FIELD AND BETA-SITE TESTING OF THE DRIPLESS BUBBLER ULTRASONIC SCANNER

Daniel J. Barnard and David K. Hsu

Center for NDE - FAA Center for Aviation Systems Reliability
Iowa State University
Ames, Iowa 50011

INTRODUCTION

The Dripless Bubbler technique [1-4] has demonstrated in both laboratory and field trials the ability to identify adhesive disbonds and quantify the metal loss due to corrosion in aircraft fuselage structures. In the latest round of field trials, this technique was successfully applied to aid in characterizing exfoliation corrosion around fasteners in thick wing skins (0.190 – 0.500 inches). In two Beta-site tests, the technique was used to identify delaminations, verify ply drop-offs and evaluate repairs in aircraft composite structures such as rudders, spoilers and flaps.

The Dripless Bubbler (DB) was developed in the FAA's National Aging Aircraft Research Program (NAARP) and was initially intended only for the evaluation of adhesive disbonds in aircraft fuselage structures [1]. Through the course of development the main emphasis has been changed to the quantifying of corrosion, although the technique has been successfully applied to a broader range of materials and structures as noted above. Although to date work has concentrated on use of the technique in a normal incidence mode of operation, the technique should be applicable to any inspections done in an immersion tank. The DB combines the consistent coupling and high spatial resolution and gain of focused immersion ultrasonic probes with a method of maintaining a stable, bubble-free water column and produces immersion-quality B-scan and C-scan images through the use of a computer controlled portable scanner. The hazard of uncontained water is eliminated by the use of a closed-cycle couplant system. The system's high resolution imaging capability is maintained in any orientation on the aircraft, scanning over surface features such as lap splices and button-head fasteners with no loss of couplant. In this report, we will discuss briefly the operation of the DB and then present the results of the latest field and Beta-Site tests of the system.

DESIGN FEATURES

The DB scanning head consists 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. The lower end of the captured water column features an acoustically transparent membrane, effectively a "window" for the focused ultrasonic beam. Between the membrane and the scan surface is the contained water pool, which provides the coupling between the captured water column and the fuselage skin. The immersion probe is glued into a nylon ring that is held firmly within the water column by o-rings, which act as a seal for the captured water column and allow for changes in the focus of the immersion probes. The current design uses standard 0.5 inch immersion probes and can accommodate 1.0 – 3.0 inch focal length transducers. The three inner concentric brush seals form three zones of contained couplant that are continually replenished. This continuous supply of couplant aids in maintaining a bubble-free pool. The couplant that is pushed 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 an integrated compressed air operated diaphragm pump, venturi vacuum, and couplant reservoir with couplant supply and return hose connections. This configuration was 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 normally operates between 0.4 and 1.0 gpm. The 2.5 gallon couplant reservoir is filled with .75-1.25 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. The entire system, with DB head, scanner, motion control cabinet, control/data acquisition computer, and couplant handling unit is shown in Fig. 1. Please refer to [3] for figures showing the DB head and the couplant handling unit in more detail.

The scanner used in this phase of work is the PANDA II® by Tektrend International, Inc. [5]. The Panda II is light (the scan frame, robot, and DB and hoses are less than 10 pounds) and relatively simple to assemble in the field. It features a flexible scan frame that conforms to the curvature of the fuselage in order to allow the DB head (transducer) to more closely maintain an orientation normal to the scan surface without the complication of a gimbal mechanism. A passive stabilization rail and rolling carriage have been added to control the end of the y-axis scan arm, which tends to pull away from the scan surface when operated in an inverted orientation because of the weight of the DB head and couplant hoses. The motion control, data acquisition and analysis software, ARIUS II®, also by Tektrend, manages all aspects of the scanning operations. The data acquisition system allows the acquisition of full waveform data and storage for post processing, which has proven to be a very useful feature.

OPERATION AND INTERPRETATION OF RESULTS

To set up the DB for scanning, the routine is much the same as in immersion scanning, that is, the focus of the transducer must be set to concentrate the probe energy at a region of interest in the piece under test. In thin fuselage skins, the focus is typically placed to maximize the back wall echo and hence any signals from corrosion or disbond . For detecting exfoliation corrosion around fasteners in thicker wing skins the focus is placed at a depth corresponding to half the countersink height. In tests involving aluminum skin structures, 15 MHz transducers are used almost exclusively. Examining composite structures is much the same in terms of focusing the transducer. The primary difference in test of composites is the use of lower

Figure 1. Dripless Bubbler ultrasonic scanner

frequency transducers (10 and 5 MHz) to minimize attenuation and provide greater penetrating power in thicker sections.

Full waveform capture is the normal mode of operation during scans because of the additional information gained from post-processing the data. During data acquisition, a record gate is placed to capture the front and back surface echoes of the outer skin. In post-processing, follower and flaw gates can be applied to the full waveform data to produce C-scan amplitude and time-of-flight images and B-Scans in either horizontal or vertical orientations, with up to six images displayed simultaneously. Individual A-scans can also be viewed and are used in set follower and flaw gate locations and lengths.

Through laboratory and field trials, several image features have been found that greatly helps in the identification of corrosion and disbond in aircraft fuselage structures. Corrosion on the inside of a skin is found to produce a characteristic "speckle" pattern in amplitude (and occasionally in time-of-flight) C-scan images, likely because of the rough surface of the corrosion which acts as a scatterer for the sound energy. In B-scan images, this back wall corrosion is seen as a rough surface, unlike the "smooth" signal from non-corroded regions. The signal from a corroded back wall is also displaced toward the front wall signal, which corresponds to a thinner material/lower transit time. Time-of-flight C-scans are used mainly to quantify the amount of metal loss due to corrosion.

In the case of adhesive disbonds, an increased backwall signal amplitude can be seen in amplitude C-scans and in B-scans. A disbond is characterized as a loss of contact between either the top skin and the adhesive layer or the adhesive layer and the botton skin or structural element. This lack of intimate contact is a barrier for sound energy, reflecting nearly all the energy back toward the front wall. Time-of-flight C-scan images show no differences between bonded and disbonded regions, as would be expected.

Although the "rules" used in interpreting the amplitude C-scan images are physically reasonable, they can be easily incapacitated by the large number of complicating factors that exist on actual aging aircraft in the field. To name just a few: (1) Corrosion products can be tightly packed and under compressive stress in a lap joint, (2) There may be multiple layers of old paint with variable degree of roughness and coverage, (3) Near the edges of a corroded region, the primer on the interior surface may show some blistering and chipping, (4) There may be exfoliation corrosion and blistering of the metal, hence affecting the estimation of remaining metal thickness, and (5) Corrosion inhibitor (e.g., LPS-3) may be present on the interior surface or in the lap splice, thus affecting the signal amplitude in unpredictable manner.

To deal with complex real structures, it is inadequate to rely on amplitude C-scan images. The following practices were used in the field testing of the Dripless Bubbler and found useful: (1) Correlate amplitude changes with time-of-flight changes. This is very useful for distinguishing between disbond and corrosion and for reducing false calls of corrosion due to other causes of signal reduction. (2) Display C-scan and B-scan images simultaneously and side-by-side. This can facilitate a visual correlation of suspected flaw regions. (3) Process B-scan data using Fourier phase spectral analysis to obtain the skin thickness [6]. (4) Use full waveform acquisition and post processing of the 3D data. In the post processing, the A-scans may be processed with different follower gates for multilayered structures where the timing of different echoes may change independently.

FIELD TRIALS

In trials at the ARINC Incorporated, Oklahoma City, OK facility, the DB participated in tests to determine the capabilities of various NDE methods in locating and characterizing exfoliation corrosion extending beyond the fasteners in wing skins. Exfoliation corrosion was induced in a selected number of fastener countersinks in sample panels of material cut from C/KC-135 and B-52 wing skins, with new fasteners installed prior to testing. Eddy Current testing was used to verify the presence of corrosion prior to installing the new fasteners.

In tests on the C/KC-135 samples, the DB was used to scan over a line of fasteners, collecting full waveform data which was post processed to produce C-scan amplitude and time-of-flight images. By simply comparing the size of the "halo" around the fasteners in the amplitude C-scan images, it was a simple matter to distinguish between corroded and uncorroded fastener countersinks. Time-of-flight images were used as to confirm the results from the amplitude images and provided additional information about the depth of the corrosion. Test results indicated that this method correctly identified all 40 corroded countersinks with a single false call. Figure 2 shows time-of-flight C-scan results from the C/KC-135 skins, with results of metallographic examination of selected countersinks showing the extent of exfoliation corrosion.

B-52 wing skin test samples, produced in same manner as the C/KC-135 panels, were also scanned using the DB. Test results were relatively poor, with the correct identification of only 3 of 15 corroded fastener countersinks and one false call. During later inspection of the countersinks by metallographic methods at ARINC, it was found that the corrosion treatments primarily only produced pitting of the countersinks in the B-52 samples. In light of this, it would be expected that the normal incidence method used with the DB would not be very successful in the tests of the B-52 samples. Figure 3 shows results from the ARINC tests, indicating "hit" and false call rates for the methods tested.

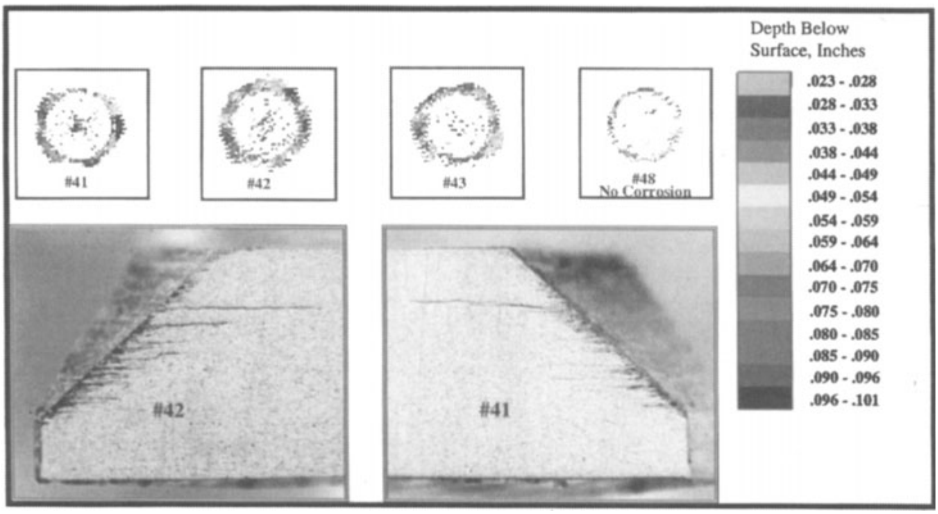

Figure 2. Time-of-flight C-scans showing corrosion around corroded and uncorroded fastener countersinks and optical micrographs showing exfoliation corrosion.

BETA-SITE TESTSING OF THE DRIPLESS BUBBLER

To date, the DB has been involved in two Beta-Site tests at airline maintenance facilities. The idea here was to have the personnel who might eventually use the system in actual practice provide a critique of the system in terms of the setup and operation of the hardware and software, evaluate the quality of the output, and offer suggestions for improvements. The airline personnel also chose the applications to test the system on.

At the United Airlines Beta-site test, United NDT engineers proposed to test the ability of the DB to resolve the number of composite ply and paint layer in a test sample. A rectangular fiberglass sample with a ply build-up from 1 to 7 along one axis and a paint layer build-up of 0 to 4 coats along the other axis was scanned using full waveform capture and post processing. The time-of-flight C-scan results shown in Figure

4a were produced with a single wide flaw gate in the post processing and show fair resolution between the 335 (7 by 5) composite ply and paint layer combinations. Figure 4b shows a much enhanced resolution over a smaller number of composite ply and paint layer combinations when a narrower gate is applied. United engineers are interested in this type of test because of their need to identify loss of composite layers due to excessive sanding during paint removal from composite panels. Tests at Northwest Airlines on a B757 elevator panel successfully demonstrated the ability to image ply drop-offs at an internal member. The result, shown in Figure 5, are time-of-flight and amplitude C-scans produced with a single wide gate and clearly shows the ply drop-offs from bottom (15 plies) to top (8 plies). Note the sharpness in the time-of-flight images, clearly indicating the edges of the plies compared to the gradually changing amplitude across the drop-offs in the amplitude image.

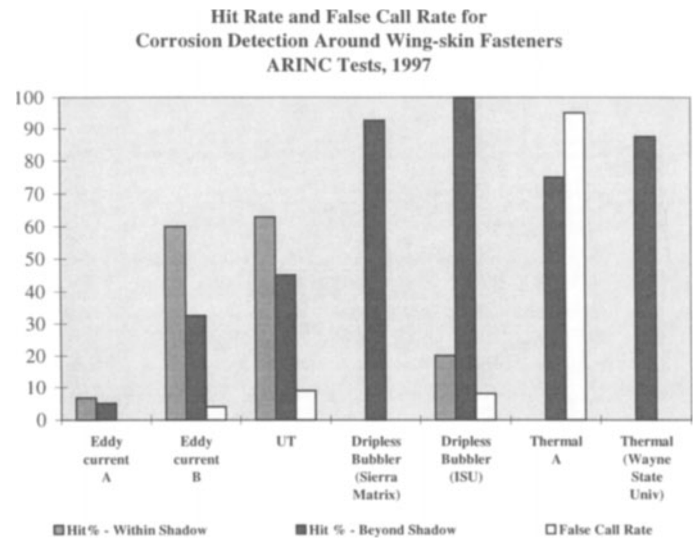

Figure 3. Results of tests to identify exfoliation corrosion in C/KC-135 and B-52 wing skin samples.

Evaluations of repaired composite control surfaces were also conducted at the Beta-site tests and found little success. Although the use of a focused beam significantly improved the thickness and lateral spatial resolution over contact mode scans, field composite repairs performed without the benefit of an autoclave tend to have higher porosity and proved more difficult to penetrate with ultrasound, even at lower frequencies (2.25 MHz). Results from these tests indicated that more work is needed on ultrasonic methods for inspecting composite structures and repairs.

Scans on aluminium fuselage structures at both United and Northwest Beta-site tests were very successful. The testing at Northwest was aimed at verifying the remaining metal thickness after the blending-out of a corrosion pit found on a DC-10. The B-scan images produced, shown in figure 6, clearly showed the thickness of the remaining skin but also revealed the smooth curvature of the blended area. Scans over a lap splices on a B727 and a B747 revealed no corrosion or disbond but did show the increased thickness along fastener rows in chemical milled skin panels, and clearly demonstrated the dripless nature of the system when scanning over button-head fasteners and lap splice edges.

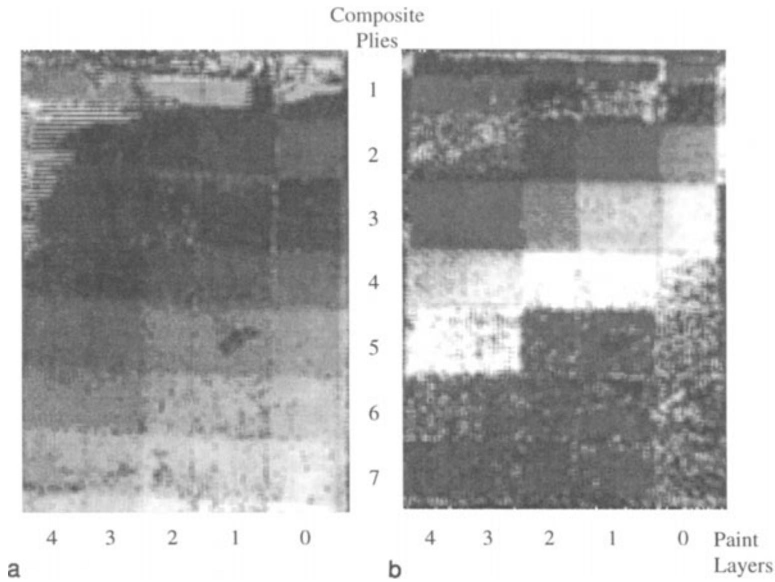

Fig. 4a) Time-of-flight C-scan showing the ability of the DB to resolve 40 composite and paint layer combinations, processed using a single wide flaw gate, 4b) Time-of-flight C-scan image showing higher resolution when using a narrower flaw gate, centered about the 3 and 4 ply region.

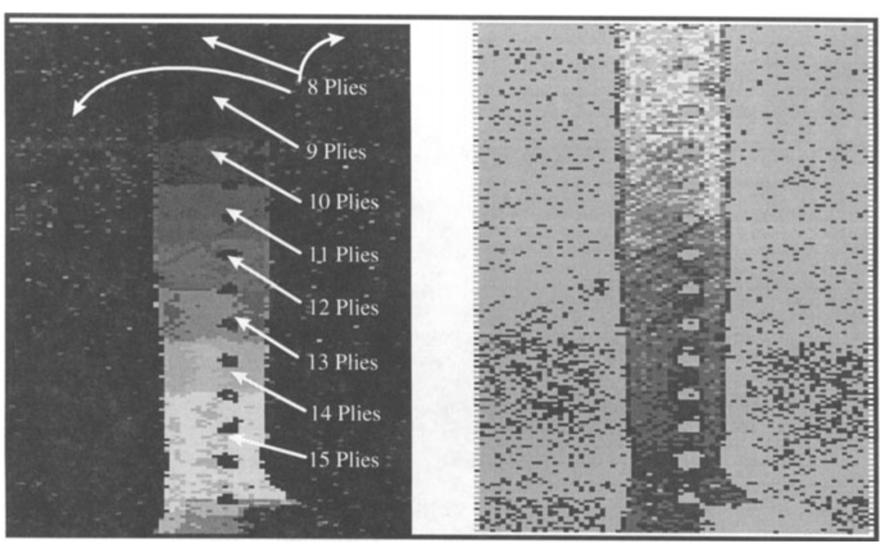

Fig. 5 Time-of-flight (left) and amplitude C-scan results of scans of ply dropoffs at an internal structural member in a B757 elevator.

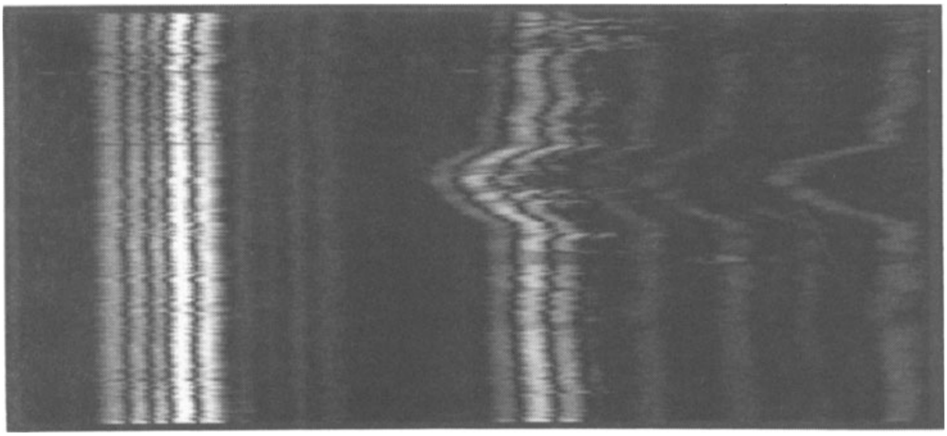

Fig. 6 B-scan results from a blended corrosion pit found in a DC-10.

CONCLUSION

Results from field trials and Beta-site tests have been quite helpful in pointing to improvements and changes to the Dripless Bubbler ultrasonic scanner that have made the system easier to setup and operate. These tests have also aided in establishing a set of "rules" that simplify image interpretation. Feedback from the Beta-site evaluators indicate the following advantages: (1) consistent coupling of the water (which also serves as a delay line), (2) higher energy (focusing gain) and a finer spatial resolution, (3) the ability to scan over surface protrusions, and (4) full waveform data acquisition and subsequent post processing allow more complete analysis of signals. Disadvantages found were: (1) the complexity of dealing with water and vacuum hoses, (2) the lack of a distance-amplitude correction (DAC) feature, (3) the lack of a direct thickness display for scan results, and (4) a number of inconveniences in software dealing with gate visibility, re-sizing of scan windows, aspect ratio and orientation of scan images, and so forth. Note that most of the disadvantages found are not related to the Dripless Bubbler itself, which should be thought of as scanner independent. NDI personnel rarely use a scanning system because of the complexity of these systems, and mating the Dripless Bubbler to a scanner will always add another layer of complexity.

The high interest in methods for composite inspection is the most significant finding in these tests. Composite structures are in wide service in airline fleets, particularly for control surfaces, and a reliable method for characterizing these structures is needed. The Dripless Bubbler has been successful in producing images of ply drop-offs or build-up in composites, but field repaired panels pose a challenge. Work should continue with the Dripless Bubbler in an effort to develop methods for evaluating composite structures and the quality of repairs, both before and once in service.

ACKNOWLEDGMENT

This work was sponsored by the Federal Aviation Administration under Grant No. 95G-032 and conducted at the FAA-Center for Aviation Systems Reliability at Iowa State University. We gratefully acknowledge the hospitality, interaction and feedback of Northwest Airlines, United Airlines, Midwest Express Airlines, ARINC, Foster Miller Inc., FAA-Airworthiness Assurance NDI Validation Center, and the Iowa State University Flight Service. We also thank Boeing commercial Airplane Group for providing corrosion samples and composite repair samples for testing. These colleagues have made important contributions to the development and testing of the Dripless Bubbler.

REFERENCES

1. David K. Hsu and Thadd C. Patton, "Development of Ultrasonic Inspection for Adhesive Bonds in Aging Aircraft", Materials Evaluation, 1993, pp 1391-1397.
2. T. C. Patton and D. K. Hsu, "Recent developments with the Dripless Bubbler Ultrasonic Scanner", Review of Progress in Quantitative NDE, Vol. 15B, ed. by D. O. Thompson and D. E. Chimenti, Plenum Press, 1996. pp. 2045 - 2051.
3. Daniel J. Barnard and David K. Hsu, "NDI of aircraft fuselage structures using the Dripless Bubbler ultrasonic scanner", Proceedings SPIE – Nondestructive Evaluation Techniques for Aging Infrastructure and Manufacturing, ed. by R. D. Rempt and A. L. Broz, 1996, pp 401- 415.
4. Daniel J. Barnard and David K. Hsu, "Developments and testing of the Dripless Bubbler Ultrasonic Scanner", Review of Progress in Quantitative NDE, Vol 16B, ed. by D. O. Thompson and D. E. Chimenti, Plenum Press, 1997. pp 2069 - 2076.
5. PANDA II ® Robotic NDT Inspection System by Tektrend International, Inc., Dollard, Quebec, Canada.