DEVELOPMENTS AND TESTING OF THE DRIPLESS BUBBLER ULTRASONIC SCANNER

Daniel J. Barnard and David K. Hsu
Center for Nondestructive Evaluation
Iowa State University
Ames, IA 50011

INTRODUCTION

The "Dripless Bubbler" technique[1-3] merges the spatial resolution and coupling advantages of focused-beam ultrasonic immersion probes with an apparatus for maintaining a contained water pool and a commercially available portable robotic scanner and image processing software. The focused probe resolution is necessary for the detection and characterization of corrosion on the inside of the fuselage skin, within laps and joints and disbonds or other defects in composite materials. The system scans over the aircraft skin, following the curvature of a fuselage while maintaining a transducer orientation normal to the surface. Surface irregularities including button-head rivets and lap splices are scanned over with no couplant loss.

The Dripless Bubbler (DB) was developed out of a need by air carrier maintenance personnel for a method of evaluating the condition of aluminum aircraft fuselage structures and is part of a technology transition development program through the FAA-National Aging Aircraft Research Program. The DB's intended purpose is in evaluating the extent of corrosion and adhesive disbonds within lap splices and tear straps, and current work is concerned with the second generation design of the DB and its use with a commercially available portable robotic scanner. The results of laboratory testing and field trials at air carrier maintenance facilities and the FAA - Airworthiness Assurance NDI Validation Center (AANC) have lead to improvements in the design and operation of the DB and scanner, as will the β-site tests at air carriers facilities scheduled to begin in November, 1996.

The DB head itself is made up of a captured water column which houses a focused immersion probe, a series of concentric brush seals for containment of the couplant, and ports for supply and recovery of couplant. Three concentric brush seals form one cylindrical and two annular rings of contained couplant that is continually refreshed. Couplant that is forced out of the contained area and any that leaks out as the DB scans over a surface irregularity is returned via vacuum to the couplant reservoir for recirculation.

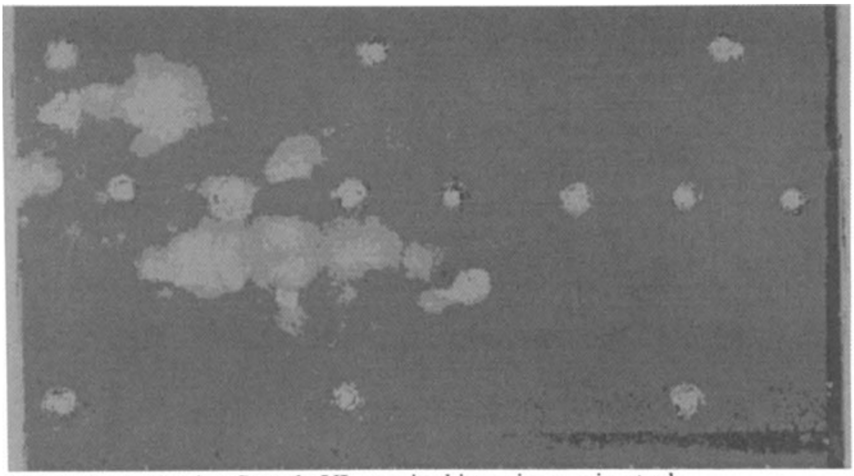
The couplant supply and return system consists of a compressed air operated diaphragm pump and venturi vacuum, a configuration chosen because of the readily available compressed air in aircraft maintenance facilities. The flow rate of the diaphragm pump is controlled by an in-line pressure regulator and runs between 0.4 and 1.0 gpm. The 2.5 gallon couplant reservoir is nominally filled with 1-1.25 gallons of fresh tap water that is normally replaced after an 8 hour shift because of dirt, dust and lint the vacuum return picks up. For detailed figures of this second generation DB design, see [1].

The scanner used in this phase of work is the PANDA II® by Tektrend International, Inc. [4]. This scanner has a flexible scan frame that conforms to the curvature of the fuselage in order to allow the transducer within the DB to more closely maintain an orientation normal to the scan surface. This unit is also very light and simple to assemble in the field. The motion control and data acquisition and analysis software, ARIUS II®, also by Tektrend, manages all aspects of the scanning operations. The entire system, with DB head, scanner, motion control cabinet, control/data acquisition computer, and couplant handling unit is shown in Fig. 1.

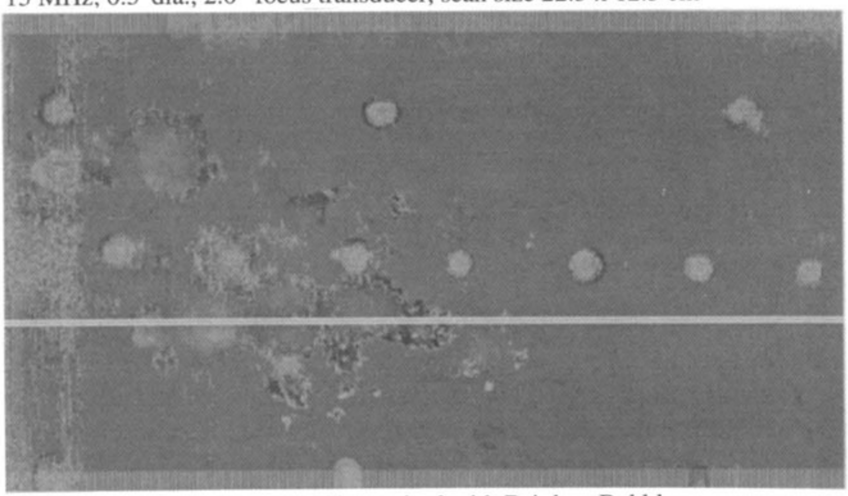
LABORATORY TESTS

Results from sample corrosion test panels are compared to images produced by scanning the same panels in an immersion tank to judge the quality of the images produced by the DB technique. The test panels, Panel III and VI, are blind samples supplied by the Boeing Commercial Airplane Group. The results from Panel VI, shown in Fig. 2, demonstrate that the images produced by the DB are of immersion quality, providing excellent resolution and identification of the extent of corroded regions. Note particularly the B-scan image that allows quick determination of the approximate loss of metal thickness in corroded areas. Typical sample rates of 100 MHz allow repeatable skin thickness measurements to approximately 5% of a standard 40 mil skin or about 50 mm. Equivalent time sampling capabilities to 200 and 400 MHz recently added to the data acquisition software by Tektrend should allow measurements to 2.5 and 1.25%, depending on scan speed.

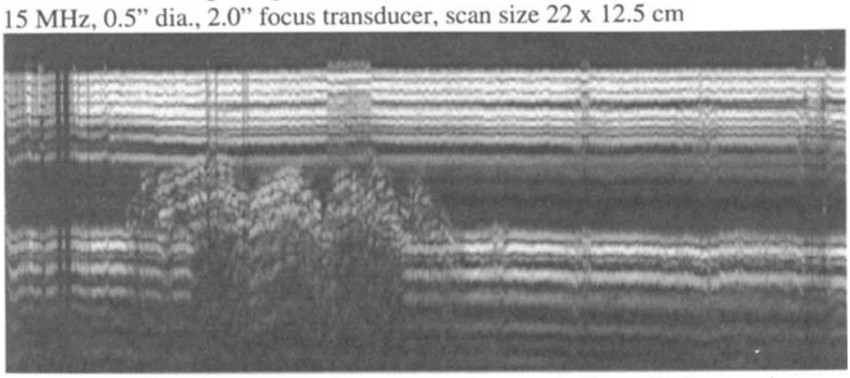
Figure 1. Dripless Bubbler Ultrasonic Scanning System.



Corrosion in Boeing Sample VI, acquired in an immersion tank
15 MHz, 0.5"dia., 2.0" focus transducer, scan size 22.5 x 12.5 cm



Corrosion in Boeing Sample VI, acquired with Dripless Bubbler
15 MHz, 0.5" dia., 2.0" focus transducer, scan size 22 x 12.5 cm



Dripless Bubbler B-scan slice through lined area as indicated in image above.
15 MHz, 0.5" dia., 2.0" focus transducer, scan size 22 x 12.5 cm

Figure 2. Time-of-flight C-scan and B-scan images from the Boeing VI Corrosion Panel.

FIELD TRIAL RESULTS

The DB system has thus far been field tested on a Iowa State University Flight Service (Ames, IA) Beechcraft KingAir 200, a Midwest Express (Milwaukee, WI) DC 9-30 and a Northwest Airlines (Minneapolis, MN) Boeing 747-200. A Boeing 737-200 was also used for evaluation of the system and its capabilities at the FAA-AANC facility in Albuquerque, NM. Field trials represent opportunities to test the system outside of the laboratory in the environment where it will eventually be put to use. The lessons learned from these tests have always pointed toward improvements to be made, including improvements for safety reasons, routine maintenance, and operations. Changes initiated by field trial results have included: (1) the addition of constant force springs to maintain bubbler head/fuselage contact, (2) a set of manual vacuum cups that act as positioning aids, safety restraints and supports for the control, couplant and signal lines, (3) contained water pool shields that allow that couplant recirculation to continue while changing position of the scanner, (4) several improvements to the rigidity of the bubbler-to-scanner mount that improves image quality, and (5) improvements to the robotic scanner and control/data acquisition software undertaken by Tektrend to make the whole system more robust, including the equivalent time sampling additions mentioned previously.

Field trials to date have involved mainly fuselage structures. Figures 3 through 5 show results of the tests conducted on the FAA-AANC Boeing 737-200 testbed aircraft that are representative examples of corrosion and adhesive disbond. These images are from a large area aft of the rear cargo door, in the region of BS877-887, S20-26R, with a composite of images from 6 scans shown in Fig. 3. Severe corrosion and adhesive disbond are present along tear straps and stringers in the region and are easily identified as the speckle (corrosion) and bright bands (disbond) in the images. The adhesive disbonds are visible in the amplitude scans but not in the time-of-flight images because a disbond manifests itself as an acoustic impedance change affecting only primarily the amplitude of the returned signal, which can also be seen, for example, in the B-scan image in Fig.4. Note the vertical striping seen in the C-scan images of Figures 4 and 5, which is caused by a lack of rigidity in the bubbler head-to-scanner mount. Other than this striping, image quality is very good and quite easily interpreted, and will only improve with the changes being made to the system.

While at the FAA Albuquerque facility, the DB head was mounted on a rigid cantilever-armed scanner made by SAIC[5] and used in a scan on the 737 testbed aircraft . Appropriate contact pressure between the bubbler head and the fuselage was difficult to maintain only because of the SAIC scanners Z-axis control is intended for use with contact transducers which have a much higher compliance than the soft bristles of the DB's brush seals. The images produced using the SAIC scanner and data acquisition software were of good quality and would be easily improved with minor tuning of the Z-axis control. This work with the SAIC scanner, and the DB's previous pairing with a rigid rectangular frame scanner constructed in the lab, two commercial manual scanners and the MAUS® [6] scanner has demonstrated that the DB is essentially scanner independent.

APPLICATION OF THE DRIPLESS BUBBLER TO COMPOSITE PANELS

The DB has also been used to examine a repair patch in a sample laminate composite panel from the Boeing Commercial Airplane Group. The full waveform capture capability was also used in this work; by using a number of equally spaced soft gates a

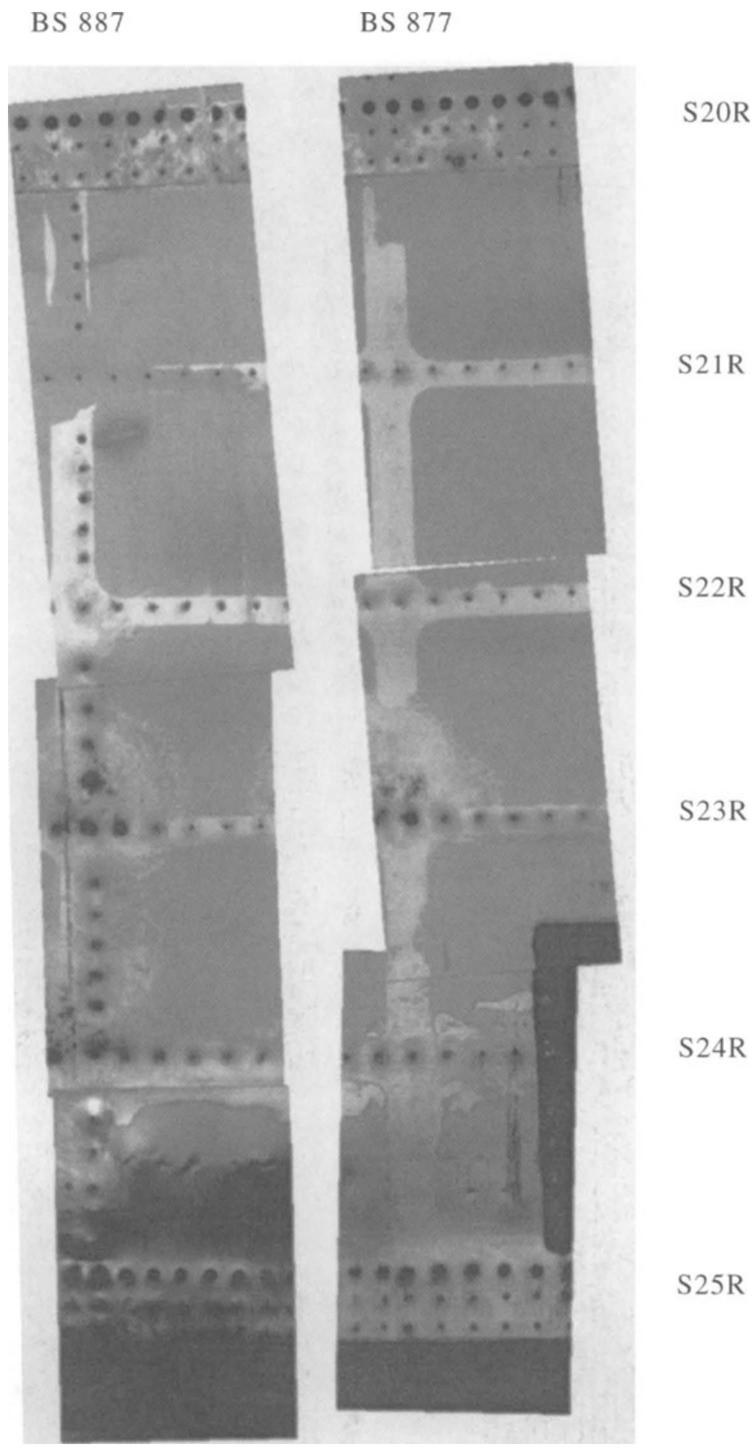


Figure 3. Composite of back surface echo C-scan peak amplitude images, showing corrosion and disbonds in the region behind the rear cargo door, at BS887-877 S20-25R, of the FAA-AANC Boeing 737 testbed (Sample 100). For all scans, transducer: 15 MHz, 0.5" dia., 2.0" focus; step size: 1 mm.

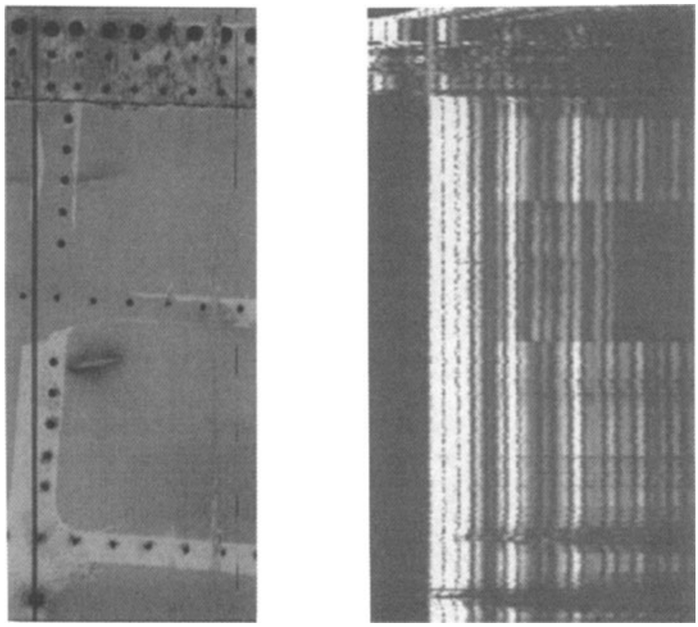


Figure 4. Peak amplitude C-scan (left) and B-scan image from Boeing 737 testbed at BS 887 S20-22R, behind rear cargo door. Location of B-scan is indicated in the C-scan image by double lines. Transducer: 15 MHz, 0.5" dia., 2.0" focus (water); scan size 55 x 22 cm; stepsize: 1 mm.

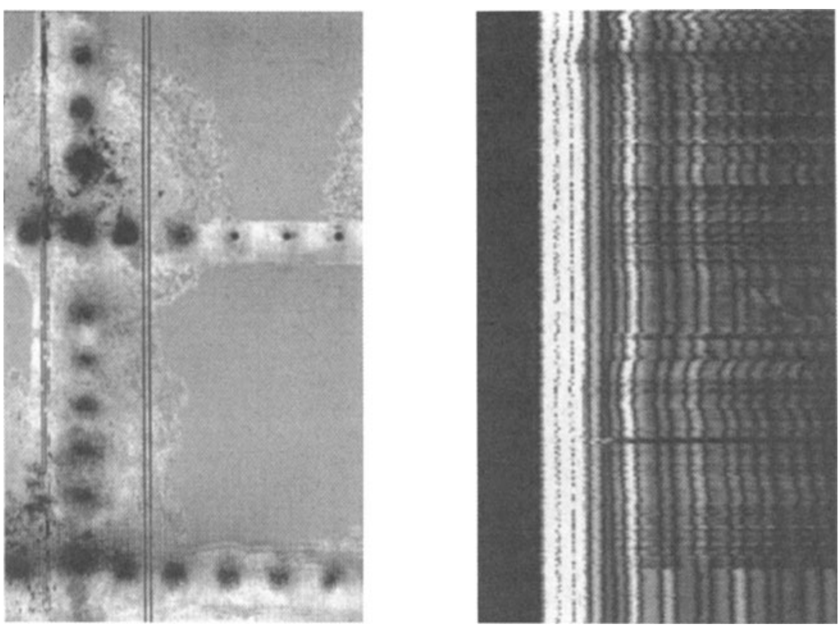


Figure 5. Peak amplitude (left) C-scan and B-scan images of fuselage skin back surface echo on Boeing 737 testbed at BS 887 S23-24R, behind rear cargo door. Location of B-scan is indicated in the C-scan image by double lines. Transducer: 15 MHz, 0.5" dia., 2.0" focus (water); scan size 39 x 22 cm; stepsize: 1 mm.

"stack" of peak amplitude C-scans was produced. With the spacing of the soft gates, the images represent a series of in-plane slices down through the thickness of the panel and repair patch and show defects placed in the repair patch at different layer locations. Also visible is the decreasing diameter of the cone-shaped scarf of the repair patch and fiber orientations. A montage of the images is shown in Fig. 6, with increasing depth from left to right, top to bottom. This work has demonstrated that the DB also has applications in composite structures and their repair inspections.

FUTURE WORK

Work will continue on the improvements suggested by the results of field trials. The scanner manufacturer, Tektrend, is developing a more robust y-axis arm with scanning capabilities and a more robust x-axis carriage, both of which will increase the stiffness and rigidity of the scanner. Tektrend is also making changes to the systems operating software for equivalent time sampling, trigger options, and unidirectional scanning. A operators manual will be completed for the unit, and remote control software is also being added that will allow changes or additions to be made to the operating software from remote locations via a modem. This software will also allow the software settings for a scan to be prepared and executed remotely: this is seen to be particularly beneficial if the NDI personnel doing the beta-site tests would need assistance. Software is also being developed to use the Fourier technique described by Hsu etal [7] on full waveform data to produce thickness C-scans. This is seen as more appropriate than time-of-flight c-scans as it gives an absolute thickness rather than a percentage of full thickness, which may or may not be known if a particular skin has been ground to remove previous corrosion damage.

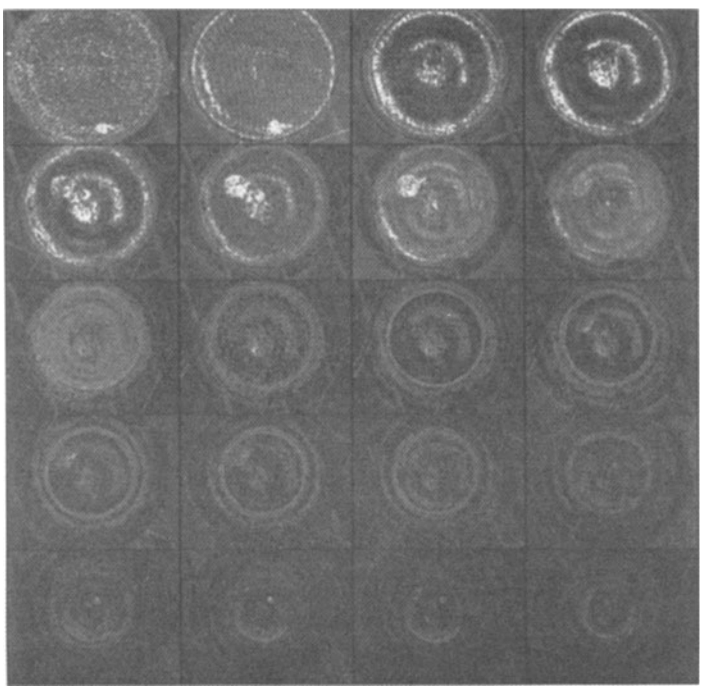


Figure 6. Montage of amplitude C-scans from Boeing Composite Repair Panel 3, with increasing depth left to right, top to bottom. Scan size 28.3 cm x 22.0 cm; step size 0.1 cm.

ACKNOWLEDGMENTS

We would like to thank the staffs of the FAA-Airworthiness Assurance NDI Validation Center, Midwest Express, Northwest Airlines, and the Iowa State University Flight Service for their help in planning and conducting the field trials of the Dripless Bubbler. Their efforts have contributed much to the developments and progress made on this project. This work was supported by the FAA-Center for Aviation Systems Reliability program under Federal Aviation Administration Grant No. 95G-032.

REFERENCES

1. T. C. Patton and D. K. Hsu, "Recent Developments with the Dripless Bubbler Ultrasonic Scanner", *Review of Progress in QNDE*, Vol. 15B, ed. by D. O. Thompson and D. E. Chimenti, pp.2045-2051, 1996.
2. T. C. Patton and D. K. Hsu, "Field Demonstrations of the Dripless Bubbler Ultrasonic Scanner", *Review of Progress in QNDE*, Vol. 14B, ed. by D. O. Thompson and D. E. Chimenti, pp 2269-2276, 1995.
3. T. C. Patton and D. K. Hsu, "Doing Focused Immersion Ultrasonics Without the Water Mess", *Review of Progress in QNDE*, Vol. 13A, ed. by D. O. Thompson and D. E. Chimenti, pp.701-708, 1994.
4. PANDA II ® Robotic NDT Inspection System by Tektrend International, Inc., Dollard, Quebec, Canada.
5. Ultra Image® Portable Automatic Scanner by SAIC, Inc., New London, CT.
6. MAUS® III Scanner by McDonnel Douglas Corp., St. Louis, MO.
7. D. K. Hsu, T. C. Patton, V. Dayal, B. L. Hinzie, and J. N. Gray, "Quantitative Measurement of Metal Loss Due to Corrosion in Aluminum Aircraft Skin", *Review of Progress in QNDE*, Vol. 15B, ed. By D. O. Thompson and D. E. Chimenti, pp.1725-1731.