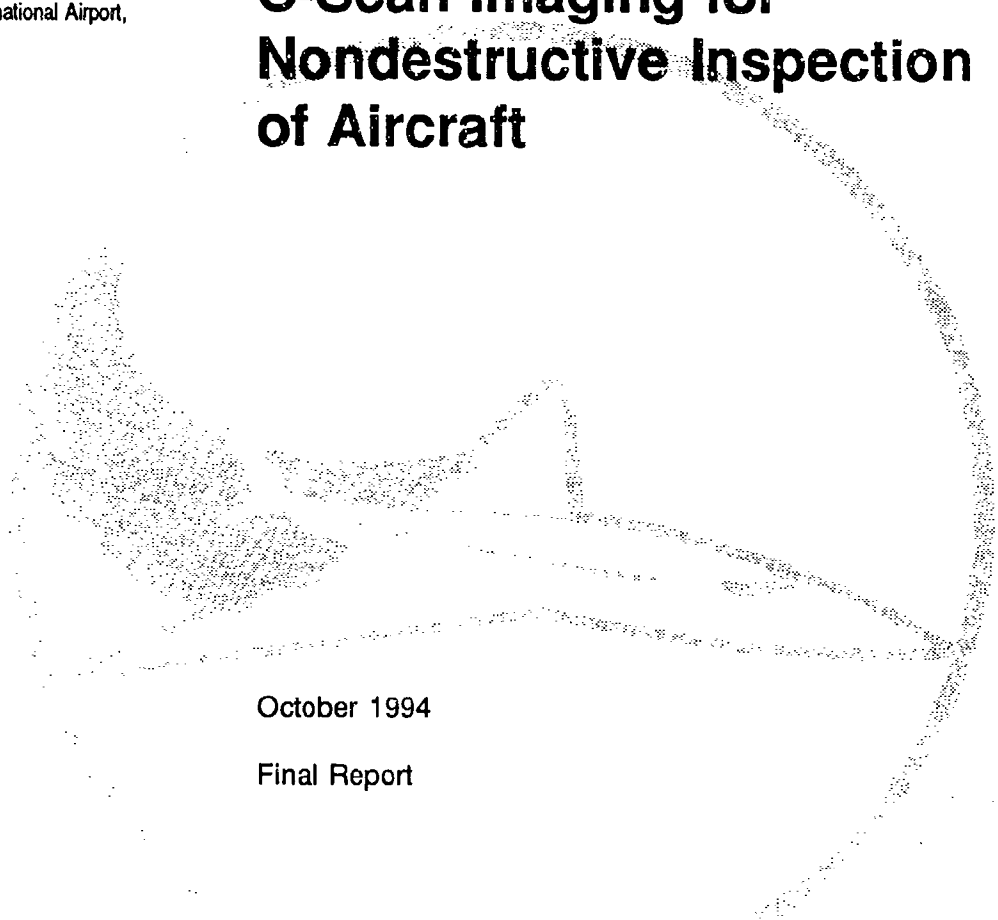
DOT/FAA/CT-94/79

FAA Technical Center
Atlantic City International Airport,
N.J. 08405

Evaluation of Scanners for C-Scan Imaging for Nondestructive Inspection of Aircraft



October 1994

Final Report

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U.S. Department of Transportation
Federal Aviation Administration

NOTICE

Technical Report Documentation Page

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
DOT/FAA/CT-94/79		
4. Title and Subtitle Evaluation of Scanners for C-Scan Imaging for Nondestructive Inspection of Aircraft		5. Report Date September 1994 6. Performing Organization Code
7. Author(s) John H. Gieske		8. Performing Organization Report No.
9. Performing Organization Name and Address Sandia National Laboratories Albuquerque New Mexico 87185		10. Work Unit No. (TRAIS) 11. Contract or Grant No. DTFA-03-91-A-0018
12. Sponsoring Agency Name and Address U.S. Department of Transportation Federal Aviation Administration Technical Center Atlantic City International Airport, NJ 08405		13. Type of Report and Period Covered Final Report 14. Sponsoring Agency Code ACD-220

15. Supplementary Notes

The Sponsoring Agency's Technical Officer was Dave Galella

16. Abstract

The goal of this project was to produce a document that contains information on the usability and performance of commercially available, fieldable, and portable scanner systems as they apply to aircraft nondestructive inspections. In particular, the scanners are used to generate images of eddy current, ultrasonic, or bond tester inspection data. The scanner designs include manual scanners, semiautomated scanners, and fully automated scanners. A brief description of the functionality of each scanner type, a sketch, and a list of the companies that support the particular design are provided. Vendors of each scanner type provided hands-on demonstrations of their equipment on aircraft samples in the Federal Aviation Administration (FAA) Aging Aircraft Nondestructive Inspection Validation Center in Albuquerque, New Mexico. From evaluations recorded during the demonstrations, a matrix of scanner features and factors and ranking of the capabilities and limitations of the design, portability, articulation, performance, usability, and computer hardware/software was constructed to provide a quick reference to compare the different scanner types. Illustrations of C-scan images obtained during the demonstration are shown.

17. Key Words	18. Distribution Statement
Aging Aircraft Portable Systems Ultrasonic Eddy Current	This document is available to the public through the National Technical Information Service, Springfield, Virginia 22161

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	52	

Form DOT F1700.7 (8-72) Reproduction of completed page authorized

PREFACE

This work was performed at the Federal Aviation Administration (FAA) Aging Aircraft Nondestructive Inspection Validation Center (AANC) in Albuquerque, NM, and sponsored by the FAA Technical Center in Atlantic City, NJ. The author was able to conduct the scanner evaluations through the cooperation of vendors who participated in the demonstrations. The author expresses his appreciation for the time, effort, and expense the vendor participants and sales representatives incurred while performing the hands-on demonstrations. The author also thanks other members of the AANC staff for their support.

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NOMENCLATURE

AANC	Aging Aircraft Nondestructive Inspection Validation Center
ASNT	American Society for Nondestructive Testing
B737	Boeing 737
BS	Body station
FAA	Federal Aviation Administration
LED	Light-emitting diode
NDI	Nondestructive Inspection
S	Stringers

EXECUTIVE SUMMARY

Fieldable nondestructive inspection (NDI) systems based on eddy current and ultrasonic inspection methods, and utilizing scanners to produce images, have been used in the nuclear and petrochemical industry for years to detect cracks, corrosion, and disbonds. Similar systems have the same potential in the airline industry for early detection of hidden damage in aircraft structures.

The images produced by the scanning systems mentioned above are called C-scans. C-scans are 2-D images produced by digitizing the point-by-point signal variations of an interrogating sensor while it is scanned over a surface.

To provide the encoded sensor position for the computer during C-scan imaging, a number of portable scanner designs and scanner methodologies have been developed in recent years. Both manual and automated portable scanners have been developed that may be useful for aircraft NDI.

The goal of this project was to produce a document that contains information on the evaluation of scanner systems as they apply to aircraft inspections.

From a literature survey and discussions with vendors, a variety of different portable scanner designs were identified. The designs include manual scanners, semiautomated scanners, and fully automated scanners. Scanners included both mechanized and nonmechanized designs.

The basic scanner designs were divided for the purposes of this report into eight different types. These are

1. dual axis, tilting arm and bridge, manual (mechanized);
2. dual axis, tilting arm and bridge, automated (mechanized);
3. radial axis, tilting arm with rotation axis bridge, manual (mechanized);
4. dual axis, cantilever arm bridge, manual and automated (mechanized);
5. mobile, automated, ultrasonic scanner (mechanized semiautomated);
6. dual axis, rectangular bridge, automated (mechanized);
7. hands free x-y digitizer (nonmechanized acoustic or video tracking); and
8. square transducer array (nonmechanized electronic switching).

Appendix A includes a brief description of the functionality of each scanner type, a sketch, and a list of the companies that support the particular design.

Vendors provided hands-on demonstrations of their equipment on aircraft samples in the Federal Aviation Administration (FAA) Aging Aircraft Nondestructive Inspection Validation Center (AANC) in Albuquerque, NM. The aircraft samples and the Boeing 737 (B737) airplane used in the demonstrations contained known areas of corrosion damage and disbonds from in-service conditions. Capabilities and limitations of the design, portability, articulation, performance, usability, and computer hardware/software were recorded during the demonstrations.

From observations and information recorded during the demonstrations, a matrix of features, factors, and their respective evaluations for each scanner tested was constructed to provide a quick reference for comparing the different scanner systems. A table containing the evaluations and ranking of each feature or factor for the scanners demonstrated is provided.

No attempt is made to rank the scanner systems overall with comparative scores. This is left to potential users. The users should consider features and factors that are most important for their respective applications.

Excellent C-scan images of eddy current and ultrasonic inspection data were obtained during the performance demonstrations. Illustrations of the C-scan images obtained from examinations of the five AANC aircraft samples used in the evaluation are shown in appendix E. Pictures of the attachment of a number of the scanners on the B737 airplane are also included.

A discussion of the strong points and weak points of the eight scanner types is given in appendix F. Suggestions for improvements are also provided there.

INTRODUCTION

BACKGROUND.

Fieldable nondestructive inspection (NDI) systems based on eddy current and ultrasonic inspection methods, and utilizing scanners to produce images, have been used in the nuclear and petrochemical industry for years to detect cracks, corrosion, and disbonds. Similar systems have the same potential in the airline industry for early detection of hidden damage in aircraft structures. Corrective repairs initiated by early detection of damage can be cost effective by reducing the need for subsequent major repairs that impact the availability of the aircraft for revenue.

Another possible application area aside from aluminum structures is composites. New aircraft rely increasingly on composite technology. Periodic inspections of a composite structure for delaminations and impact damage during the service life of the aircraft are essential for safety. Ultrasonic imaging of composites has the potential to provide the inspection data needed to detect these defects and assess the structural integrity of the composite during the life of the aircraft. Thus, imaging technology is applicable to both new and aging aircraft.

The images produced by the scanning systems mentioned above are called C-scans. C-scans are 2-D images produced by digitizing the point-by-point signal variations of an interrogating sensor while it is scanned over a surface. The X-Y position of the sensor is recorded simultaneously with the signal variations. A computer converts the point-by-point data into a color representation and displays it at the appropriate point in an image. This image usually makes it much easier to interpret defects than the individual measurements.

To provide the encoded sensor position for the computer, a number of portable scanner designs and scanner methodologies have been developed in recent years. Both manual and automated portable scanners have been developed that may be useful for aircraft NDI.

GOAL.

The goal of this project was to produce a document that contains information on the evaluation of scanner systems as they apply to aircraft inspections. The document is based on demonstrations of commercially available, portable inspection systems that were observed while scanning representative aircraft structures.

OBJECTIVES.

The objectives of this project were to:

1. Demonstrate and evaluate the capability of commercially available portable scanner systems to generate C-scan images on representative aircraft structures.
2. Evaluate the usability and performance of the different scanner types to help inspection personnel choose an appropriate scanner and to help scanner vendors to improve the usability and performance of the scanners for aircraft inspection requirements.

DEMONSTRATION AND EVALUATION PROCESS

SCANNER SYSTEM DESIGN IDENTIFICATION.

From a literature survey and discussions with vendors, a variety of different portable scanner designs was identified. The designs include manual scanners, semiautomated scanners, and fully automated scanners. Scanners included both mechanized and nonmechanized designs.

All mechanized scanners employ optical encoders on one or more of the moving parts of the scanner to indicate the sensor position. Nonmechanized scanners employ diverse techniques to encode the sensor positions. An example of a nonmechanized scanner involved transmitting a high frequency acoustic pulse at the sensor from a distance and detecting the propagating pulse through the air with a pair of microphones. The position of the sensor is calculated by triangulation techniques from arrival time data. Another example employed a light-emitting diode (LED) at the sensor with a video camera encoding system positioned above the sensor for tracking and coding the position of the sensor. A third example employed a 2-D array of small transducer elements embedded in a flexible vacuum blanket that is applied in contact with the surface; the C-scan image is formed by electronic switching through the transducer elements of the array.

The basic scanner designs were divided for the purposes of this report into eight different types. These are

1. dual axis, tilting arm and bridge, manual (mechanized);
2. dual axis, tilting arm and bridge, automated (mechanized);
3. radial axis, tilting arm with rotation axis bridge, manual (mechanized);
4. dual axis, cantilever arm bridge, manual and automated (mechanized);
5. mobile automated ultrasonic scanner (mechanized semiautomated);
6. dual axis, rectangular bridge, automated (mechanized);
7. hands free x-y digitizer (nonmechanized acoustic or video tracking); and
8. square transducer array (nonmechanized electronic switching).

These scanner types are described in appendix A. Each entry in appendix A includes a brief description of the functionality of each scanner type, a sketch, and a list of the companies that support the particular design.

CHOOSING VENDORS FOR HANDS-ON DEMONSTRATIONS.

Vendors provided hands-on demonstrations of their equipment on real aircraft samples in the Federal Aviation Administration (FAA) Aging Aircraft Nondestructive Inspection Validation Center (AANC) in Albuquerque, NM. The aircraft samples and the Boeing 737 (B737) airplane used in the demonstrations contained known areas of corrosion damage and disbonds.

Capabilities and limitations of the design, portability, articulation, performance, usability, and computer hardware/software were recorded during the demonstrations for later evaluation.

For each scanner type, vendors were contacted and performance demonstrations of their equipment were discussed. If the vendor was receptive and volunteered to conduct the hands-on demonstrations, arrangements were made to perform the demonstrations in the FAA/AANC hangar. Each vendor was asked to bring its own eddy current, ultrasonic, and bond tester equipment to be used with the scanners. Multimode scans using the different NDI techniques could then be evaluated at the same time. In some cases, two demonstrations were scheduled at different times for a given NDI technique when two different vendor representatives of the respective techniques were involved.

Priority was given to vendors who supported both eddy current and ultrasonic testing equipment with their scanner systems. Their integrated system would have the best chance of performance and largest potential payback for providing significant information on the capabilities and limitations of the scanner design type for the different NDI modes.

The scope of this project was to evaluate all the basic scanner types that are appropriate for aircraft NDI examinations. A number of vendors sell very similar scanners of the same basic design. They have integrated the scanner with their data acquisition and software system but they do not sell NDI equipment. In this case, only one or two scanners of the same basic design were evaluated with vendors who offered the most integrated NDI capability. It is expected that similar results would be obtained with other scanners of the same basic design.

A list of the vendors and participants who took part in the performance demonstrations is provided in appendix B.

AIRCRAFT SAMPLES.

The demonstrations were performed on a group of samples that represented defects from in-service conditions. Samples with lap splice joint corrosion, various surface conditions and thickness, and disbond conditions were chosen. Also, various geometric configurations on the B737 aircraft where the scanner must be mounted in a vertical or upside down (overhead) position were chosen for the evaluation.

Five samples used in the evaluation were:

1. A.D. Little aluminum lap splice joint intergranular corrosion attack specimens of 0.04-inch thickness. (AANC Test Specimen Library Numbers 115 through 122)
2. Large 0.07-inch-thick aluminum panel with visible pitting and intergranular/exfoliation corrosion and pillowing of the surface. (AANC Test Specimen Library Number 111)
3. Calibration standards used for setting up tests for circumferential tear strap disbond. (AANC Test Specimen Library Numbers 183 through 185)
4. Textron Specialty Materials boron/epoxy composite repair sample with implanted disbonds and delaminations on an aluminum skin. (AANC Test Specimen Library Number 152)

5. Various locations on the B737 AANC aircraft with disbonds and corrosion. (AANC Test Specimen Library Number 100)

Detailed descriptions of these samples are given in appendix C.

STEPS OF THE PERFORMANCE DEMONSTRATION.

The performance demonstration of each scanner by the vendor was conducted with the following steps:

1. An overview of the AANC activities was provided to the vendor by a member of the AANC staff.
2. A calibration and initial setup of the equipment were performed on flat horizontal samples on a table top to become familiar with the equipment. C-scan images were generated to demonstrate the general capabilities of the system and scanner operation. At this time, an overview of the equipment hardware and software capabilities was provided by the vendor.
3. For the first eddy current test, the A.D. Little intergranular corrosion attack samples of a lap splice joint of 0.04-inch skin thickness were examined. C-scan images of the hidden corrosion over the 12-inch length joint was recorded and saved in a data file on the computer system. The A.D. Little samples were used to observe the general operation and function of the scanner and observe the effort the examiner needed to obtain meaningful C-scan images representing the areas of corrosion damage.
4. For the second eddy current test, the large panel with skin thickness of 0.07 inch was scanned. This panel contained visible corrosion and pillowing of the surface between the rivet locations. This panel was used to demonstrate how well the scanner functions on wavy and rough surfaces representative of significant pillowing. The time to scan and obtain meaningful C-scan images of the corrosion for an area of 4 and 8 square inches was recorded.
5. The scanner with the eddy current sensor was then attached to the B737 airplane where a demonstration was conducted at the area bounded by body station (BS) 877 and BS 887 and stringers (S) 22R and S 24R. The scanner must be positioned somewhat vertical and upside down to perform this test. This area of the airplane had corrosion and a tear strap disbond could be seen by viewing the interior panel surface. This test demonstrated the ability of the scanner and effort required by the examiner to take inspection data on a curved surface and with the scanner in an upside down or overhead position. The scan time to produce a C-scan image of the inspection data was recorded for this area. Notes as to the operation of the equipment under these conditions were recorded and C-scan images of the inspected areas showing the detected damage were saved for comparison with different scanner systems. If time permitted, C-scan images were also obtained at the lap splice joint at S 20R and the butt joint at BS 907. A final test was made on the airplane at the lap splice joint S 10L on the left side of the airplane above the windows between BS 817 and BS 907. The equipment must be carried up a scaffold and attached to the fuselage above the windows for this last eddy current test. This exercise provided information on the portability of the scanner.

6. For the first ultrasonic pulse-echo and resonance evaluations, area scans with C-scan images were made on the tear strap disbond calibration standards and the Textron boron/epoxy repair patch calibration standard. These samples were used to observe the general operation of the scanner for ultrasonic inspections. If the vendor also had a bond tester capability, then data were also obtained with the bond tester sensor. If a bond tester was not available, the pulse-echo technique was set up to simulate the resonance bond testing technique to obtain the inspection data.
7. The scanner with the ultrasonic sensor was then attached to the B737 airplane at BS 877 at S 22R. This is the same area on the airplane where eddy current evaluations were accomplished. An ultrasonic scan in this area where corrosion and tear strap disbonds have occurred demonstrated the ability of the scanner and effort required by the examiner to take ultrasonic inspection data for the vertical and overhead position of the scanner. The functionality of the scanner under these conditions to maintain ultrasonic couplant and sensor perpendicularity to the surface was observed. The scan time to produce the C-scan image of the inspection data was recorded. C-scan images of the inspected area were saved for comparison of the detected damage with different scanner systems.

Later in the program, a boron/epoxy repair patch was placed on the airplane and on a large lap splice joint fatigue panel. Demonstrations of ultrasonic resonance techniques on these repair patches were made when these became available. This provided additional information on the effort and effectiveness of ultrasonic C-scan imaging for assessing the integrity of the repair patches.

If not made during the demonstration, hard copy images or image files of the C-scans were obtained from the vendor so that copies of the images could be compared at a later date.

SCANNER EVALUATION MATRIX

EVALUATION MATRIX CONTENTS.

As a result of the observations and information recorded during the demonstrations, a matrix of features, factors, and their respective evaluations for each scanner tested was constructed to provide a quick reference for comparing the different scanner systems. Table 1 contains the evaluations and ranking of each feature or factor for the scanners demonstrated.

The evaluations concentrated on the mechanics and efficiency of the scanner to provide XY position data while maintaining proper sensor orientation and articulation so that meaningful C-scan images were obtained. The matrix contains observations made by the author while witnessing the demonstrations for the different NDI methods of eddy current scans, ultrasonic pulse-echo scans, or ultrasonic bond testing scans.

Each feature or factor in table 1 is ranked from 1 (not applicable for aircraft applications) to 5 (ideal for aircraft applications). The ranking criteria for each feature or factor is given in appendix D. The purpose of ranking the features is meant as an aid to document observations made during the hands-on demonstrations and to differentiate them from the characteristics of the author's idea of an ideal scanner system, which is given in appendix F. The ranking is meant to point out differences observed by the author during the hands-on demonstrations and is not meant to be a recommendation of one system over another. Each system has certain merits that may make it useful in one application but undesirable in another application. Every feature of the ideal scanner system is not attainable in any one scanner design. The characteristics of an ideal scanner are discussed in appendix F.

All systems evaluated contained software that generated basic C-scan images. The basic C-scan images were quite adequate for aircraft applications. Some systems contained software tools for advanced image processing that could be used to enhance interpretation of a particular inspection data set. These tools are valuable, but the evaluation of the imaging tools available in the various systems was not attempted.

No attempt is made to rank the scanner systems overall with comparative scores. This is left to potential users. The users should consider features and factors that are most important for their respective applications. The evaluation of the features and factors for all of the scanners demonstrated are given in table 1.

EXAMPLE C-SCAN IMAGES

Excellent C-scan images of eddy current and ultrasonic inspection data were obtained during the performance demonstrations. Illustrations of the C-scan images obtained from examinations of the five AANC library samples used in the evaluation are shown in appendix E. Pictures of the attachment of a number of the scanners on the B737 airplane are also included. In some cases, the color palette of the original C-scan images was changed so that black and white reproductions of the illustrations would show the inspection results clearly. The C-scan images are provided to show the potential benefits of C-scan imaging in inspection of aircraft structures.

DISCUSSION

Commercially available portable scanners can provide excellent C-scan imaging of NDI data. The images shown in appendix E illustrate the potential of C-scan imaging for providing quantitative measurements of hidden corrosion and disbonds for aircraft applications.

Setup of the eddy current and ultrasonic equipment was done by using the experience gained from testing similar structures by the vendor representatives and the author. The parameters used may not have been optimal for quantitative NDI results especially since only limited time was available to demonstrate the equipment. Quantification of corrosion damage can be done through proper calibration procedures. The purpose of this study was to evaluate the usability and performance of scanner systems to acquire and display meaningful inspection data of corrosion damage and disbonds. No attempt was made to calibrate and optimize equipment parameters or quantify the corrosion damage detected.

When applications are identified and the use of C-scan imaging is concurred by industry to be valuable for future NDI aircraft applications, then the test parameters, calibration, and test procedures must be developed and established for these defined applications. The development of these optimum test parameters, procedures, and reliability of inspection results on the variability of surface conditions, paint thickness, etc., would be the subject of possible future work for knowledgeable researchers in the field.

CONCLUSIONS

Conclusions derived from this evaluation study can be summarized as follows:

- Eddy current C-scan imaging can be implemented easily with available commercial equipment and the benefits realized immediately. Ultrasonic resonance techniques may also be implemented in the near future after experienced users have correlated results with calibration samples and gained confidence in its use. Ultrasonic pulse-echo measurements may be used only after the more experienced operators have developed a technique and procedure for each specific inspection application.

- Every mechanized scanner tested scratched the surface of the aluminum panels for both the eddy current and ultrasonic techniques. Automated scanners in some cases scratched the surface more severely since larger forces are needed to keep the sensor holder in contact and perpendicular to the surface. New designs of sensor holders are recommended that in effect would result in more nearly frictionless contact deployment. However, scanning over composite surfaces and composite repair patches with the present scanners did not damage the surface of the composite.

- Eddy current data acquisition with the mechanized scanners was more reliable and easier to obtain than ultrasonic data acquisition. This is because small couplant variations and tilt of the ultrasonic transducer influenced the inspection data significantly, whereas small lift-off variations for the eddy current sensor has little effect on the inspection data.

- Both manual and automated scanners performed well over flat rivets and over surfaces with nominal pillowing between rivets.

- Manual scanners are most useful for small area scans where surface obstructions (raised rivets) may be present. Inspection times for 1 square foot coverage ranges from approximately 10 to 20 minutes depending on the spot size resolution desired.

- Automated scanners are recommended for both small area scans and large area scans where obstructions are not present. Inspection times for 1 square foot coverage varied from approximately 5 minutes to 15 minutes. Spot size resolution is not a major concern for automated scanners since fine and large spot sizes result in approximately the same scan time.

- Hands-free digitizer scanners have the potential of being the most useful manual scanner since they are the least expensive and most versatile for areas of complex curvatures and obstructions. They may also be useful in areas on and around the stringers on the interior surface of the fuselage.

- Manual scanners are more labor intensive and tiring to operate than automated scanners especially in overhead applications. In general, manual ultrasonic C-scan imaging is very difficult to implement for overhead applications. Inspection times longer than 1 hour would be taxing on the examiner.

- Passive rubber cup suction feet are unreliable for vertical and overhead deployment. An active vacuum system either by hand pumps or an AC vacuum pump is more reliable.

- The dual axis tilting arm bridge automated scanner provided the best results for portability, performance, and overall usability of all the automated scanners tested.

- The radial axis tilting arm with rotation manual scanner provided the best results for portability, performance, and overall usability of all the manual scanners tested.

- The heads-up display used to acquire data with the dual axis XY manual scanner did not add to the performance or ease of data acquisition for C-scan imaging.

- The 2-D transducer array system performed very well resolving 0.04-inch aluminum skin thickness for possible quantitative and accurate corrosion damage assessment. Excellent resolution of the implanted delaminations in the thin boron/epoxy repair patches was obtained. Portability and usability of the 2-D array system were excellent.

- The 2-D transducer array system has great potential in the initial and periodic assessment of composite repair patches. It may also be useful for the assessment of impact damage of composite structures.

- An experienced ASNT Level 2 NDI inspector would be required to operate every one of the C-scan systems evaluated for general applications. However, an experienced ASNT Level 1 NDI inspector could operate every one of the C-scan systems with proper training and supervision by Level II or Level III inspectors in specific applications.

- Setup time from off the shelf to start of scan was reasonable (10 to 20 minutes) for all systems evaluated.

- The cost of scanner systems for C-scan imaging ranged from approximately $30,000 to $150,000.

The strong points and weak points of the eight scanner types are discussed in appendix F. Suggestions for improvements are also provided.

TABLE 1 - SCANNER EVALUATION MATRIX FOR EDDY CURRENT AND ULTRASONIC C-SCAN IMAGING OF INSPECTION RESULTS.

[5] Ideal, meets all requirements for aircraft applications

UT = Ultrasonic Test, ET = Eddy current Test

Features and Factors \ Company and Scanner	Krautkramer Branson Hocking ANDSCAN	DuPont CalData Zetec PORTASCAN	ABB Amdata AMAPS	MATEC SONIX HANDI-SCAN
DESIGN				
Basic Design and Scan Motion	[4] Tilting Radial Arm with circular motion Manual & Random	[4] Tilting Arm Bridge with X-Y linear motion Automated	[3] Cantilever Arm with rigid X-Y linear motion Automated	[3] Tilting Arm Bridge with X-Y linear motion Manual & Random
Mount Type	[3] Three suction cups in series with one hand vacuum pump	[4] Three independent suction cups with three manual vacuum pumps	[2] Numerous suction cups in series, one AC vacuum pump	[3] Static rubber suction cups without manual vacuum pumps
Probe Holder and Gimbals Design	[5] Excellent	[4] Good	[4] Good	[3] Adequate
Couplant Feed UT only, NA for ET	[5] Water drip feed at fluted probe holder	[5] Water drip feed at fluted probe holder	[5] Water drip feed at probe holder	[2] Manual spray or wipe on with cloth
Scanner Working Distance Height	[4] Minimum 10 inches	[4] Minimum 10 inches	[3] Minimum 12 inches	[4] Minimum 6 inches
X-Y Axis Resolution	[5] 0.012 inch	[5] 0.01 inch	[5] 0.01 inch	[5] 0.005 inch
PORTABILITY				
Scanner Weight	[4] 4 lbs	[4] 5 lbs	[2] 25 lbs	[4] 1 lb
Ruggedness	[5] Excellent	[5] Excellent	[5] Excellent	[4] Good
Deployment Ease	[5] Excellent	[5] Excellent	[3] Adequate	[5] Excellent
Computer Hardware	[5] Excellent	[5] All in suitcase size	[4] Good	[5] Excellent
Motor Controller	[X] Not applicable	[5] Card in PC	[3] Heavy, rack mounted	[X] Not applicable
ARTICULATION				
Complex Shapes	[4] Scanner is usable on flat and irregular shapes with dual curvatures	[3] Scanner is usable on moderate dual curvatures at vertical sides and overhead	[3] Scanner is usable on large flat and moderate dual curvatures that are vertical and overhead	[3] Scanner is usable on moderate dual curvatures at vertical sides and overhead
Surface Conditions	[4] No problem over pillowing or raised rivets/joints etc.	[3] No problem over pillowing and lap joints, no raised rivets	[3] No problem over pillowing and lap joints, no raised rivets	[4] No problem over pillowing or raised rivets/joints etc.
PERFORMANCE				
Speed of Coverage	[3] 2 sq. ft. at 0.1 in. spot size, 15-30 minutes	[4] 2 sq. ft. at 0.1 in. spot size, 10-15 minutes	[4] 2 sq. ft. at 0.1 in. spot size, 10-15 minutes	[3] 2 sq. ft. at 0.1 in. spot size, 15-30 minutes
Accuracy	[5] Excellent	[5] Excellent	[4] Good	[4] Good
Problems encountered during Demonstration	[4] Suction cup feet relax and slip after extended use	[4] Probe was not held firmly against curved and overhead surface	[3] Scanner fell to floor 3 times during test, due to suction cup failures	[3] Sensor mount design did not keep sensor securely in holder

TABLE 1 - SCANNER EVALUATION MATRIX FOR EDDY CURRENT AND ULTRASONIC C-SCAN IMAGING OF INSPECTION RESULTS. (CONTINUED)

Features and Factors \ Company and Scanner	Krautkramer Branson Hocking ANDSCAN	DuPont CalData Zetec PORTASCAN	ABB Amdata AMAPS	MATEC SONIX HANDI-SCAN
USABILITY				
Ease of Scan for Examiner	[2] Area greater than 1 sq. ft. is very labor intensive	[4] Area greater than 1 sq. ft. is easily done even overhead scans	[4] Area greater than 1 sq. ft. is easily done even overhead scans	[2] Area greater than 1 sq. ft. is very labor intensive
Vertical Obstruction Clearance Needed	**[4] Scanner height plus examiner arm clearance**	**[4] Scanner height plus tilt angle of scanner arm**	**[3] Scanner working distance height**	**[4] Scanner height plus examiner arm clearance**
SOFTWARE				
Ease of Use for Examiner	[4] Easy user menus	[4] Easy user menus	[4] Easy user menus	[4] Easy user menus Single letter select
Ease of Setup Input Parameters	**[4] Icon file menu for easy input parameters**	**[4] Routine user mode easy to define scan**	**[4] Routine user mode easy to define scan**	**[4] Easy setup file input or change on-screen data**
Data Acquisition Characteristics	[4] 8 bit analog input digitizer, 386/20 PC min.	[4] 8 bit digitizer 486/25 PC	[5] 16 bit digitizer 486/33 PC	[4] 8 bit digitizer 386 PC
Image Display Image Aspect Ratio	**[4] Real time 16 colors 1 to 1**	**[5] 256 color/gray scale, 1 to 1**	**[2] Real time 9 colors may not be 1 to 1**	**[2] Real time 16 colors may not be 1 to 1**
Image & Data Processing	[5] Zoom, 3D, TOF, B-scan, new palettes etc.	[5] Zoom, spreadsheet view, 3D, B-scan, etc.	[5] Zoom, differential view, new null point, etc.	[5] Zoom, palette change B-scan, TOF, etc.
Hard Copy	**[5] Yes with print screen software & printer**	**[5] Yes with print screen software & printer**	**[5] Yes with print screen software & printer**	**[5] Yes with print screen software & printer**
Operator Training for Experience Level	[4] 2 to 3 days Level II	[4] 2 to 3 days Level II	[3] 3 to 5 Days Level II	[4] 2 to 3 days Level II
NDI Mode Support Ultrasonic (UT) Eddy Current (ET) Bond Tester	**[5] Any analog output Tested/KB USD 10 Tested/Phasec 3.4 Yes/Test Simulated**	**[5] Any analog output Tested/QuantumQBT Tested/MIZ 22 Yes/Test Simulated**	**[5] Any analog output Tested/ABB PC Card Tested/ABB PC Card Yes/Test Simulated**	**[5] Any analog output Tested/Explorer 9000 Yes/Not Tested Yes/Not Tested**
COST				
Hardware & Software	[4] $40,000 for scanner and software, PC and NDI instrument separate	[3] $50,000 total system UT and software, EC instrument separate	[3] $35,000 one mode sys plus $40,000 for scanner, track and controller	[4] $36,000 for PC,UT cards,scanner, software, EC instrument separate

SUMMARY

Company and Scanner	Krautkramer Branson Hocking ANDSCAN	DuPont CalData Zetec PORTASCAN	ABB Amdata AMAPS	MATEC Sonix HANDI-SCAN
Pros	Handy local area scanner for all geometries, fast coarse scan with fine scan overlap at areas of interest.	Good scanner for local and large areas, little effort required for long inspection times.	Fast large area scanner, 16 bit digitizer allows new EC null for processing images without rescan.	Light weight easy attachment. Can choose min, max, or last data point for real time display.
Cons	Tedious for large area and overhead scans, surface is scratched slightly, tiring for long inspection times	Sensor holder severely scratched aluminum surfaces.	Heavy scanner, two man operation above ground level.	Probe holder inadequate for easy probe articulation. Not easy to fill image area.
Conclusion	Excellent manual scanner for small area ET examinations, but not so easy for UT exams.	Excellent automated and easy to use scanner for most ET and UT inspections.	Very good scanner for large area scans of moderate geometry.	Not readily usable for UT exams but adequate for ET small area inspections.

TABLE 1 - SCANNER EVALUATION MATRIX FOR EDDY CURRENT AND ULTRASONIC C-SCAN IMAGING OF INSPECTION RESULTS. (CONTINUED)

Company and Scanner / Features and Factors	SAIC Ultra Image International ULTRAIMAGE IV	SAIC Ultra Image International ULTRAIMAGE IV	Infometrics MS-XY-2	SmartEDDY Systems SAC GP10
DESIGN				
Basic Design and Scan Motion	[2] Cantilever Arm with rigid X-Y linear motion Manually driven	[3] Cantilever Arm with rigid X-Y linear motion Automated	[3] Tilting Arm Bridge with X-Y linear motion Manual & random	[3] PZT sound microphones con Manual & rando
Mount Type	[4] **Two large suction cups with independent manual vacuum pumps**	[4] **Three suction cups with check valves for parallel vacuum from AC pump**	[3] **Static rubber suction cups without manual vacuum pumps**	[4] **Microphon with small sucti AC vacuum pu**
Probe Holder and Gimbals Design	[3] Adequate but needs improvement	[3] Adequate but needs improvement	[3] Adequate but needs improvement	[5] NA
Couplant Feed UT only, NA for ET	[2] **Spray or wipe on**	[4] **Water flow at transducers**	[2] **Spray or wipe on**	[X] **NA**
Scanner Working Distance Height	[3] Minimum 12 inches	[3] Minimum 12 inches	[4] Minimum 6 inches	[5] Minimum 2
X-Y Axis Resolution	[5] **0.04 inch**	[5] **0.04 inch**	[5] **0.01 inch**	[5] **0.01 inch**
PORTABILITY				
Scanner Weight	[3] 15 lbs	[2] 25 lbs	[4] 5 lbs	[5] 5 ounces
Ruggedness	[3] **Adequate**	[3] **Adequate**	[4] **Good**	[5] **Excellent**
Deployment Ease	[4] Good	[4] Good	[5] Excellent	[5] Excellent
Computer Hardware	[5] **Excellent**	[5] **Excellent**	[5] **Excellent**	[5] **Excellent**
Motor Controller	[X] Not Applicable	[5] Card in PC slot	[X] Not Applicable	[X] Not Applica
ARTICULATION				
Complex Shapes	[3] **Scanner is usable on large flat and moderate dual curvatures that are vertical and under sides**	[3] **Scanner is usable on large flat and moderate dual curvatures that are vertical and under sides**	[3] **Scanner is usable on moderate dual curvatures at vertical sides and under sides**	[5] **Scanner is complex surface protrusions etc., and under sides**
Surface Conditions	[3] No problem over pillowing and lap joints, no raised rivets	[3] No problem over pillowing and lap joints, no raised rivets	[4] No problem over pillowing and lap joints, no raised rivets	[5] No problem pillowing or raise rivets/joints etc
PERFORMANCE				
Speed of Coverage	[2] **2 sq. ft. at 0.1 in. spot size, 30-45 minutes**	[3] **2 sq. ft. at 0.1 in. spot size, 20-30 minutes**	[3] **2 sq. ft. at 0.1 in. spot size, 15-30 minutes**	[3] **2 sq. ft. at size, 15-20 minu**
Accuracy	[4] Within one spot size	[4] Within one spot size	[4] Within one spot size	[4] Within one
Problems encountered during Demonstration	[3] **Sensor mount design did not keep sensor securely in place, PC hung at times**	[3] **Sensor mount design did not keep sensor securely in place**	[3] **Difficult to maintain UT couplant, no choice on max, min data update**	[3] **Conflect of resulted in false positions freque**

TABLE 1 - SCANNER EVALUATION MATRIX FOR EDDY CURRENT AND ULTRASONIC C-SCAN IMAGING OF INSPECTION RESULTS. (CONTINUED)

Company and Scanner / Features and Factors	SAIC Ultra Image International ULTRAIMAGE IV	SAIC Ultra Image International ULTRAIMAGE IV	Infometrics MS-XY-2	SmartEDDY Systems SAC GP10
USABILITY				
Ease of Scan for Examiner	[3] Area greater than 1 sq. ft. is labor intensive	[4] Area greater than 1 sq. ft. is easily done even overhead scans	[2] Area greater than 1 sq. ft. is very labor intensive	[2] Area greater than 1 sq. ft. is very labor intensive
Vertical Obstruction Clearance Needed	[3] Height of scanner plus inspector's body clearance	[4] Height of scanner	[4] Height of scanner and clearance for inspector	[4] Height of scanner and clearance for inspector
SOFTWARE				
Ease of Use for Examiner	[3] User menus	[3] User menus	[4] Easy user menus	[4] Easy user menus
Ease of Setup Input Parameters	[4] Icon file menu for easy input parameters	[3] Software use not easy for scan parameter input	[4] Routine setup files and user defined inputs	[4] Easy setup file input or change on-screen data
Data Acquisition Characteristics	[4] 8 bit digitizer, rf 486/33 PC	[4] 8 bit digitizer, rf 486/25 PC	[4] 8 bit digitizer 386/33 PC	[5] 16 bit digitizer 486/50 PC
Image Display Image Aspect Ratio	[5] Real time 256 colors 1 to 1	[5] Real time 256 colors 1 to 1	[4] Real time 16 colors 1 to 1	[4] Real time 16 colors 1 to 1
Image & Data Processing	[5] Zoom, TOF, 32 gates B-scan, new palettes etc.	[5] Zoom, TOF, 32 gates B-scan, new palettes etc.	[5] Feature extraction if added software	[5] Zoom, etc, options many 16 bit impedance vectors
Hard Copy	[5] Immediate with print screen software & printer	[5] Immediate with print screen software & printer	[5] Immediate with print screen software & printer	[5] Immediate with print screen software & printer
Operator Training for Experience Level	[3] 3-5 days Level II	[3] 3-5 days Level II	[4] 2 Days Level II	[4] 2 days Level II
NDI Mode Support Ultrasonic (UT) Eddy Current (ET) Bond Tester	[5] Any analog output Tested/SAIC UT card Tested/Rohmann(elotest) Yes/Test Simulated	[5] Any analog output Tested/SAIC UT card Yes/Not Tested Yes/Test Simulated	[5] Any analog output Tested/UT ext module Tested/Nortec 19e Yes/Not Tested	[3] Eddy Current Only No Yes No
COST				
Hardware & Software	[3] ~$65,000 minimum for system, extra software $10,000	[3] ~$65,000 minimum for system, extra software $10,000	[4] ~$30,000 system plus $7,000 for scanner,	[4] ~$25,000 for EC PC system and scanner

SUMMARY

Company and Scanner	SAIC Ultra Image International ULTRAIMAGE IV	SAIC Ultra Image International ULTRAIMAGE IV	Infometrics MS-XY-2	SmartEDDY Systems SAC GP10
Pros	Easier to use than random manual scanners; extensive software capability.	Not as labor intensive to operate as manual SAIC scanner; good for long inspection times.	Light weight; easy attachment; intuitive software maneuvering.	Free movement of probe over complex geometries; excellent ET 16 bit data acquisition and display.
Cons	Tedious for large area and overhead scans, need experience to use software effectively.	Probe holder severely scratched surface; probe holder not designed for easy continuous use.	Not easy to fill inspection area; probe holder design not adequate for UT straight beam examinations.	False X-Y positions from triangulation system hinders scanned image coverage.
Conclusion	Adequate for small local area UT & ET scans.	Good scanner possibilities for most inspection purposes with an improved holder.	Good only for small area ET scans.	Excellent for ET scans of complex geometries; tedious for large area scanning.

TABLE 1 - SCANNER EVALUATION MATRIX FOR EDDY CURRENT AND ULTRASONIC C-SCAN IMAGING OF INSPECTION RESULTS. (CONTINUED)

Features and Factors \ Company and Scanner	McDonnell Douglas MAUS III	Panametrics Automated systems MULTISCAN	Sierra Matrix Heads Up Display HU-UTV	Failure Analysis Associates PARIS
DESIGN				
Basic Design and Scan Motion	[4] Hand held manipulater of 1 to 4 oscillating sensors Semi-automated	[2] Rectangular Bridge with rigid X-Y motion Automated	[3] Tilting Tee Bar with X-Y linear motion X axis auto-step, Y random	[4] 2-D Array of 0.25 inch square transducer elements Electronic XY
Mount Type	[4] Scanner is held in place by hand and is moved to and fro to form image	[4] Four independent suction cups with AC vacuum pump	[2] Miniature scanner taped in place, heads up display and backpack PC	[4] RTV Rubber suction blanket with AC vacuum pump
Probe Holder and Gimbals Design	[4] Excellent	[2] Inadequate, needs design improvements	[3] Adequate	[X] NA
Couplant Feed UT only, NA for ET	[2] Spray or wipe on	[4] Water feed or squirted at sensor holder	[2] Spray or wipe on	[5] Spray on water, feed not needed
Scanner Working Distance Height	[4] Minimum 10 inches	[3] Minimum 15 inches	[4] Minimum 6 inches	[5] Minimum 1 inch
X-Y Axis Resolution	[5] 0.04 inch	[5] 0.01 inch	[5] 0.05 inch	[3] 0.25 inch
PORTABILITY				
Scanner Weight	[4] 3 lbs	[2] over 25 lbs	[4] 5 lbs	[5] 1 lb
Ruggedness	[5] Excellent	[5] Excellent	[5] Excellent	[5] Excellent
Deployment Ease	[5] Excellent	[4] Good	[3] Adequate	[5] Excellent
Computer Hardware	[5] Portable work station	[3] Rack mounted chasis	[5] Back Pack PC	[5] Excellent
Motor Controller	[5] Card in mainframe	[3] Rack mounted	[5] In back pack worn by user	[X] Not Applicable
ARTICULATION				
Complex Shapes	[4] Scanner is usable on flat and moderate dual curvatures that are horizontal vertical or overhead	[3] Scanner is usable only on flat or slightly curved surfaces, can be mounted on vertical sides and overhead	[3] Scanner is usable only on small flat and moderate curvatures, horizontal, vertical, and overhead	[4] Scanner is usable on flat and curvatures up to 1 foot radius, horizontal, vertical, or overhead
Surface Conditions	[3] No problem over waviness (pillowing) or raised joints and edges	[3] Sensor holder was not designed for pillowing in surface no problem for squirter	[4] Slight problem over pillowing and corrosion pits etc.	[3] Scanner can not operate over raised rivets, raised joints need to be filled at vacuum seal
PERFORMANCE				
Speed of Coverage	[4] 2 sq. ft. at 0.1 in. spot size, 10-15 minutes	[4] 2 sq. ft. at 0.1 in. spot size, 10-15 minutes	[2] 2 sq. ft. at 0.1 in. spot size, over 45 minutes	[3] 2 sq. ft. at 0.25 in. spot size, 15 -30 minutes
Accuracy	[4] Within one spot size	[4] Within one spot size	[4] Within one spot size	[3] 0.25 inch
Problems encountered during Demonstration	[3] Longitudinal encoder wheels slipped on wet UT couplant on aluminum surface	[3] Probe was not held firm against curved surface at all times	[3] Consistent transducer couplant was not achieved with gel or water	[4] Initiating vacuum seal was not immediate in some cases for the array blanket

TABLE 1 - SCANNER EVALUATION MATRIX FOR EDDY CURRENT AND ULTRASONIC C-SCAN IMAGING OF INSPECTION RESULTS. (CONCLUDED)

Features and Factors \ Company and Scanner	McDonnell Douglas MAUS III	Panametrics Automated systems MULTISCAN	Sierra Matrix HF-UTV	Failure Analysis Associates PARIS
USABILITY				
Ease of Scan for Examiner	[2] Area greater than 1 sq. ft. is easily inspected, but overhead usage is tedious	[4] Area greater than 1 sq. ft. could be done with squirter technology	[2] Area greater than 1 sq. ft. is very labor intensive	[4] Area greater than 1 sq. ft. is easily done
Vertical Obstruction Clearance Needed	[3] Height of scanner and clearance for inspector	[4] Height of scanner	[4] Height of scanner and clearance for inspector	[5] Height of scanner
SOFTWARE				
Ease of Use for Examiner	[4] Easy window user menus	[3] Window menus not as easy to use as possible	[3] Window menus not as easy to use as possible	[5] Easy user menus with function keys operation
Ease of Setup Input Parameters	[4] Easy setup menu and recall user files	[4] Software use needs training, macros eases its use	[4] Easy setup file input or change on-screen data	[4] Easy setup file input or change on-screen data
Data Acquisition Characteristics	[4] 8 bit digitizer Unix operating system	[4] 8 bit 400 MHz digitizer n, 486/33 PC	[4] 8 bit 64 MHz digitizer n 486/25 PC	[4] 8 bit 100 MHz ADC n 486/33 PC
Image Display Image Aspect Ratio	[4] Real time 16 colors 1 to 1	[5] 256 color, multi-window 1 to 1	[1] Real time, monochrome 1 to 1	[4] Real time 16 levels 1 to 1
Image & Data Processing	[5] TOF, phase,Framaker to make montage of scans	[5] Zoom, B-scan, A-scan TOF, new palletes, etc.	[4] C-scan, B-scan images analysed aft rf data scan	[5] A-,B-,C-scan, 3-D TOF, waveform averaging
Hard Copy	[4] Only after data set is post analysed	[5] Immediate with print screen software & printer	[4] Only after data set is post analysed	[5] Immediate with print screen software & printer
Operator Training for Experience Level	[3] 5 days Level II	[3] 3 to 5 days Level II	[4] 2 Days Level II	[4] 2 days Level II
NDI Mode Support Ultrasonic (UT) Eddy Current (ET) Bond Tester	[5] UT, ET, Bond test Tested/MCAIR card Tested/MCAIR card Tested/MCAIR card	[5] UT only Tested/Panametrics Yes/Not Tested Yes/Not Tested	[5] UT or ET Tested/Sierra Matrix Yes/Not Tested Yes/Not Tested	[3] UT only Tested/PARIS No No
COST				
Hardware & Software	[2] ~ $140,000 for one mode $156,000 all three modes	[3] ~$50,000 total system UT scanner and software	[2] ~$125,000 UT system and scanner	[3] ~65,000 total system Array and software

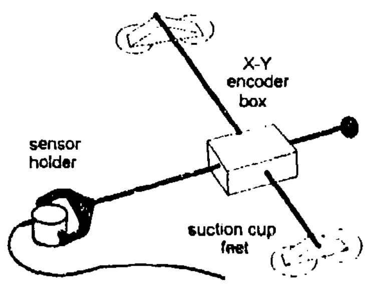
SUMMARY

Company and Scanner	McDonnell Douglas MAUS III	Panametrics Automated systems MULTISCAN	Sierra Matrix HF-UTV	Failure Analysis Associates PARIS
Pros	Handy and fast local area scanner for flat and moderate curvatures, very effective for composite UT inspections.	Very comprehensive and superior data acquisition and display system for squirter technology.	Very portable compact system. Can work in small area and move quickly between new locations.	Very good scanner for smooth surfaces ~ 1 foot radius, excellent thickness resolution with PVDF 7MHz transducers.
Cons	Tedious and heavy for overhead use, aluminum surface is scratched; expensive.	Scanner is heavy; versitility limited for aging aircraft applications of portable systems.	Heads up display did not improve scanning capabilities for C-scan imaging for aircraft; expensive.	Cannot be used on surfaces with raised rivets etc.
Conclusion	A very effective scanner for fast multi-mode inspections; very good for composites, and repair patch evaluation.	Portable squirter system not immediately useful for aging aircraft inspections.	Useful inspection tool for A-scan inspection in remote areas; no added value for C-scans.	Very useful scanner for composites characterization and composite repair patch assessment.

Appendix A
Scanner Descriptions

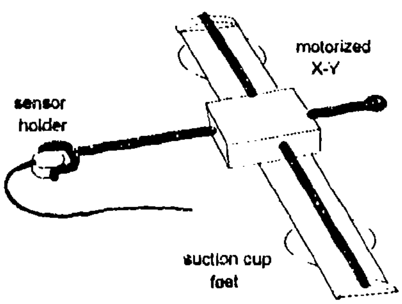
A sketch and brief description of the functionality of each type of scanner design, the method of physical attachment to the aircraft, and companies that support the design type is provided below.

1. Dual Axis Tilting Arm and Bridge Manual Scanner



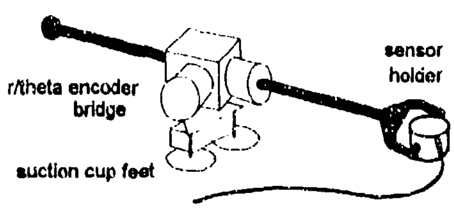
Functionality: Manual random motion in X and Y directions or lock one axis and linear motion in the other axis. The sensor is attached to a gimbals that is hand held against the surface of the part to be scanned.
Attachment: Rubber suction cup feet and/or tape
Companies: Matec/SONIX, Infometrics, Sierra Matrix, Physical Acoustics, Nuson, ABB Amdata, DuPont.

2. Dual Axis Tilting Arm and Bridge Automated Scanner



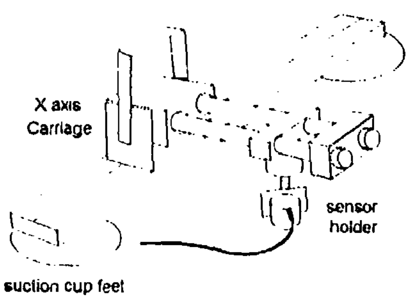
Functionality: Stepping motor control in X and Y directions with one axis as a step axis and the other as a linear fast scan axis. Tilting arm is spring loaded to keep the sensor firmly against the surface to be scanned. The sensor is attached to a gimbals and kept perpendicular to the surface.
Attachment: Three rubber suction cup feet with independent hand vacuum pumps.
Companies: DuPont/CalData.

3. Radial Axis Tilting Arm with Rotation Axis Bridge Manual Scanner



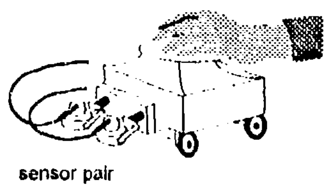
Functionality: Manual random motion in radial and angular directions, either axis can be locked. The sensor is attached to a hand held gimbals and held firmly against the surface to be scanned.
Attachment: Rubber suction cup feet with independent hand or AC vacuum pump.
Companies: Krautkramer Branson, Tecrad, Systems Research Laboratories (Tilting arm replaced by articulated arm).

4. Dual Axis Cantilever Arm Bridge Manual or Automated Scanner



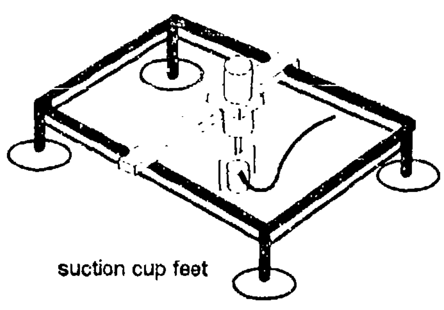
Functionality: Step in X direction and manual or automated scan in Y direction. Step axis consisting of a carriage holding the rigid Y axis arm cantilevered over the area of interest. X axis guide can be rigid or flexible and of long length. For some designs, sections can be butted together for automated scans of extremely long distances. X axis carriage is attached mechanically to the guide or held in place with magnetic wheels on a steel flexible track. Sensor holder is in a gimbals and spring or hydraulically loaded against the scanning surface.
Attachment: Rubber suction cup feet with hand or AC vacuum pump.
Companies: SAIC, ABB Amdata, Tecrad.

5. Mobile Automated Ultrasonic Scanner



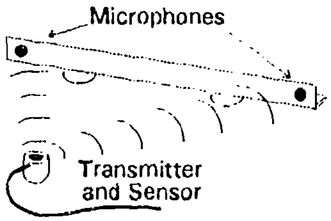
Functionality: Automated oscillating linear motion of multiple sensors in the Y axis and manual to or fro motion in the X axis.
Attachment: Scanner carriage is hand held to the surface to be scanned.
Companies: McDonnell Douglas.

6. Dual Axis Rectangular Bridge Automated Scanner



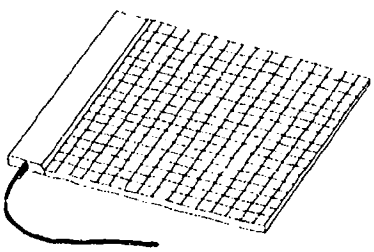
Functionality: Step or fast motorized motion in X or Y directions. Sensor holder is fixed to motorized Y bridge and spring loaded against the surface to be scanned.
Attachment: Rubber suction cup feet with AC vacuum pump.
Companies: Panametrics, Xactex

7. Hands Free X-Y Digitizer



Functionality: X-Y digitizing by acoustic triangulation system or LED Video system. Hands-free random manual motion in X or Y directions. Sensor holder is held in the hand and the high frequency acoustic source or LED is attached to the holder. A pair of microphones attached to a bar is placed in front of the area to be scanned or the video camera is placed above the area to be scanned.
Attachment: Microphones are on a bar that is attached by rubber suction cup feet to the surface to be scanned.
Companies: SE Systems, Inc.(acoustic), Sonomatic Inc.(LED)

8. 2-D Square Transducer Array



8-inch square array
in vacuum blanket

Functionality: Electronic switching between small transducer elements of the 2-D square transducer array arranged in a flexible rubber sheet.
Attachment: Suction to the surface with a vacuum blanket and AC pump.
Companies: Failure Analysis Associates.

Appendix B
List of Vendors Who Participated in the Demonstrations

KRAUTKRAMER BRANSON / HOCKING

Eddy Current Test	Dave Jankowski Krautkramer Branson, Inc. 50 Industrial Park Road Lewistown, PA 17044	Paul Martin Wells Krautkramer Milburn Hill Road University of Warwick Science Park Coventry CV4 7HS UK
Ultrasonic Test	Terry Battema Krautkramer Branson, Inc. 11503 Springfield Pike Cincinnati, OH 45246-3550	

DUPONT / CALDATA / ZETEC

Eddy Current Test Ultrasonic Test	Kim Kober DuPont NDT Systems 15751 Graham Street Huntington Beach, CA 92649
Sales Representative	Jerry Scott Energy Equipment Sales 73 West Ranch Trail Morrison, CO 80465

ABB AMDATA

Eddy Current Test Ultrasonic Test	Mark W. Kirby ABB Amdata Inc. 1000 Day Hill Road Windsor, CT 06095
Sales Representative	Karl Kuchling ABB Amdata Inc. P.O. Box 701127 San Antonio, TX 78270-1127

MATEC / SONIX

Ultrasonic Test	Charles J. Bushman, Jr Matec Instruments, Inc. 75 South Street Hopkinton, MA 01748	Gregory L. Piller Sonix 8700 Morrissette Drive Springfield, VA 22152

Sales Representative — Ev Westfahl
Westfahl and Associates
6101 Marble NE #4
Albuquerque, NM 87110

SAIC ULTRAIMAGE INTERNATIONAL

Ultrasonic Test — Robert H. Grills
SAIC
Two Shaw's Cove, Suite101
New London, CT 06320

Eddy Current Test / Marketing Consultant — Raymond A. Zickus
16 Marlowe Road
Nashua, NH 03062

INFOMETRICS

Ultrasonic Test / Eddy Current Test — Anthony N. Mucciardi
Infometrics
814 Thayer Avenue, Suite 350
Silver Spring, MD 20910

SMARTEDDY SYSTEMS

Eddy current Test — Duane P. Johnson
SE Systems, Inc.
26203 Production Avenue , Suite 10
Hayward, CA 94545

Sales Representative — Ernie Vandergrief
Stroud Sales Co., Inc.
680 Grapevine Hwy, Suite 24
Hurst, TX 76054

McDONNELL DOUGLAS

Ultrasonic Test / Eddy Current Test — Nancy L. Wood
McDonnell Douglas Aircraft Company
Mailcode 1021111
P.O. Box 516
Saint Louis, MO 63166-0516

PANAMETRICS

Ultrasonic Test

Thomas E. Michaels
Panametrics
102 Langmuir Lab
95 Brown Road
Ithaca, NY 14850

SIERRA MATRIX

Ultrasonic Test

Marvin F. Fleming
Sierra Matrix, Inc.
48890 Milmont Drive,
Ste 105D
Fremont, CA 94538

John Carruthers
Sierra Matrix, Inc.
48890 Milmont Drive,
Ste 105D
Fremont, CA 94538

FAILURES ANALYSIS ASSOCIATES

Ultrasonic Test

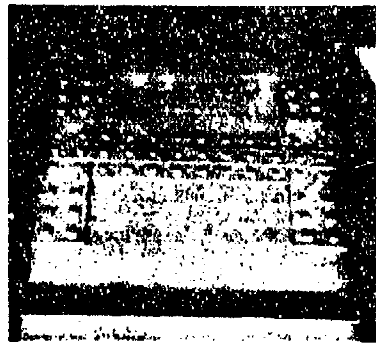
Tim Harrington
Failure Analysis Associates, Inc.
8411 154th Avenue, NE
Redmond. WA 98052

Tom Davis
Failure Analysis Associates, Inc.
8411 154th Avenue, NE
Redmond. WA 98052

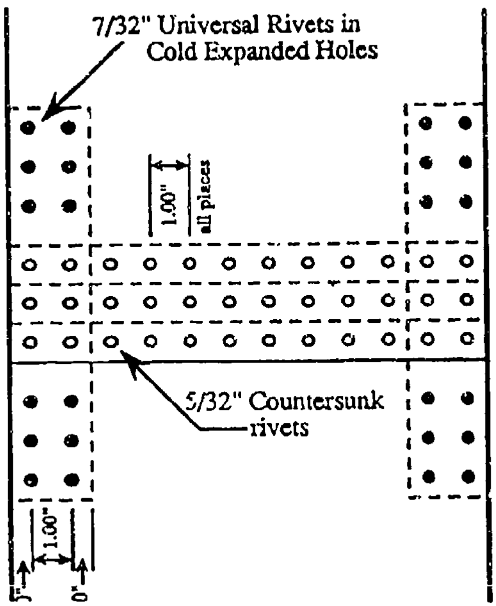
Appendix C
AANC Aircraft Sample Descriptions

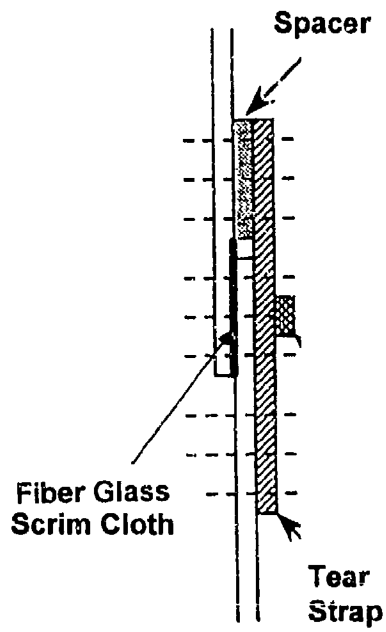
1. A. D. Little Aluminum Lap Splice Joint Samples (AANC Test Specimen Library Numbers 115 through 122)

Front View



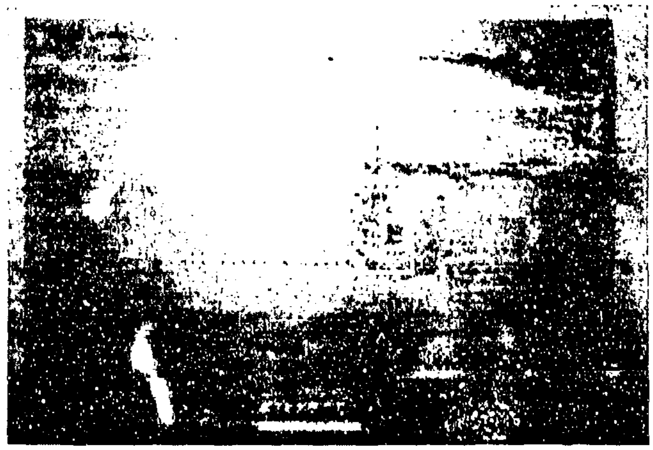
Back View





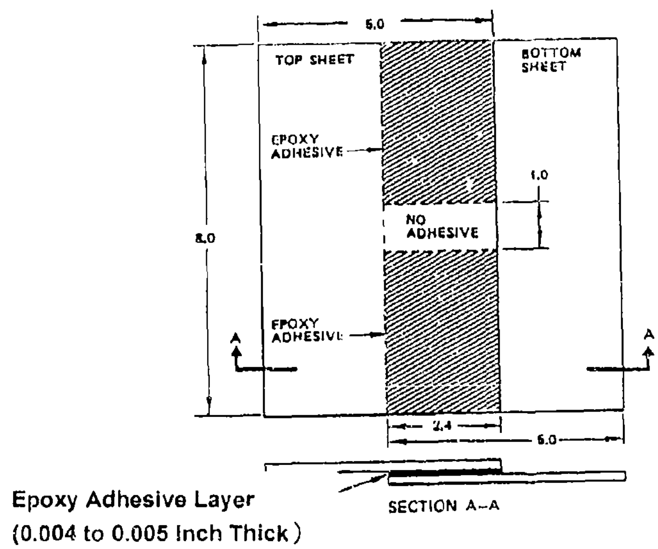
The test panel was fabricated with 0.040 inch thick 2024-T3 sheet aluminum. Panel was in a hot water quench material for 55 days for which approximately 0.008 inch depth of intergranular corrosion attack would occur.

2. Large 0.07 Inch Thickness Aluminum Panel (AANC Test Specimen Library Number 111)



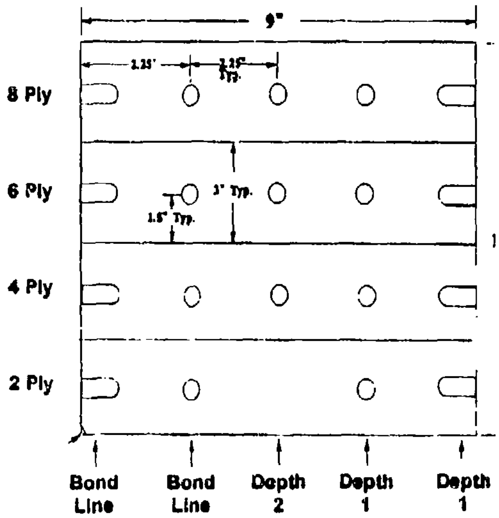
This actual aircraft aluminum panel 0.07 inch thick shows areas of pillowing and corrosion around the middle section of the panel. Scanner tests were performed at the 8 inch square section indicated.

3. Tear Strap Disbond Calibration Samples (AANC Test Specimen Library Numbers 183 through 185)

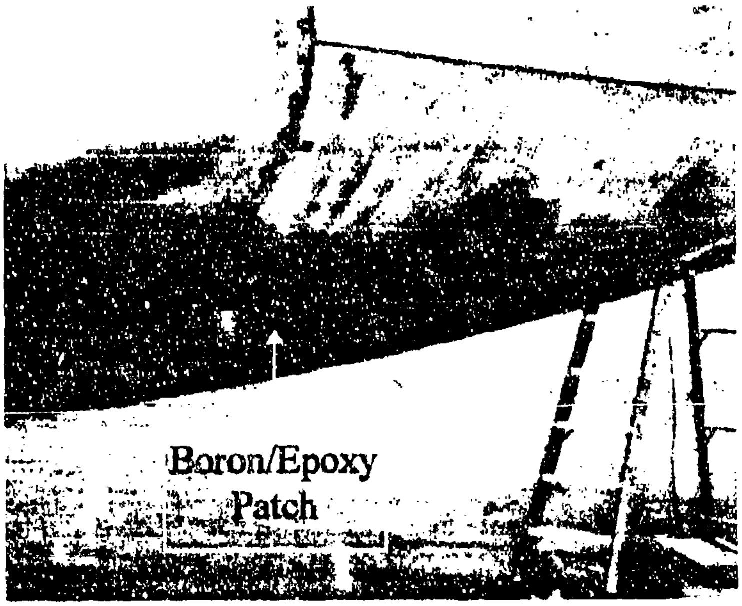


Aluminum sheets 2024-T3. Dimensions are in inches. Top sheet is 0.040 inch, 0.050 inch, 0.070 inch. Bottom sheet is 0.070 inch.

4. Boron/Epoxy Composite Repair Patches (AANC Test Specimen Library Number 152)



Boron epoxy doubler ultrasonic reference standard showing 2 ply, 4 ply, 6 ply and 8 ply sections on a curved aluminum skin. Teflon implants (0.005 inch thick x 0.5 inch diameter disks) are placed at the bond line and at interfaces between the plies. Pull tabs (0.5 inch wide x 0.75 inch long) were place at the bond line at the left and right edges of each ply. The area of the four plies is 9 inches wide and 12 inches high.



Octagonal shaped boron epoxy patch applied to the skin of the B737 airplane aft of the wing on the left side of the airplane.

5. B737 Airplane Locations (AANC Test Specimen Library Number 100)

The full scale B737 aircraft was received by AANC on October 9, 1992. The aircraft is being used as a commercial transport aircraft test specimen that provides a means to assess human factors issues, accessibility issues, and hangar environment for evaluating NDI inspection requirements.

Aircraft Model:	737-222
Date of Manufacture:	July 1968
Airframe Total Hours:	38,342
Airframe Total Cycles:	46,358

Appendix D
Evaluation Matrix Features and Factors Ranking Criteria

The ranking of the features and factors of the scanner systems listed below used the general criteria for assigning numbers from 1 to 5;

Rank	Explanation
1	Not applicable for aircraft applications
2	Limited for aircraft applications
3	Adequate but could be improved for aircraft applications
4	Good, generally applicable for aircraft applications
5	Ideal, meets all requirements for aircraft applications

Specific features and factors in the Evaluation Matrix Table were ranked with the following criteria:

Feature	Rank	Explanation
DESIGN		
Basic		General functionality for easy scan coverage of area of interest
Design	1	Not applicable for aircraft applications
	2	Limited for aircraft applications
	3	Adequate but could be improved for aircraft applications
	4	Good, generally applicable for aircraft applications
	5	Ideal, meets all requirements for aircraft applications
Mount		Implementation, relocation ease, stability
Type	1	Not stable, fails often during scan
	2	Fails occasionally during scan
	3	Adequate but could be improved for aircraft applications
	4	Good, generally applicable for aircraft applications
	5	Ideal, meets all requirements for aircraft applications
Sensor Holder,		Ability to accommodate various sensor sizes and maintain
Gimbals		sensor perpendicularity
Design	1	Not applicable for aircraft applications
	2	Limited for aircraft applications
	3	Adequate but could be improved for aircraft applications
	4	Good, generally applicable for aircraft applications
	5	Ideal, meets all requirements for aircraft applications
Couplant		Ultrasonic pulse-echo or resonance testing only
Feed	1	Not applicable for aircraft applications
	2	Limited, couplant sprayed or wiped on
	3	Adequate but could be improved by better design
	4	Good, automatic feed with few problems
	5	Ideal, automatic feed with no problems

Scanner Working Distance Height		Distance needed to scan between vertical obstruction and aircraft
	1	Greater than 48 inches
	2	Between 24 and 48 inches
	3	Between 12 and 24 inches
	4	Between 6 and 12 inches
	5	Less than 6 inches
X-Y Axis Resolution	1	Greater than 0.50 inch
	2	Between 0.35 to 0.50 inch
	3	Between 0.20 to 0.35 inch
	4	Between 0.05 to 0.20 inch
	5	Between 0.01 to 0.05 inch

PORTABILITY

Scanner Weight	1	Over 30 pounds
	2	Between 15 to 30 pounds
	3	Between 5 to 15 pounds
	4	Between 1 to 5 pounds
	5	Under 1 pound
Ruggedness		General use of scanner without failure of machanical components
	1	Not applicable for aircraft applications
	2	Limited for aircraft applications
	3	Adequate but could be improved for aircraft applications
	4	Good. generally applicable for aircraft applications
	5	Ideal, meets all requirements for aircraft applications
Deployment Ease		Time from off the shelf to start of scan or relocation
	1	Greater than 1 hour
	2	Between 30 to 60 minutes
	3	Between 15 to 30 minutes, 5 minutes relocation
	4	Between 10 to 15 minutes, 2 minutes relocation
	5	Under 10 minutes, 1 minute relocation
Computer Hardware		Portability of total system, scanner, computer, motor controller etc.
	1	System components greater than 100 pounds
	2	System components greater than 50 pounds
	3	System components between 25 and 50 pounds
	4	System components between 10 and 25 pounds
	5	System components less than 10 pounds
Motor Controller		Physical size and weight considerations
	1	Not applicable for aircraft applications
	2	Limited for aircraft applications
	3	Adequate but could be improved for aircraft applications
	4	Good, generally applicable for aircraft applications
	5	Ideal, meets all requirements for aircraft applications

ARTICULATION		
Complex Shapes		Scanner is usable on curvatures and irregular shapes
	1	Scanner can only be used on flat surfaces
	2	Scanner can only be used on curvatures greater than 10 feet radius
	3	Scanner can only be used on curvatures greater than 5 feet radius
	4	Scanner can be used on compound curvatures greater than 1 foot radius
	5	Scanner can be used on all aircraft structures
Surface Conditions		Surface roughness, obstructions, raised rivets, raised lap joints
	1	Scanner operates on smooth surfaces only
	2	Scanner cannot operate over lap joints
	3	Scanner can operate over or around lap joints but not raised rivets
	4	Scanner can operate over or around raised rivets
	5	Scanner can accommodate all conditions
PERFORMANCE		
Speed of coverage		Time to scan 2 square foot area on fuselage
	1	Greater than one hour
	2	Between 30 to 60 minutes
	3	Between 15 to 30 minutes
	4	Between 5 to 15 minutes
	5	Less than 5 minutes
Accuracy		Scanner sensor location with respect to increment spot size (0.1 inch)
	1	Over 5 spot sizes (greater than 0.5 inch)
	2	5 spot sizes (0.5 inch)
	3	2 spot sizes (0.2 inch)
	4	1 spot size (0.1 inch)
	5	Less than one spot size (< 0.1 inch)
Problems		Factors that limit use of the scanner for some applications
	1	Numerous and serious for aircraft applications
	2	Serious but can be remedied for aircraft applications
	3	Annoying but can be improved for aircraft applications
	4	Minor
	5	None
USABILITY		
Ease of Scan for Examiner		Operator effort to scan an area greater than 1 square foot
	1	Effort not tolerable for aircraft applications
	2	Effort is tiring, tedious, but tolerable
	3	Effort requires continuous operator attention, labor intensive
	4	Effort requires occasional operator attention, not labor intensive
	5	Effort is not required

Vertical Obstruction Clearance Needed		<u>Clearance needed to operate the scanner with the examiner conducting the scanner.</u>
	1	Greater than 48 inches
	2	Between 24 to 48 inches
	3	Between 12 to 24 inches
	4	Between 6 to 12 inches
	5	Less than 6 inches

<u>SOFTWARE</u>

Ease of Use for Examiner		<u>Experience and intuitive operation of software execution of commands</u>
	1	Difficult to execute, need to remember steps, commands etc.
	2	Steps are not clear and confusing
	3	Adequate but need to remember some commands
	4	Good, generally needs 1 day of training
	5	Very intuitive, self explanatory steps to follow
Ease of Setup Input Parameters		<u>Examiner ease to define scan area, scan limits, scan increments file names etc</u>
	1	Difficult, need to run different programs etc.
	2	Separate programs for scanner and image construction
	3	All input parameters must be typed in from key board
	4	Good, default values easy to change at graphical user interface
	5	Ideal, macros, values easy to change as desired
Data Acquisition Characteristics		<u>Fast, high resolution data acquisition capabilities</u>
	1	Not applicable for aircraft applications
	2	Less than 8 bit resolution
	3	8 bit resolution, 286 PC or equivalent CPU
	4	8 bit resolution, 386 PC or equivalent CPU
	5	16 bit resolution, 486 PC or equivalent CPU
Image Display		<u>Large screen, 16 color palette or better, proportional XY image</u>
	1	Monochrome screen
	2	8 color palette, image XY not proportional, 10 inch or less screen
	3	8 color palette, image XY proportional but small, 10 inch or less screen
	4	16 color palette, image XY proportional, large screen
	5	256 color palette, image XY proportional and large, 15 inch screen
Imaging and Data Processing		<u>Advanced image processing features was not rated, the system</u> real-time C-scan imaging capabilities were ranked
	1	No real-time C-scan image
	4	Real-time image but post processing necessary for final image
	5	Real-time image for immediate interpretation of results
Hard Copy Capability		<u>Ability to provide immediate hard color copy of results</u>
	1	No hard copy capability
	4	Hard copy only after data and image processing
	5	Immediate hard copy capability

Operator Training for Experience Level		Training for ASNT Level recommended by vendor when system is procured
	1	Greater than two weeks for experienced Level II
	2	2 weeks for Level II, or Level III
	3	3 to 5 days for Level II or Level III
	4	2 to 3 days for Level II or Level III
	5	1 to 2 days for Level II or Level III
NDI Mode Support		Modes supported can be eddy current, ultrasonic pulse-echo, and resonance bond testing
	3	Only one mode supported
	4	Two modes supported
	5	Three Modes supported
COST		
Cost Hardware & Software	1	Over $200,000
	2	Between $100,000 and $200,000
	3	Between $50,000 and $100,000
	4	Between $25,000 and $50,000
	5	Less than $25,000

Appendix E
Examples of C-scan Images

C-scan images of the inspection data for the eddy current and the ultrasonic examinations taken during the vendor demonstrations are illustrated.

A. Eddy Current C-scan Images

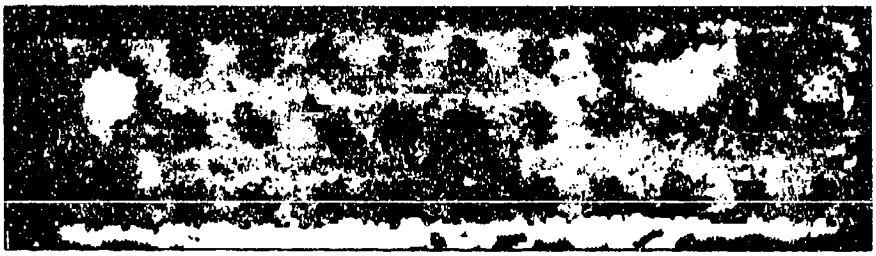
1. A. D. Little Splice Joint Samples

The eddy current inspection data c^f the one foot length lap splice joint samples are illustrated. The first sample is a reference sample that contained no corrosion and only one image of this sample is shown as a comparison with the second sample containing corrosion. C-scan images of the second sample which contained intergranular corrosion in localized areas of approximately 0.007 inch depth are shown for all scanners used in the eddy current demonstrations. There is no visual evidence of corrosion seen in the second sample.

Reference Sample, 0.040 inch thickness with no corrosion

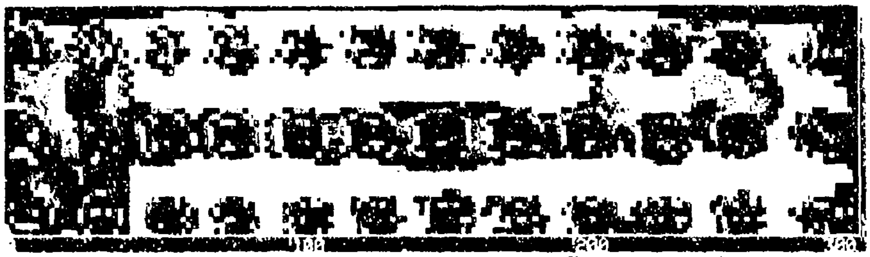
Krautkramer, Branson, Hocking manual scanner. No corrosion is shown.

Intergranular Corrosion Sample, 0.040 inch thickness with ~ 0.007 inch depth corrosion

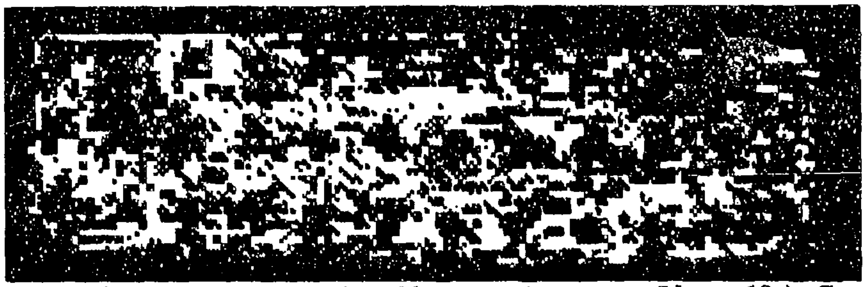


Krautkramer, Branson, Hocking manual scanner. Corrosion is shown in orange and white

DuPont, CalData, Zetec automated scanner. Corrosion is shown in black and yellow

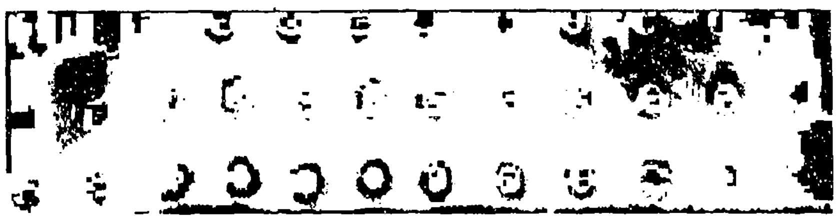


SAIC Ultra Image International manual scanner. Corrosion is shown in orange, yellow, and green.



Infometrics manual scanner with eddy current instrument (Nortec 19e). Corrosion is shown in yellow, green, and red.

SmartEDDY manual scanner. Corrosion is shown in green and dark blue.

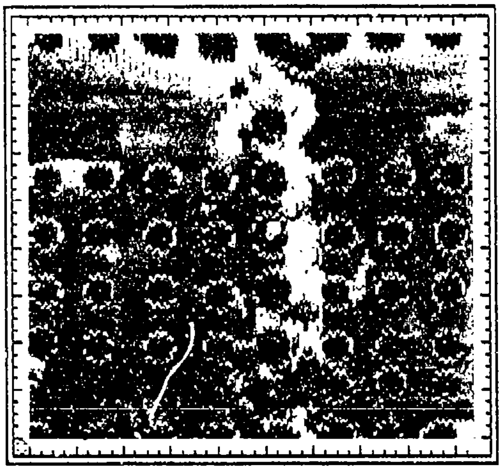


McDonnell Douglas semi-automatic scanner. Corrosion is shown in orange and red.

2. Large 0.07 Inch Thickness Panel

The eddy current inspection data of an eight inch square section of the panel is illustrated for four of the scanners. The corrosion displayed was due to exfoliation with a reduction in thickness of approximately 0.005 inches. Extensive pillowing of the panel surface between the rivet locations was also present.

Krautkramer Branson image of the corrosion shown in orange and white.



Dupont image of the corrosion shown in yellow.

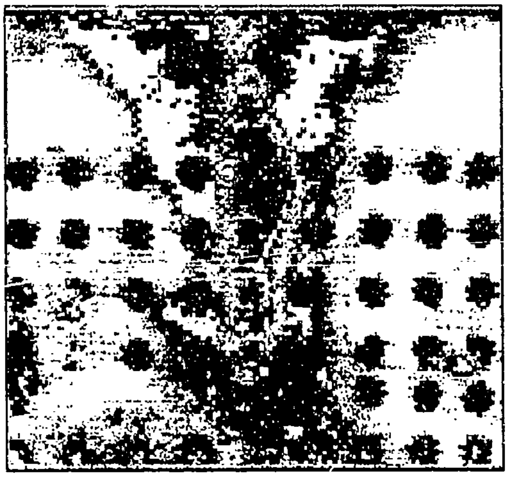
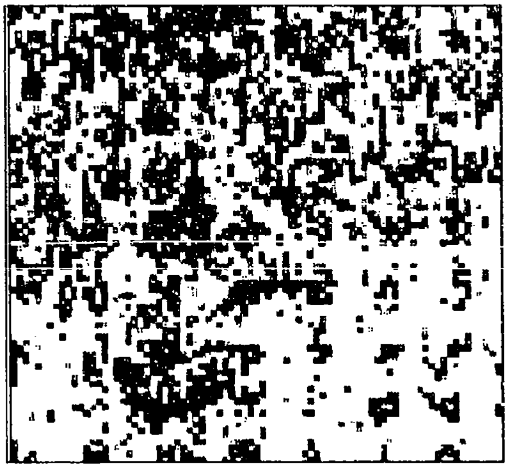


ABB Amdata image of the corrosion shown in orange, yellow, and dark blue.

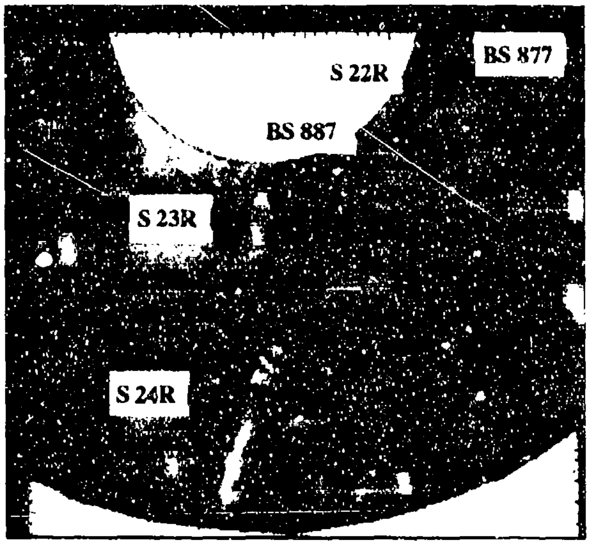


Infometrics image of the corrosion shown in green, yellow, and red.

3.B737 Airplane Locations

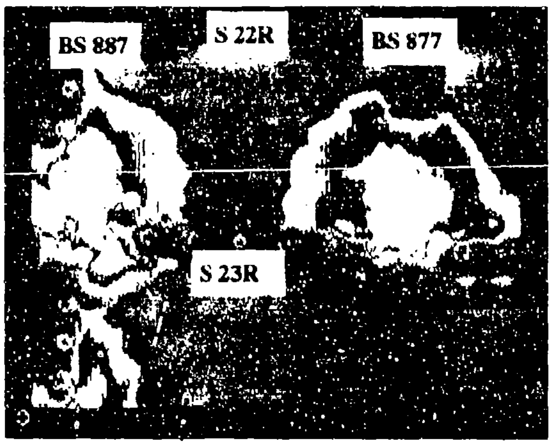
The following illustrations show the physical attachment of the scanners on the B737 airplane and the resultant C-scan eddy current inspection images obtained during the demonstrations.

Krautkramer, Branson, Hocking with Paul Martin articulating the manual scanner.



Corrosion is shown in orange arround BS 877 and BS 887.

DuPont, CalData, Zetec with Kim Kober adjusting the automated scanner.



Corrosion is shown in areas around BS 877 and BS 887.

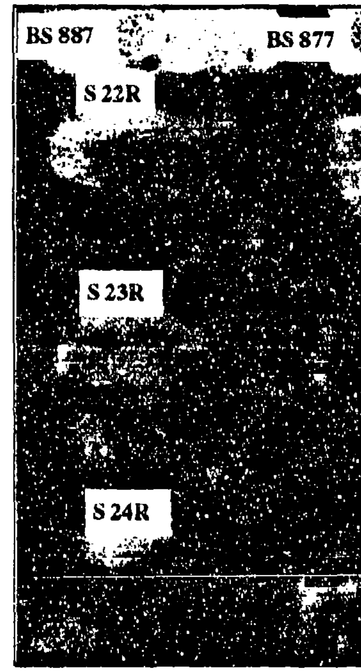
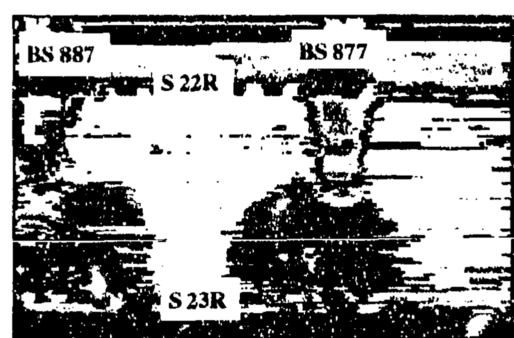


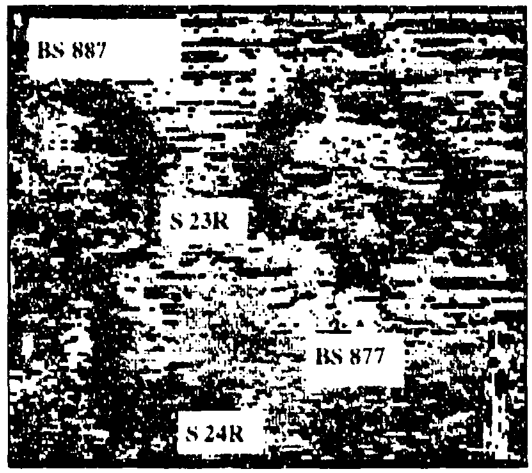
ABB Amdata automated scanner attached to the B737 at BS 877. The C-scan eddy current image for BS 877 and BS 887 is shown to the right where corrosion is shown in red and dark blue.



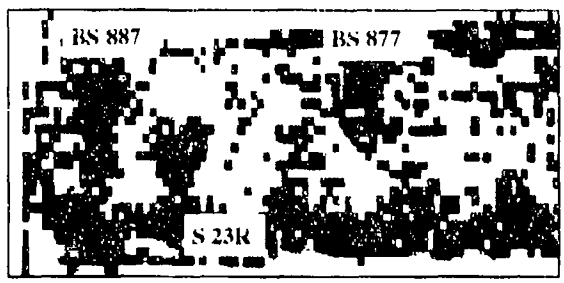
SAIC manual scanner at BS 887 with Raymond Zickus articulating the scanner.

Corrosion is shown in dark blue around BS 877 and BS 887.

Infometrics manual scanner attached to the B737 at BS 877. The C-scan eddy current image for BS 877 and BS 887 is shown to the right where corrosion is indicated in light green and yellow.

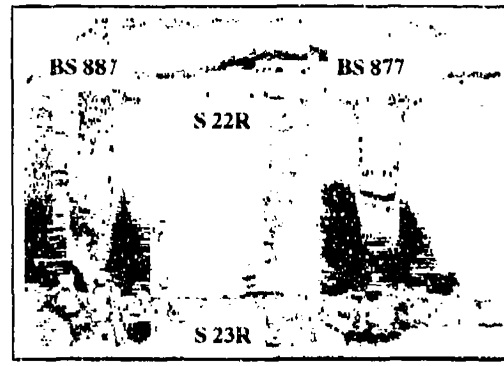


Black areas in the image are due to missing data characteristic of labor intensive manual scanning when insufficient time is taken to cover all data points.



SmartEDDY Systems acoustic triangulation manual scanner shown at left is being articulated by Duane Johnson to obtain the above C-scan image at BS 877 and 887. Corrosion is shown in dark green and yellow.

McDonnell Douglas with Nancy Wood articulating the MAUS III scanner.



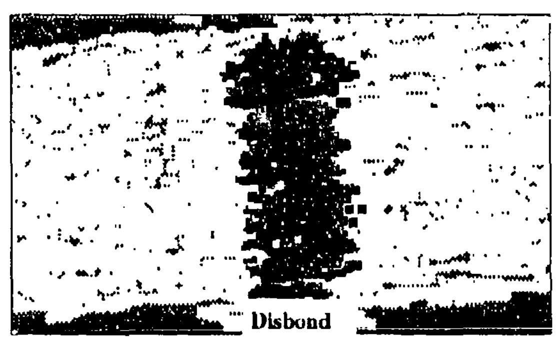
Corrosion is shown in magenta and blue around BS 877 and BS 887.

B. Ultrasonic C-scan Images

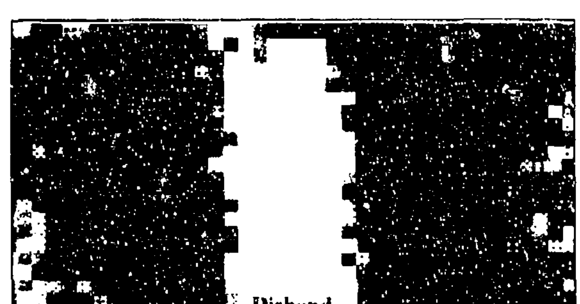
1. Tear Strap Disbond Samples

Three ultrasonic C-scan images are illustrated for the tear strap disbond calibration samples.

Krautkramer, Branson manual scanner image of the disbond calibration sample. The disbond area is shown in dark blue (no adhesive) and the bonded area is shown in light blue (epoxy adhesive).



Infometrics manual scanner image of the disbond calibration sample. The disbond area is shown in white (no adhesive) and the bonded area is shown in dark blue (epoxy adhesive).

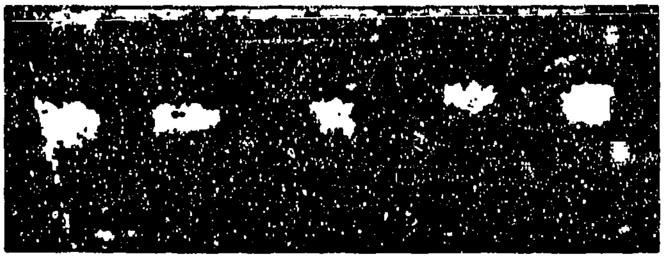


Panametrics automated scanner image of the disbond calibration sample. The disbond area is shown in dark blue (no adhesive) and the bonded area is shown in light blue (epoxy adhesive).

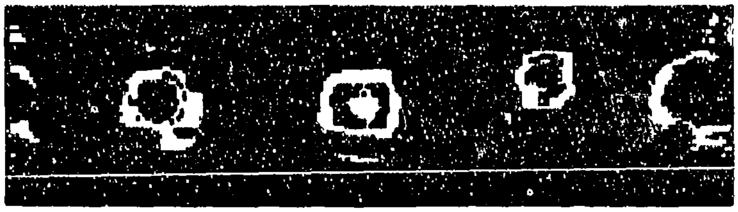
2. Boron/Epoxy Composite Repair Patches

Five ultrasonic C-scan images are illustrated showing defects in the Textron boron/epoxy repair patch sample.

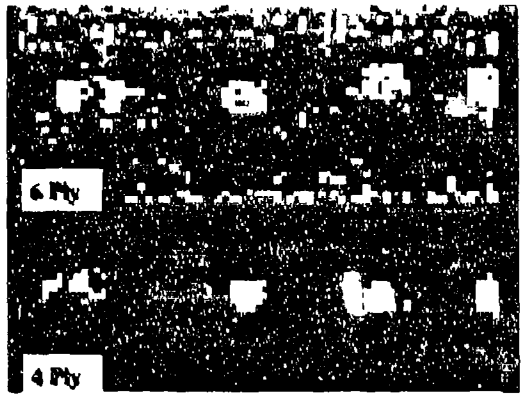
Kraukramer Branson manual scanner image of defects in the six ply region of the sample. The defects are shown in yellow.



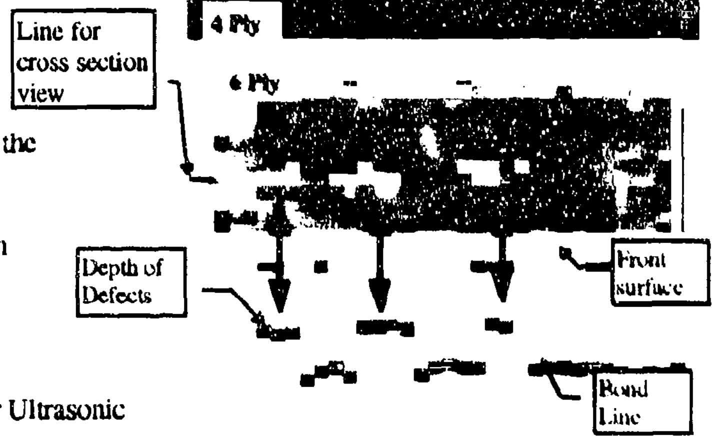
SAIC manual scanner image of the defects in the six ply region of the sample. The defects are in yellow and red.



Infometrics manual scanner image of the defects in the six ply region of the sample. The defects are in yellow.



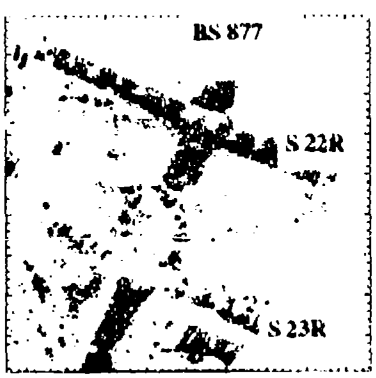
Panametrics automated scanner image of the four and six ply regions of the sample. The defects are in yellow.



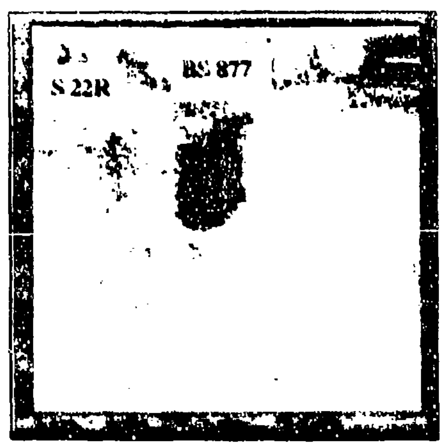
Failure Analysis array image of the 6 ply region of the sample. The cross section view of the data across the flaws shows the depth resolution acheived with the array transducers.

3. B737 Airplane Locations for Ultrasonic Demonstrations

With the same physical attachment shown above for the Krautkramer Branson scanner, the DuPont scanner, and the ABB Amdata scanner, the following ultrasonic C-scan images were obtained for the B737 aircraft locations BS 877 between stringers S22R and S23R.



Krautkramer Branson manual ultrasonic C-scan image showing corrosion in yellow. Gray area in the image is missing data due to labor intensive manual scanning when insufficient time is taken to cover all data points.



DuPont automated ultrasonic C-scan image showing a tear strap disbond at BS 877 in dark blue.

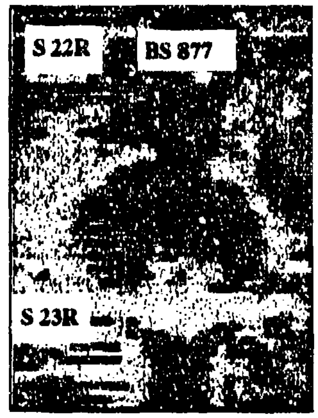
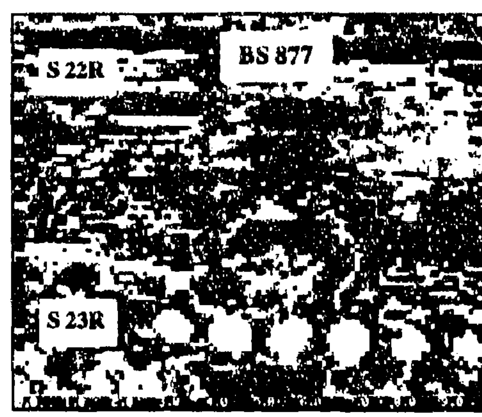


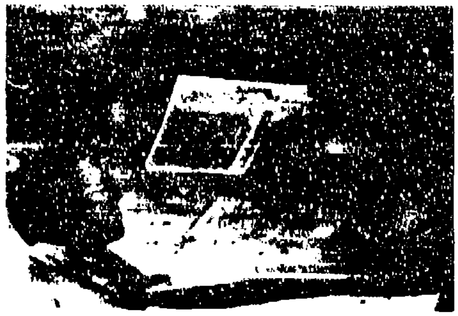
ABB Amdata automated ultrasonic C-scan image showing corrosion at BS 877 in blue.

The following illustrations show a number of the ultrasonic scanners attached to the aircraft with the C-scan inspection results.

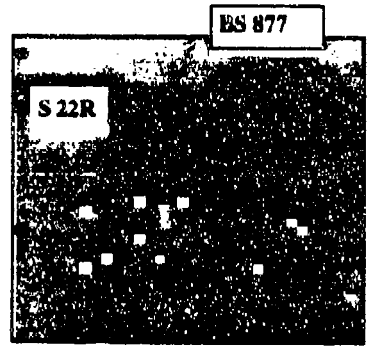
SAIC automated scanner being adjusted by Raymond Zickus.



SAIC automated ultrasonic C-scan image showing corrosion at BS 877. Image nonuniformity was due to difficulty in maintaining transducer perpendicularity during the scan.



Failure Analysis array scanner attached to the B737 at BS 877 with Tom Davis checking the placement of the scanner.

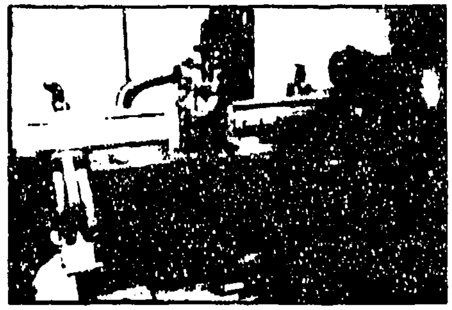


Failure Analysis ultrasonic array 8 x 8 inch C-scan image at BS 877. Area of corrosion is shown in light blue surrounded by green.

Failure Analysis Array attached to the B737 at the boron/epoxy repair patch with Tim Harrington at the portable computer.

Image of repair patch showing defects in dark blue and green.

Sierra Matrix and heads up display with a manual scanner attached to the B737. Meaningful C-scan images of the corrosion at BS 877 were not obtained.



Panametrics portable scanner on a bench top. Shown is a scan of the Textron Specialty Materials boron/epoxy repair sample. A demonstration on the B737 was not made.

Appendix F
General Comments on the Scanner Types

A. Ideal Scanner

Each of the eight basic scanner designs that are available commercially has advantages and disadvantages that differentiate them from the ideal scanner. The ideal scanner would be one that normal experienced airline maintenance NDI personnel can use with ease and confidence to obtain meaningful, repeatable, reliable, easy-to-interpret, and quantitative C-scan images of the inspection data. The ideal scanner would provide accurate XY position data for multimode NDI testing methods without undue physical effort by the examiner for a variety of scanner positions, orientations, structural geometry and surface conditions. The scanner would be affordable and the set-up time, scan time, and relocation time must be quick and compatible with cost effective implementation.

B. Scanner Type Comparisons

From observations made while witnessing the hands-on operation of each scanner type, a table of strong points, weak points, and future improvements was constructed to compare the available scanners with the ideal scanner characteristics. Potential operators of scanners may use the table to compare the benefits of one scanner versus another. Suggestions for improvements are given to aid vendors in developing a favorable scanner system that would increase their general acceptance by the airline inspection industry.

SCANNER TYPE COMPARISONS

Scanner Type	Strong Points	Weak Points	Future Improvements
1. Dual Axis Tilting Arm and Bridge Manual Scanner	Light weight; works well with modular systems; can be used around raised rivets; price is moderate. Integrates easily with eddy current, ultrasonic, and resonance instruments.	Encoder slides when arm gets wet; mechanism holding sensors not well designed; labor intensive to operate; adequate for small area scans only.	Independent hand vacuum pumps for three suction cup feet that provides adaptability to many surface geometries and overhead operation.
2. Dual Axis Tilting Arm and Bridge Automated Scanner	Efficient, easy operation over long inspection times; compact and light weight automated system; good for small and large area scans.	Spring forces on tilting arm are not adequate or constant for general vertical and overhead operation; sensor holder scratches aluminum surface.	Develop a pneumatic tension system for the tilting arm to provide adequate and constant pressure at the sensor to surface interface.

3. Radial Axis Tilting Arm with Rotation Axis Bridge Manual Scanner	Versatile for many surface geometries and large curvatures; can articulate over a large area without repositioning. Integrates easily with eddy current, ultrasonic, and resonance instruments.	Labor intensive for scan times longer than one hour and overhead operation; sensor holder leaves scratches on aluminum surfaces even with Teflon tape over sensor.	Design of a frictionless sensor holder; a set of larger suction cup feet needs to be available for greater adherence to the surface in the overhead operation.
4. Dual Axis Cantilever Arm Bridge Manual or Automated Scanner	Very adaptable for large area scans; automated system is not labor intensive; Areal coverage for C-scan images is easier to obtain than with manual tilting arm systems.	System design is heavy and not as easy to implement as tilting arm scanners; manual system is labor intensive in vertical and overhead operation.	Design of a frictionless sensor holder that maintains sensor perpendicularity over nominal panel curvatures; check valves on multiple suction cup feet need to be installed for positive adherence at all times.
5. Mobile Automated Ultrasonic Scanner	Fast, efficient linear areal scans of widths from 2, 4, 6, or 8 inches, fast and easy mode change for eddy current, ultrasonic, or resonance testing.	Encoder wheels slide when they get wet from the ultrasonic couplant; scanner head is heavy and nor easy to operate for vertical and overhead operation.	Design of a light weight head; frictionless sensor holders; and positive traction encoder wheels are needed.
6. Dual Axis Rectangular Bridge Automated Scanner	Adaptable for large area scans of moderate curvatures; most useful for squirter technology over raised rivets and protrusions etc.	System design is heavy and rigid; not flexible for different surface geometries.	Design of a surface tracking device for implementation with squirter or captured water column technology.
7. Hands Free X-Y Digitizer	Free movement of sensor over complex surface geometries.	False position data occurs frequently from environmental noise and multiple paths within the aluminum structure.	Noise immunity algorithm needs to be developed and a method of decoupling the source waves from the structure surface.
8. 2-D Square Transducer Array	Adaptable for fast characterization of inspected area; straight forward to apply and obtain inspection data; Excellent resolution of thin skin thickness and defect location for boron/epoxy repair patches.	Transducer array can not be used over protrusions like raised rivets etc. Gray scale display used during demonstration lacked contrast needed for easy interpretation of the inspection results.	Large color monitor would improve viewing and interpreting the inspection results, a number of parallel vacuum seals with check valves to improve initial application of the array to the surface.