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DEFENCE SCIENCE AND TECHNOLOGY ORGANISATION

AERONAUTICAL RESEARCH LABORATORY

MELBOURNE, VICTORIA

Technical Report 4

IN-SITU ULTRASONIC C-SCANNER

by

S.C. GALEA
D.S. SAUNDERS

Approved for public release.

NOVEMBER 1992

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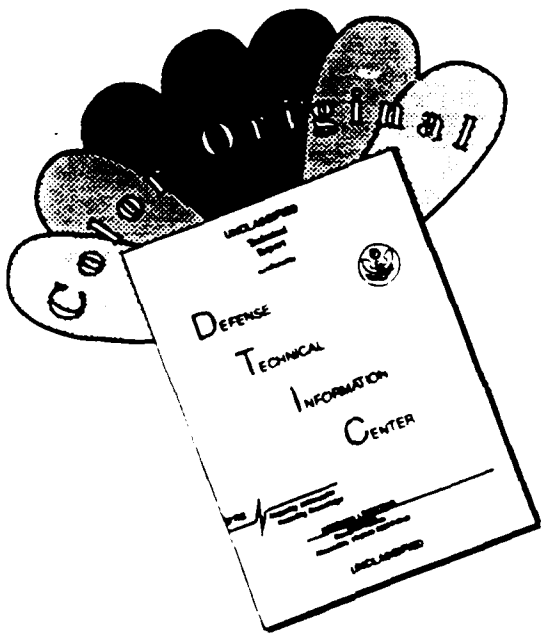

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S.C. GALEA and D.S. SAUNDERS

SUMMARY

Monitoring damage growth in composite materials during axial fatigue tests, without removing the specimen from the loading machine, is normally achieved using techniques such as shadow moiré fringe, X-radiography, thermography or residual stiffness measurements. All except the last method provide an indication of the extent of damage. However none of these techniques provide information on the through-the-thickness location of the damage. For detailed inspection, the specimen would normally be removed from the testing machine and C-scanned using an immersion scanning system. This Technical Report describes an in-situ C-scanning apparatus, based on the time-of-flight C-scanning technique developed at DSTO-ARL, for monitoring damage growth whilst the specimen is still located in the testing machine. This system uses a semi-impervious membrane and water couplant which allows the specimen to be scanned without full immersion of the specimen and the probe. Set-up procedures and operational details are also described. Comparisons of in-situ C-scans with immersion tank C-scans and optical macrographs of cross-sectioned specimens were undertaken, in order to validate the new system.

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TABLE OF CONTENTS

1. INTRODUCTION 1

2. DESCRIPTION OF IN-SITU C-SCANNER 2
   - 2.1. Background 2
   - 2.2. Traversing Mechanism 2
   - 2.3. Probe Holder 3
   - 2.4. Controller 3

3. DISCUSSION 4
   - 3.1. System Validation 4
   - 3.2. Monitoring Damage Growth 4
   - 3.3. Environmental Testing and C-scanning 5

4. CONCLUSION 5

ACKNOWLEDGEMENTS 6

REFERENCES 6

A. PTFE Membrane Filter Specifications 7

B. PROCEDURE 8
   - B.1. Probe Holder 8
   - B.2. Novascope (NDI Instruments etc) 8
   - B.3. Traversing Mechanism and C-scan Program 9
   - B.4. C-Scan Program 'M2' 9

C. OPERATIONAL PROBLEMS 11

FIGURES 1-9

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DOCUMENT CONTROL DATA

1. INTRODUCTION

Advanced materials such as carbon fibre reinforced plastics (CFRP) have been used increasingly in recent years. These materials are used extensively in both civil and military aircraft, and are currently finding extensive use in secondary structural components such as fuselage, wing and control surface skins. It is widely accepted that the use of composite materials will increase as a better understanding of the material behaviour is attained and as designs begin to utilise the anisotropic nature of the material.

Laboratory testing is required to determine material allowables[1] such as residual strengths of damaged and fatigued composite laminates, as well as to determine their S/N curves. The static and fatigue properties of these materials deteriorate under hot/wet environments hence laboratory testing is also required to determine their behaviour under adverse environmental conditions. Indeed the complicated interaction of variable loading, laminate damage and variable environmental conditions can be determined only through extensive laboratory testing. As a result, non-labour intensive and accurate non-destructive inspection methods to both detect and quantify damage in composite laminates, under test conditions, are extremely desirable.

Fatigue testing of metallic specimens is relatively straight forward since cracks normally appear on the surface and can be measured by optical methods. However, the damage in composite materials is normally sub-surface and may consist of fibre breakage, intralaminar or interlaminar cracks (i.e. delaminations), the latter two being the more common. To measure these damage states is not straight forward. Techniques such as residual strength and fractography can be used but these are destructive. Non-destructive techniques include: residual stiffness measurements, measurements from shadow moiré fringe patterns, X-radiography, thermography and ultrasonic C-scanning[2]. Shadow moiré fringe, X-radiography and thermography have been successfully used in-situ to detect and monitor damage growth. Residual stiffness measurements do follow damage development but do not give information on the extent of damage, and normally do not show large changes until failure is imminent[3]. The shadow moiré fringe, X-radiography and thermography techniques give an indication of the extent of damage but do not give any through-the-thickness information (i.e. the structure of damage).

The ultrasonic C-scan technique has proven to be a reliable method for determining damage, such as delaminations and cracks, and other defects such as porosity and foreign body inclusions in fibre reinforced materials[4,5]. It is one of the main techniques used for the quality control of composite materials during fabrication and assembly.

When subjecting CFRP specimens to cyclic loads, ultrasonic C-scans need to be regularly undertaken to determine the state of damage in the specimen. In the past this has necessitated the time consuming exercise of removing, C-scanning, replacing and realigning the specimen in the machine for each survey of damage. The development of an in-situ ultrasonic C-scanning device was thus appropriate to the damage assessment program and the design was based on an immersion tank and portable C-scanner developed by Aircraft Materials Division, Defence Science and Technology Organisation-Aeronautical Research Laboratory (DSTO-ARL)[6,7]. This Technical Report describes the facility, and discusses the set-up procedure and its operation.

Also discussed are operational difficulties with suggested causes and solutions. Comparisons of in-situ C-scans with immersion tank C-scans and optical macrographs of cross-sectioned specimens were undertaken, in order to validate the new system.

2. DESCRIPTION OF IN-SITU C-SCANNER

2.1. Background

The basic principle involves an ultrasonic pulse, generated by a transmitting/receiving sensor, propagating through the laminate. Typically, a 5 MHz signal is generated by the transducer which then enters the specimen via a coupling medium (normally water) to maximise energy transfer. While the pulse travels through the laminate it is attenuated by reflections due to any change in impedance, e.g. voids, delaminations and to a lesser extent volume fraction anomalies and translaminar cracking. The signal received by the transducer is a time history of the pulse travelling through the specimen. This information can be presented in a number of ways, viz.: A-, B- and C-scans which convey information involving point, cross-section along the length of the specimen, and areas, respectively. These various scans are illustrated schematically in Figure 1. As observed, conventional C-scanning provides little information on the structure of the damage. For a more detailed through-the-thickness assessment of the damage, DSTO-ARL has developed the time-of-flight technique[8,9].

The time-of flight technique, involves determining the time taken between the reflection of the pulse from the front face and the first major echo. For a perfect specimen the first echo will be off the back face, whereas if delaminations are present the first echo will be from the first layer of delamination encountered. The system records A-scan information at a number of points on the specimen, i.e. as a function of position on the specimen. This information can then be displayed as colour coded images, thus illustrating areas of damage (C-scan), or as cross-sectional plots showing the location through-the-thickness of the first delaminations (B-scan).

A schematic diagram of the set-up is given in Figure 2. Photographs of the in-situ C-scanner are given in Figures 3 and 4. These show an overall view of the device and a detailed view of the probe holder, respectively. The scanning apparatus is attached to a hinged rigid frame which is mounted onto two support pillars of a uniaxial testing machine, and when not in use can be retracted from the testing area.

2.2. Traversing Mechanism

As shown in Figure 2 the X-Y plane refers to the plane of the specimen, with the X and Y axes being parallel and perpendicular to the load direction, i.e. vertical and horizontal, respectively. The Z-axis is perpendicular to the X-Y plane. The X-Y mechanism consists of two horizontal guides which provide yaw free movement in the Y-axis direction. Movement in the X-axis is provided by a vertical guide attached to the two horizontal guides, with one end being attached by means of a bearing block. A perspex probe holder slides into a metallic tube which is in turn attached, via a bearing block, to the vertical guide. Adjustment of the probe in the Z-axis is achieved by means of an aluminium square tube which slides within the bearing block (see Figure 3).

Movement of both bearing blocks is achieved using a stepping motor (400 steps per revolution) driving a rolled thread ball screw. This arrangement achieves a positional accuracy of ± 0.01mm.

2.3. Probe Holder

The perspex ultrasonic probe holder, shown in Figures 4 and 5, slides freely within a metallic tube. Located in the tube is a spring, which forces the front of the probe holder to maintain firm contact with the specimen. The cavity in the probe holder is filled with a distilled water/propanol mixture to acoustically couple the transducer with the specimen. One end of the cavity is sealed using a teflon diaphragm* which is held in position by a rubber collar. This method also enables the diaphragm to be kept taut at all times. An O-ring is located between the teflon and the perspex in order to reduce the wear and tear of the teflon as it slides against the specimen. The teflon, when wet with alcohol, becomes acoustically transparent and allows slow passage of the water/propanol mixture without excessive leakage occurring. It will remain transparent as long as it is in contact with the distilled water/propanol mixture. Two O-rings are used to locate the 5 MHz ultrasonic transducer in the back end of the perspex probe holder. These O-rings enable alignment of the transducer and provide a seal. Also shown is a bleeder valve, which is used to purge any air bubbles that may become trapped in the system.

The scan data are collected by the probe undertaking a raster motion across the face of the specimen. That is, the probe moves stepwise in the Y-axis direction and then scans along the X-axis. Each time the probe steps, an A-scan is made and data stored in a file with data describing the position of the probe within its X-Y plane. At present the system has a degree of X-axis backlash due to flexibility of the probe arm about the Y-axis. This is noticeable when the arm changes direction whilst undertaking an X-axis traverse. To eliminate this would require a major modification. However, because the system collects A-scan data in only one direction (i.e. a one-way scan), the backlash does not influence the actual C-scan maps. If two-way scans were required to decrease scanning time, then backlash would need to be reduced considerably.

2.4. Controller

The in-situ C-scanner is controlled using a Compaq 286 computer in conjunction with a Digiplan SD3 stepper motor drive (see Figure 2). Micro-switches located in the upper, lower, left and right limits of the scan region provide the computer with the upper/right and lower/left reference locations to define the size of the scan area. A 1217 port interface card is used to interface the computer with the stepper motor drive. Data acquisition of the ultrasonic C-scan signal by the computer is achieved via a Data Translation DT 2817 A/D converter board.

*Specifications of the PTFE membrane are given Appendix A.

3. DISCUSSION

3.1. System Validation

The procedure for the operation of this device is given in Appendix B.
To validate the in-situ C-scanner, a scan was undertaken of a damaged specimen mounted in an axial testing machine (see Figure 6a). The specimen was also scanned using an immersion ultrasonic scanning system, see Figure 6b. The typical scan maps given in Figure 6 show the through thickness information from the specimen being segmented into 8 separate regions (i.e. colours). The results show reasonable agreement between the in-situ scans (Figure 6a) and the scans made in the immersion tank (Figure 6b), with slight differences due to variations in calibration between the two scans. Damage that lies at the interface of two adjacent regions, i.e. colours, can appear in either region depending on the initial calibration. This can be observed in the corresponding line scans shown in Figure 6. The general overall observation is that the pattern and colour schemes are similar. Also the overall damaged areas are 1200 and 1160 mm^2, respectively, i.e. a 3% variation. Other scan areas, not shown here, have agreed to within 10%.

Large variations in area will occur if line (Y direction) and sample point (X direction) spacings are coarse. For example line/point spacing settings of 0.5/0.4 mm and 1.0/0.2mm caused variations of up to 20% in the measured damage area. There is therefore a compromise in setting the line spacing between higher resolution and time required to scan. It was found from experience that a setting of 0.4/0.4mm line/point spacing setting gave consistent results, with a typical variation of less than ±10%.

3.2. Monitoring Damage Growth

A number of investigations of the fatigue behaviour of AS4-3501/6 carbon fibre/epoxy resin 50 ply laminate of layup $[(\pm 45_2, 0_4)_3, 90]_{sym}$ have been undertaken using the in-situ C-scanner to monitor damage growth. Figure 7 shows one example of the monitoring of damage growth using this technique; 7a shows damage growth around an open hole, and 7b shows the damage growth in a specimen containing impact damage around an open hole. By monitoring the damage, specific tests could be terminated before failure so that the specimens could be sectioned and optical microscopy undertaken to determine the morphology of fatigue damage. An interesting observation is the preferred directions of damage growth resulting from the different initial conditions. For this particular fibre-dominated layup, when an open hole is present, the damage grows parallel to the loading direction and is contained mainly within the surface plies. However, for a specimen with both impact damage and an open hole, the damage growth is complicated and appears to be influenced by the morphology of the initial damage. As shown, in Figure 7b, the impact damage in the top/left region is contained within the ±45° plies immediately below the laminate mid-plane and these delaminations tended to grow along this interface at 45° to the loading direction when subjected to fatigue loading. A further observation is that the major damage growth is perpendicular to the load direction (and along plies on the non-impact face), indicating that the damage has caused a drastic redistribution of the stress field. Therefore, as the number of fatigue programs increases, the damage changes in appearance from circular to elliptical (with the minor axis parallel to the load direction). Similar observations have been cited in the literature for other impact damaged carbon fibre/epoxy resin systems with different fibre dominated layups[3]. Figure 8 shows the C-scan and optical macrographs of the corresponding sectioned specimen.

This illustrates that the C-scan gives an accurate indication of the "through-the-thickness" damage, even though parts of the damage are masked by those on an upper interface.

The scanner was also used to monitor damage around fastener holes, with fasteners installed, during fatigue tests. These tests were undertaken to simulate mechanical composite-to-metal joints in regions of an aircraft where the load is transferred from the wing skin to the wing spar. Figure 9 shows the in-situ ultrasonic C-scan map of an undamaged and fatigued composite bolted joint specimen. To the authors' knowledge, this is the first time that investigations utilising in-situ C-scanning to monitor the progressive damage around the fastener region have been undertaken. The use of the in-situ scanner allows damage mapping without the need to disassemble the composite-to-metal mechanically fastened joint, therefore, this system provides more realistic results of fatigue life and damage growth since it has been found that the removal of the fasteners increases the hole wear rate.[10,11]

3.3. Environmental Testing and C-scanning

Future work in the study of the fatigue behaviour of composite laminates includes investigating the growth of damage around the fastener holes, in composite-to-metal mechanically fastened joints, under hot/wet conditions. This requires a chamber around the specimen in the testing machine. A chamber has been designed such that one side can be removed giving access to the specimen for C-scanning. The advantage of this arrangement is that it allows the experiment to proceed with minimum interruptions, thus achieving a reasonably constant moisture level in the specimen.

4. CONCLUSION

An in-situ C-scanner has been developed and installed on an axial fatigue testing machine to monitor the damage growth in fibre composite materials thus reducing the testing time considerably. The C-scanner uses a time-of-flight technique to achieve accurate "through-the-thickness" damage mapping of the composite whilst the specimen remains positioned in the testing machine. The C-scans obtained were consistent with those from a full immersion probe C-scanning system. The in-situ C-scan maps were also shown to give an accurate representation of the damage morphology as observed by optical microscopy of sectioned specimens. The system has been used successfully in a number of fatigue investigations, such as detecting and monitoring damage states in composites and composite-to-metal joints under cyclic loading conditions.

ACKNOWLEDGEMENTS

The authors would like to acknowledge the assistance of Mr. M. Dvorak, Mr. M. Ryan and Mr. C. Ellis in the development and testing of the apparatus and Mr. H. Morton who undertook the ultrasonic C-scanning of the damaged specimens using the immersion tank C-scanner. Also, considerable help from Mr. H. Morton and Mr. B. Bishop in overcoming operational difficulties is appreciated.

REFERENCES

1. **Whitehead, R.S.** 'Certification of Primary Composite Aircraft Structures' *Proceedings of the 14th ICAF Symposium, Ottawa, Canada* (1987) pp 585-617
2. **Clarke, B.** 'Nondestructive Evaluation of Composite Materials' *Metals and Materials-Inspection and Testing* (March 1990) pp 135-139.
3. **Saunders, D.S. and Van Blaricum, T.J.** 'Effect of Load Duration on Fatigue Behaviour of Graphite/Epoxy Laminates containing Delaminations' *Composites* **19** No 3 (1988) pp 217-228.
4. **Cantwell, W.J. and Morton, J.** 'Detection of Impact Damaged CFRP Laminates' *Composite Structures* **3** (1985) pp 241-257.
5. **Subramanian, K. and Rose, J.L.** 'C-scan Testing for Complex Parts' *Advanced Materials and Processes (Metal Progress)* **2** (June 1979) pp 40-43.
6. **Preuss, T.E. and Clark, G.** 'Use of Time-of-Flight C-Scanning for Assessment of Impact Damage in Composites' *Composites* **19** (1988) pp 145-148.
7. **Clark, G. and Bishop, B.** 'Application of Ultrasonic C-Scanning to Aerospace Composites' *Acoustics Australia* **19** (1990) pp 17-21.
8. **Preuss, T.E.** 'The Development of a Thickness C-scan Ultrasonic Technique for the Non-destructive Inspection of Composite Materials' *Australian Department of Defence, Defence Science and Technology Organisation, Aeronautical Research Laboratory, ARL-MAT-TM-395* (1987).
9. **Broughton, W.R. and Chester, R.J.** 'The Development of a Portable Ultrasonic Facility for NDI of Graphite/Epoxy Composites' *Non-destructive Testing Australia* **23** (1986) pp 38-40.
10. **Saunders, D.S., Stimson,M.G., Kowal E. and Rey, C.** 'Preliminary Investigations of the Static Failure and Fatigue Behaviour of Mechanical Joints in Composite Materials' *Australian Department of Defence, Defence Science and Technology Organisation, Aeronautical Research Laboratory, ARL-STRUC-TM-572* (1990).
11. **Saunders, D.S., Galea, S.C. and Deirmendjian, G.K.** 'The Development of Fatigue Damage Around Fastener Holes in Thick Carbon Fibre Composite Panels' *Composites* **24** (1993) pp 1-13.

A. PTFE Membrane Filter Specifications

Filters used were Sartorius Membrane Filters SM118-07-47N*.

1. SM118 indicates PTFE filters
2. 47N indicates 47mm diameter (packet of 100)
3.

	Pore sizes (µm)	Thicknesses (µm)
-42-	5.0	100
-03-	1.2	100
-06-	0.45	80
-07-	0.2	65

4. Other specifications: maximum temperature 200°C
   flow rate of isopropanol at pressure drop of 1bar is 12ml/min/cm^2

* The smallest pore size was used because the ability of the membrane to become and remain transparent is inversely proportional to the membrane's pore size. However the smaller the pore size the higher the rate of 'blockage' of the membrane. Therefore care needs to be taken to ensure that the water/propanol mixture contains no impurities.

B. PROCEDURE

B.1. Probe Holder

A rubber O-ring is placed onto the front lip of the probe holder. On top of the rubber O-ring is then placed the teflon diaphragm and a rubber collar is then pushed over the teflon to hold the teflon firmly in position. The diaphragm is then wetted with pure propanol.

The cavity in the perspex probe holder is filled with a 90/10 distilled water/propanol mixture which has been de-aerated by placing it in an ultrasonic bath for approximately 10 minutes. Any air bubbles that may be trapped in the probe holder are removed by opening the bleeder valve shown in Figure 5. The distilled water/propanol mixture reservoir is then placed about half a metre above the transducer holder, to ensure that a positive pressure exists in the cavity of the transducer holder thus ensuring no air leakage and that the teflon diaphragm will attain a convex shape. The probe holder then slides into the probe arm. Note that a certain amount of free play is allowed so that the probe holder can slide further back into the probe arm once the former has made contact with the specimen. The spring, located in the probe arm, ensures that one end of the probe holder is always in contact with the specimen. Operational problems, as well as possible causes and solutions, are given in Appendix C.

B.2. Novascope (NDI Instruments etc)

Once the frame has been swung into position and locked, the probe holder is placed in contact with the specimen and two pulses can be seen on the Novascope screen. The probe should be located on an area of the specimen that does not contain any internal damage, so that the full depth is indicated on the Novascope screen. In this case the first pulse indicates the reflection off the front face of the specimen and the second is off the back face. The reject (R) is adjusted until the second pulse is approximately 1 division in height. The Novascope 3000 has the option of adjusting the damping of the generated pulse. In this case the damping of the pulse is adjusted until the number of cycles of the ring down is minimised. (N.B. This adjustment is made with the autogain switched off.) The Interface Lock (IF), i.e. the gate used to disregard this ring down, is then adjusted so that it contains all of the ring down. However care needs to be taken here, since any genuine pulses that occur within this gate are also disregarded. So, ideally, this gate must be as narrow as possible (nominally 0.3-0.4 divisions). The ultrasonic transducer is now ready for use.

Generally, for a 6.8mm thick carbon fibre/epoxy resin specimen the gate width from the initial to the back face pulse is 4.8 divisions. Note that if the IF is set to 0.4 divisions then any damage in the top 0.5mm or 4 plies of the specimen will not be detected.

B.3. Traversing Mechanism and C-scan Program

Limit micro-switches on the traversing mechanism are first adjusted to set the boundaries of the maximum possible scanning area. Note that, the lower/left point set by the micro-switches is used as the origin (0,0) by the controller. Once the limits are set an ultrasonic C-scan map of the test specimen is obtained by executing the computer program "M2"#. More detailed instructions on the use of "M2" are given below.

B.4. C-Scan Program 'M2'

The following is the procedure for running the C-scan program, "M2", and obtaining a C-scan map:-

i) enter M2*. (i.e. to run program)

ii) enter 1. (i.e. to use mouse)

iii) Select Collect and display data from scanner (this option is selected by moving the cursor via the up/down arrows and then pressing enter).

iv) a) enter file name, initials of user and brief file description.

b) set both scan line (Y-axis) and point (X-axis) spacing to 0.4mm {N.B Data can only be entered when the entry area is flashing (this is done by positioning cursor and pressing enter. After inputing data, press enter)}.

v) Select Collect/display data.

vi) Switch stepper motor controller on and then select Define scan pattern. The probe will then be moved by the controller to the lower/left position defined by the limit micro-switches. The program then asks the user to define the lower/left diagonal of the required scan area. By using the up/right arrow keys the user can position the probe at the desired lower/left diagonal and then press enter when the position is reached. Next the program prompts the user for the upper/right diagonal of the scan pattern which is attained by positioning the probe using the up/right arrow keys and then selecting enter. The program now has stored the lower/left to upper/right diagonal of the required scan pattern.

M2 is a computer program written in both Fortran and C computer codes. New versions developed are CVW2U and CVW2B which are one-way and two-way scans (i.e. in one and two directions), respectively. Also the new versions produce $^1/_2$ scale C-scan maps, whereas the original version produces full scale maps.

* Commands are indicated by underlining.

vii) Select scan speed. This is set at 6000 by default. However because of physical constraints, in that the probe needs to be in continuous firm contact with the specimen, the speed needs to be reduced to between 700 and 160. Changing the value is achieved by selecting and then using the up/down arrows.

viii) Select Cal thickness/X-section. This allows the voltage acquired by the computer to be scaled so that the full scale voltage, i.e. the voltage corresponding to full thickness, corresponds to 100% of the thickness. When this option is selected the controller will then wait for the user to position the probe. Ideally the probe should be moved so that a X-axis traverse will encounter damaged and undamaged areas. Also, the probe should be positioned at the start of the calibration run in order to ensure that any misalignment of the probe with respect to the specimen (which often causes a loss of signal at the start of the calibration scan) is kept to a minimum. By pressing enter a second time the program will start a line scan, the result of which is illustrated on the screen in a plot of % thickness (i.e. acquired voltage) versus X distance. (N.B. This is similar to the B-scan shown in Figure 6). By positioning the cross-hair on the maximum value of the resultant scan and then selecting this, the program will thereafter scale all input voltages such that this voltage corresponds to 100% thickness. The system is now ready to generate the C-scan map.

ix) Select Start scan. (N.B. The C-scan program "M2" is the original version. This program scans in one direction only.

C. OPERATIONAL PROBLEMS

Originally ethanol was used to wet the teflon diaphragms to make them acoustically transparent, and distilled water was then used in the probe holder cavity. However it was found that after a time the teflon tended to become acoustically opaque, causing a high degree of ringing. This problem was overcome by using a distilled water/propanol (90/10) mixture.

The table below lists the number of problems that may be encountered with the in-situ C-scanner. Also listed are possible causes and solutions:-

Problem	Possible cause	Solution
Loss of signal from the specimen's back face (i.e. loss of second pulse)	misalignment of probe with the specimen (i.e. the transducer is not perpendicular to the specimen surface)	the probe arm needs to be adjusted to align it perpendicular to the specimen surface.
	teflon diaphragm not transparent, i.e. teflon is white in colour	re-wet the teflon with pure propanol.*
	teflon diaphragm may still appear transparent but may be blocked due to captured fine particles	replace with new diaphragm.
	air bubbles in the cavity	distilled water/propanol solution needs to be further de-aerated in an ultrasonic bath
		use bleeder valve in the perspex holder.
	Novascope reject set too high	adjust reject
no change in C-scan pattern (i.e. pattern is constant in width direction and appears stretched)	mechanical coupling between driver rod and stepper motor is loose	re-tighten the coupling
loss of signal during C-scan	insufficient distilled water/propanol mixture	refill mixture reservoir bottle
tearing of teflon diaphragm	rough specimen surface	smooth out surface using wet abrasive paper
stepper motor not responding	controller	switch on
		replace stepper motor fuse

* Sometimes, to achieve adequate results, the water/propanol mixture needs to be drained completely from the system and the diaphragm then dried until it is white. Pure alcohol is then applied until the diaphragm becomes transparent.

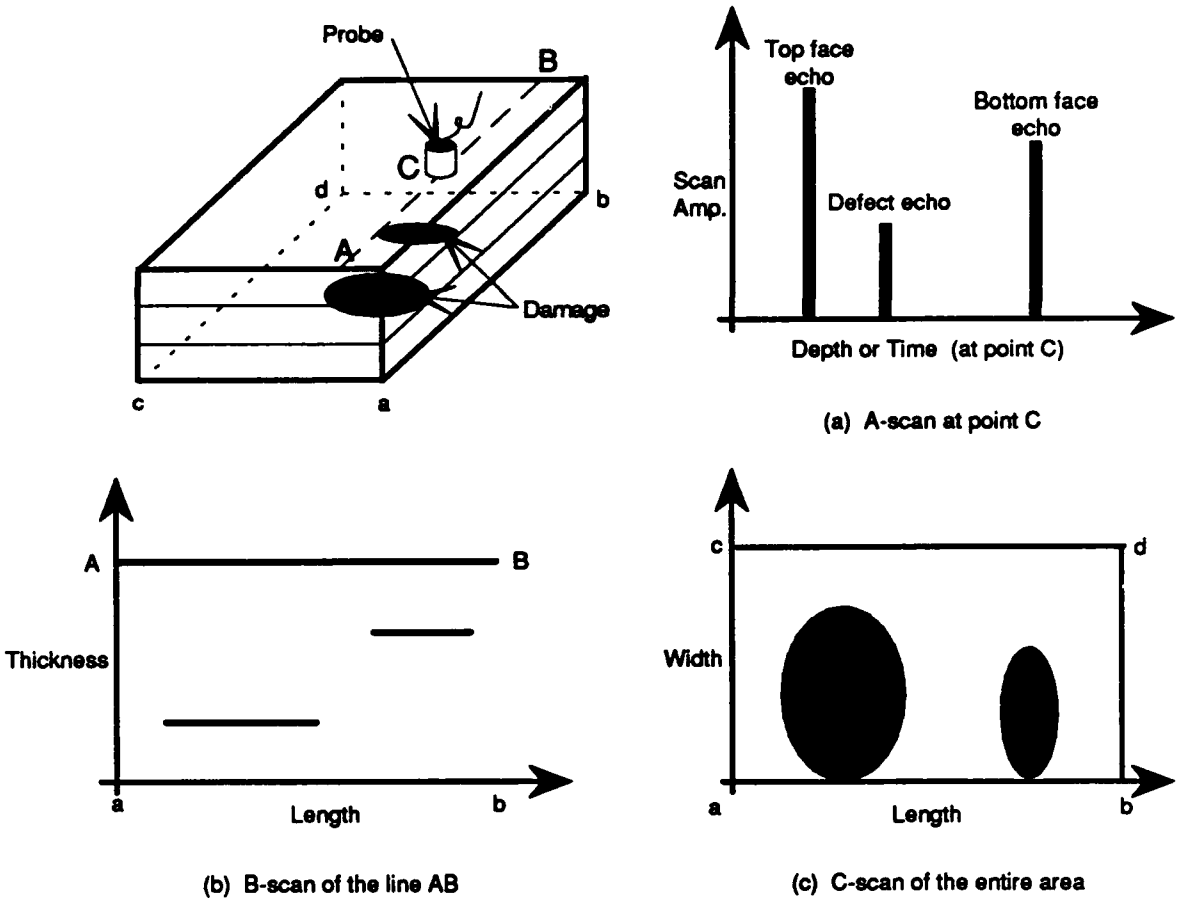


Figure 1: Schematic diagram showing damage in a specimen and the types of ultrasonic scans.

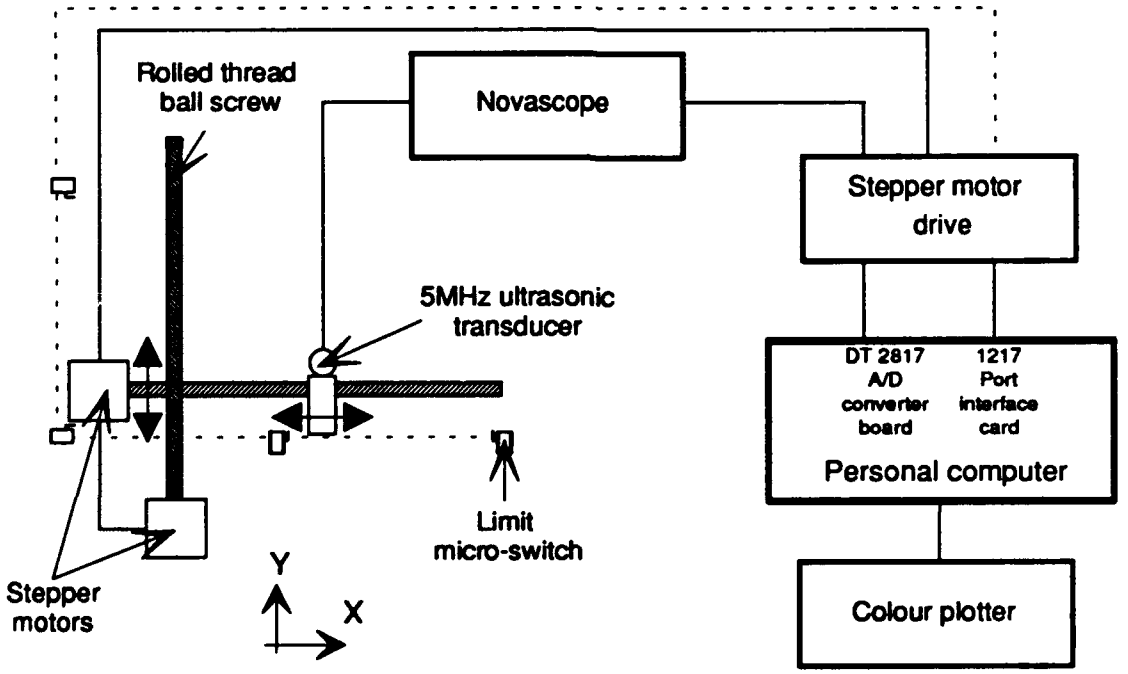


Figure 2: Schematic diagram of the in-situ C-scanner.

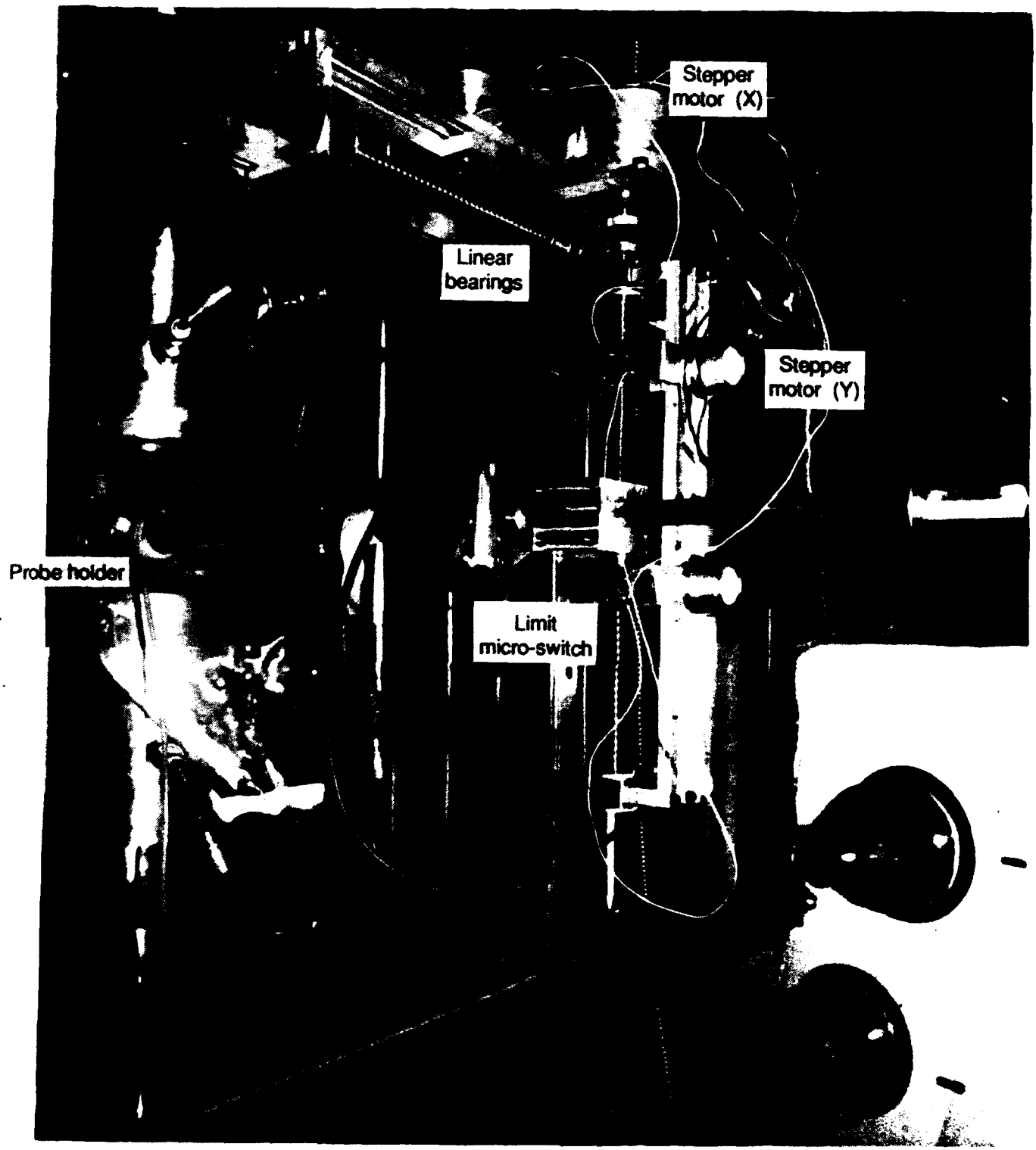


Figure 3: View of the in-situ C-scanner.

Figure 4: View of the ultrasonic probe holder.

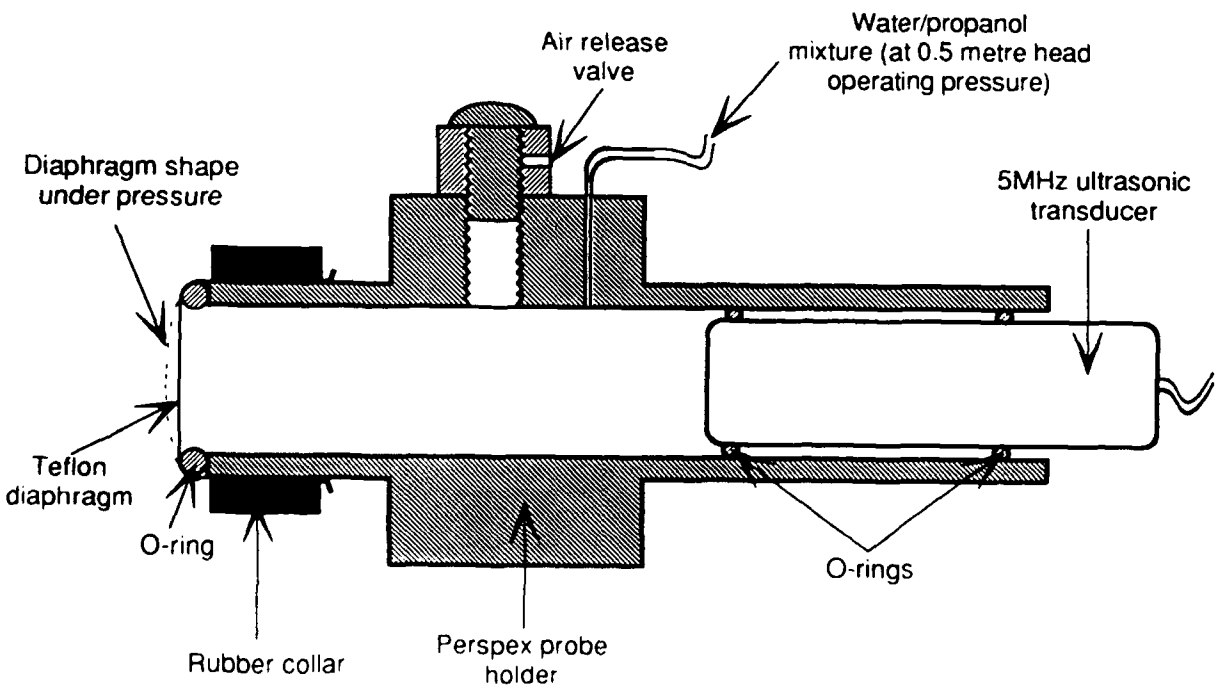


Figure 5: Schematic diagram of the probe holder

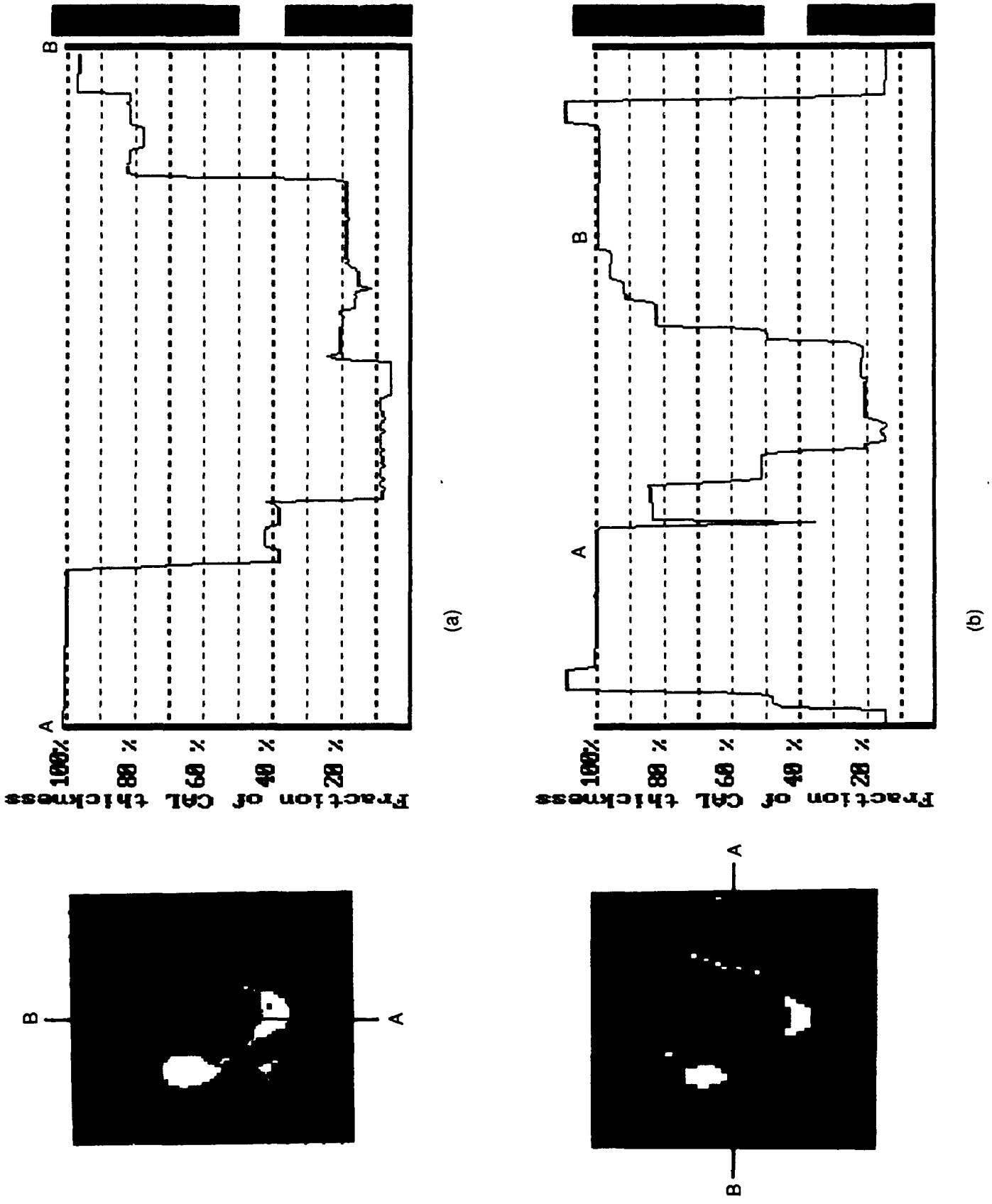


Figure 6: Ultrasonic C-scan maps of a damaged AS4/3501-6 specimen with line scans at the various cross-sections.
(a) In-situ C-scan (0.4/0.2).
(b) Immersion tank C-scan (0.3/0.3).
[NB: values in brackets are line/point space settings, resp., in mm.]

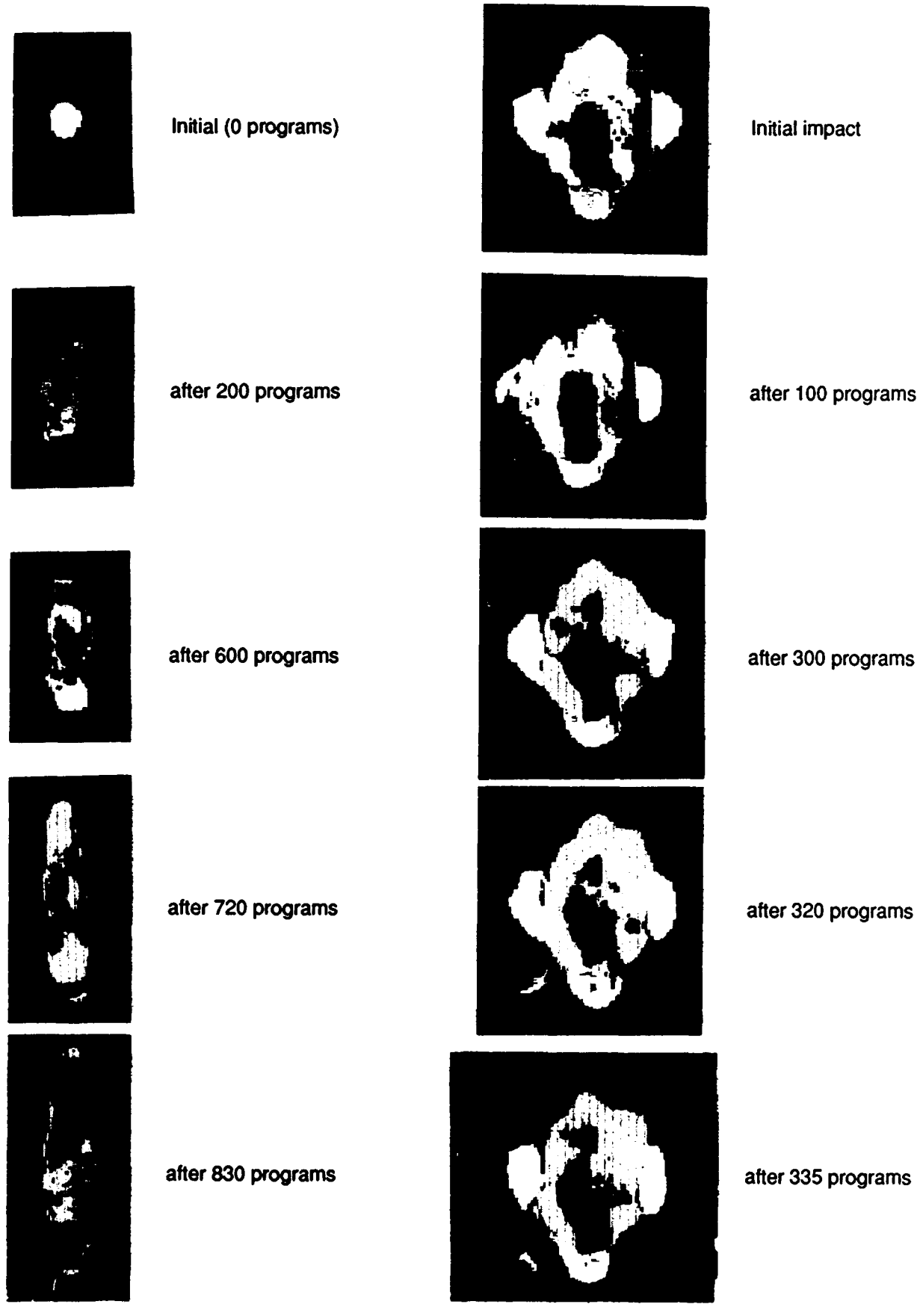
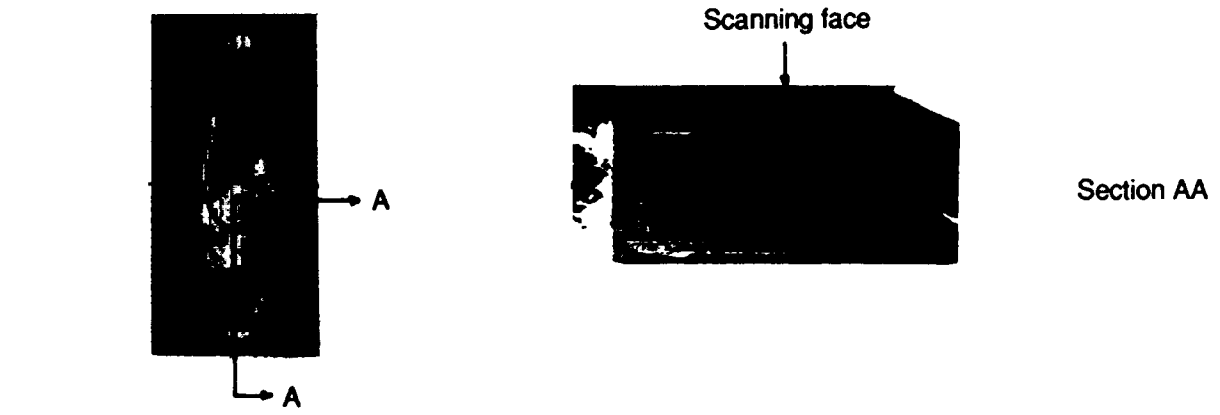


Figure 7: In-situ ultrasonic C-scan maps of progressive fatigue damage around an open hole in CFRP laminates of layup $[(\pm 45_2, 0_4)_3, 90]_{sym}$. The loading spectrum was compression dominated FALSTAFF[3].
(a) No initial damage.
(b) Initial impact damage.



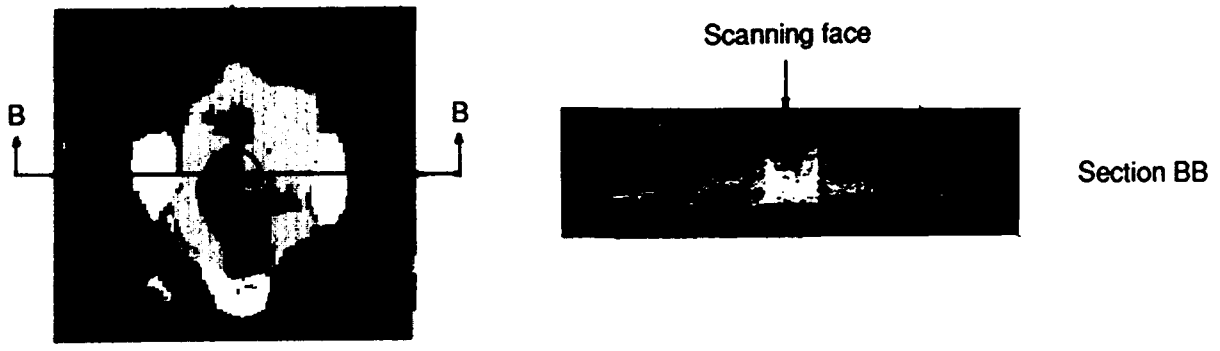


Figure 8: In-situ ultrasonic C-scan maps of damaged CFRP laminates, of layup $[(\pm 45_2, 0_4)_3, 90]_{sym}$, with corresponding optical macrographs of sectioned specimens.
(a) Open hole and fatigue damage.
(b) Open hole with impact and fatigue damage.

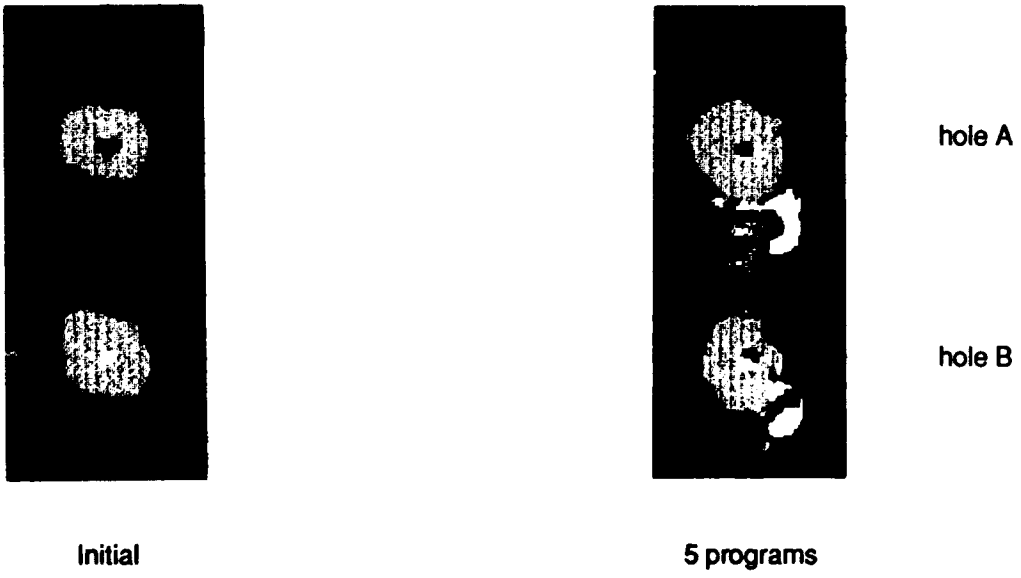


Figure 9: In-situ ultrasonic C-scan maps illustrating damage growth around the fastener holes, with fasteners installed, in a CFRP bolted joint specimen.

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Monitoring damage growth in composite materials during axial fatigue tests, without removing the specimen from the loading machine, is normally achieved using techniques such as shadow moiré fringe, X-radiography, thermography or residual stiffness measurements. All except the last method provide an indication of the extent of damage. However none of these techniques provide information on the through-the-thickness location of the damage. For detailed inspection, the specimen would normally be removed from the testing machine and C-scanned using an immersion scanning system. This Technical Report describes an in-situ C-scanning apparatus, based on the time-of-flight C-scanning technique developed at DSTO-ARL, for monitoring damage growth whilst the specimen is still located in the testing machine. This system uses a semi-impervious membrane and water couplant which allows the specimen to be scanned without full immersion of the specimen and the probe. Set-up procedures and operational details are also described. Comparisons of in-situ C-scans with immersion tank C-scans and optical macrographs of cross-sectioned specimens were undertaken, in order to validate the new system.

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