Enhanced Defect Detection on Aircraft Structures
Automatic Flaw Classification Software (AFCS)

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Abstract:
There are many challenges related to ultrasonic inspection of large and complex structures. During an ultrasonic inspection process; proper data acquisition (good return signals) as well as review and analysis of the acquired data can be time consuming and subjective. The main focus of this presentation will be on the analysis of the acquired data using the near real time Automatic Flaw Classification Software (AFCS). The AFCS software is taught by example to discern signals from the fastener hole, geometry, corrosion, multi-layer noise, signal quality, delaminations and crack signals. When analyzing ultrasonic shear wave signals from fastener holes for crack detection the AFCS is directed to locate the fastener hole and then geometrically compare the 3-D alignment of the indication (crack) with the fastener hole focusing on spatial regions of interest. Most ultrasonic C-scan inspection systems that are used for fastener hole inspection are capable of collecting the raw ultrasound data and can present the data in A, B, and C-scan formats. The data is then reviewed and evaluated by an engineer or trained evaluator. The manual review of large data sets can be very time consuming and subject to human factors. The review cycle time is reduced significantly by using the AFCS because it classifies the fastener and its surrounding 3-D area looking for clusters of return signals in the proper location in space with respect to the fastener hole location. AFCS can also provide feedback to the inspector on the quality of the fastener hole signal(s) before moving to the next area to be inspected. This near real time feedback feature improves the quality of the acquired data and reduces the need for the inspector to re-examine the area of interest at a later time. Reducing the time for the overall process is always a key objective in any man power application; AFCS reduces the time for re-examination of poor signals and a significant time reduction in data review cycle (based solely on an examiner reviewing the data). After the fastener holes have been classified by a configured AFCS routine, a trained examiner will review flagged the fastener hole data to verify the defect indication(s), this would greatly reduce the false call rate.

This same AFCS technology can be applied to longitudinal ultrasonic for both composite and metallic inspections. AFCS can help determine corrosion, delaminations, inclusions, lack of bonding, impact damage, back wall plotting and statics for loss of signal due to excessive signal attenuation due to scattering and absorption that is sometimes caused by corrosion, porosity and ply wrinkles.

Background for an AFCS need:
In the aerospace industry Ultrasonic shearwave inspections are commonly used for detection of cracks coming out of fastener holes. Cracks can be detected in many inspection methods such as Eddy Current (ET), Radiographic (RT) and Ultrasonic Test (UT) to name a few of the methods. The main concentration on this paper will be geared towards Ultrasonic testing. With the introduction of

Ultrasonic phased arrays in the inspection realm there has been an order of magnitude increase of data acquisition and storage. Because of the multiple elements in a phased array transducer the multiple passes over an area with a single element has been reduced by a factor that is equal to the single element's index size to the area of coverage of the phased array transducer. Shown below is an example of the reduction. The raster scanning requirement of the single element is reduced by the width of the phased array transducer.

Phased Array Element width = 1.0"
Single element scan grid size = 0.025"
The reduction is 1.0"/0.025" = 40

In the past the scanning acquisition time on the aircraft was about same time as the analysis/reporting time. Depending on the procedure most reporting was reviewing the C-scans and adjusting the gates and the colors on the time-of-flight and amplitude scans. If the A-scans were captured reviewing the data for indications took more time. There was a need for automatically reviewing and analyzing the data to help the inspector and reviewer perform their tasks. With inspections accomplished with ultrasonic phased arrays the inspection time was greatly reduced by the nature of parallel data collection and the analysis time remained the same as a single element inspection. The AFCS (Automatic Flaw Classification Software) design goals were put to paper. The AFCS was developed to provide an automated image analysis tool to assist the evaluator and provide near real-time inspection feed back during the acquisition of the data. The on aircraft inspector receives a simplified report of categorized findings such as indication calls, good signal returns and poor signal returns.

Each ultrasonic inspection is usually unique in its own procedure. The AFCS has adjustable thresholds for fastener locations, detection parameters, selective regions of interest, and sizes to name a few properties that can be set into the AFCS program through a setup file. The inspection is procedure driven and the parameters can be adjusted to provide the desired results.
The AFCS software is a tool that an inspector/evaluator uses to remove unwanted information that would normally require a great deal of time to review and analyzed. The software focuses (filters) on the regions of interest and the other information in the scan data that exceeds reject threshold(s). Using this technique the AFCS can quickly report on areas of interest so the evaluator can focus on a more in depth evaluation of those indications. There has to be a real indication (data cluster) in a particular location (region) and meet amplitude and area requirements. The software does not operate on fuzzy logic. In other words the defect indication has to be in the data for AFCS to detect it.

Typical example of multiple layer fastener hole crack detection process:
This example is based on an aluminum two layer sample with introduced EDM notches at various angles, layers and sizes to simulate cracks. The area of interest is a wing slice joint that is fastened together with Hi-Lok® fasteners and the layers bonded with a sealant. Each layer is approximately 0.150" thick. The test panels were scanned using a 5MHz phased array probe with a shoe to provide a 45^{o} shearwave angle in aluminum. Since the notches were are various

angles (*Figure 1*) the phased array probe had to be skewed at 30 degree increments to detect the various notches. All Ultrasonic data acquired is usually in raw binary data format. The shear or skew angles have not been corrected and the image(s) are distorted by both angles.

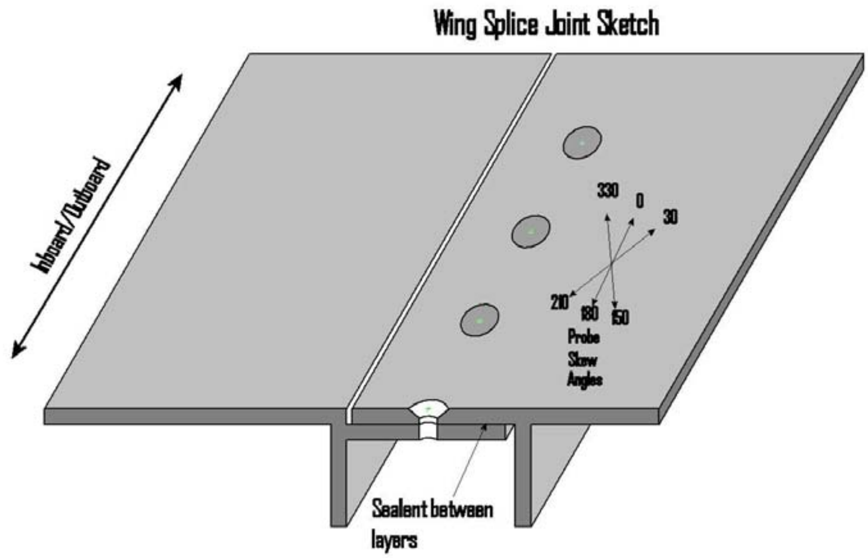

Figure 1 Typical wing skin slice joint showing probe skew angles

To get an understanding of the data it should be transformed from its original format to a corrected geometric format. The transformation process will reduce the amount of data because of multiple data points in the original data set end up same location due to the nature of the shearwave data. The new transformed data set is the peak amplitude for depth zone (layer). The peak amplitude data can be viewed in three different (X-Y-Z) planes as well as a 3-D interactive display. Show below (*Figures 2a & 2b*) is an example of a six fasteners scan before and after geometric corrections are done.

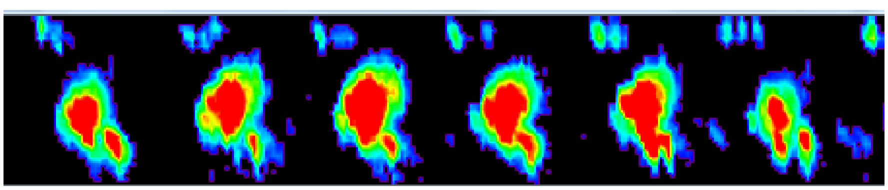

Figure 2a Untransformed Peak amplitude data fasteners

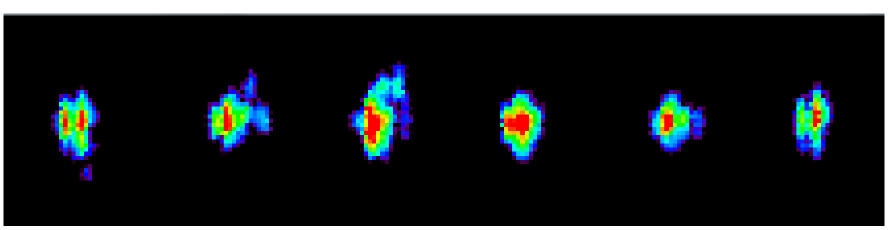

Figure 2b Geometric transformed amplitude data at .150" depth slice

The clusters of data are categorized and fastener holes are located by looking at the large areas of high intensity signals. A large cluster peak determines the location hole's front center location. The amount of total energy reflected from a hole will be recorded and used as a measure to determine the quality of signal return *(Figure 3)*. The quality number will provide an indication to the inspector that there is not enough signal return to determine if there might be a defect indication from it; or too much gain causing a blooming effect.

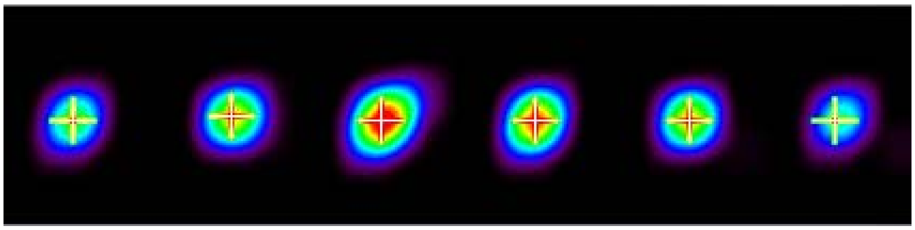

Figure 3 Amplitude intensity to determine hole locations and signal quality

Once the holes are located the smaller data clusters are categorized and tested for size, amplitude and location. Those smaller clusters will then be given a weight and based on area and intensity. The amount of occurrences of a cluster that meets the threshold and region of interest is tabulated and will determine in a truth table if it is a call or no call (*Figures 4a & 4b*). They're very well could be a low level data cluster that would not be alerted since there is only one occurrence and nothing else in the area. This feature helps reduce false calls due to the material and random electrical noise and real indications show up at more than one thickness level.

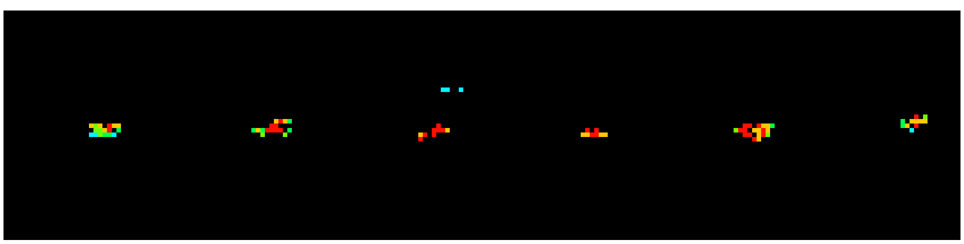

Figure 4a Small data clusters around the holes

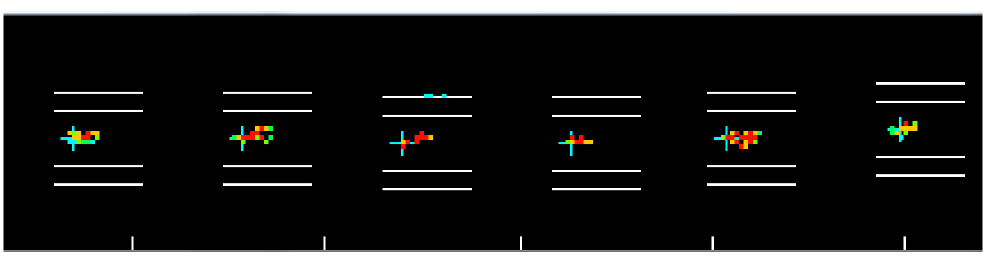

Figure 4b Areas of interest are gated above and below the hole clusters

The results are reported to a Plan view image which is exported to a BMP file along with report text files. See *Figures 5* and *Table 1*. The image files presents the fastener location, its hole number, inch scale, probe skew direction clock and different colored circles and colored + signs illustrating the No calls, Calls and Low amplitude hole signals. The green indication means AFCS has determined the hole is good; the yellow is reporting a low amplitude signal return and the blue is indicating there is a low level (weak) call.

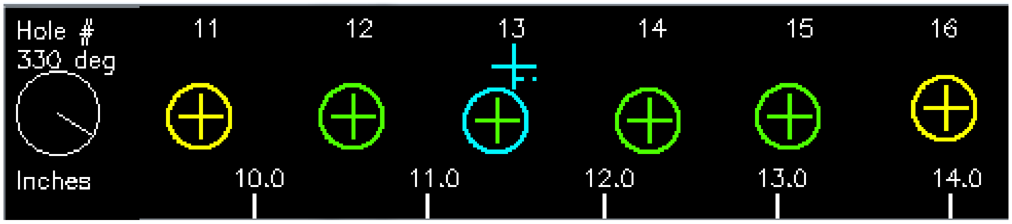

Figure 5 Final Plan view analyses on the scan data

C:\ImageData\FlawInspecta\Splice-Data\P 17 18 19 36 5M p3\P17 S5 H1-26 A30CCC.txt
JR Mandeville NDI Consulting Services 2009 (c)
AFCS Output Flawinspectra Data - CALL REPORT
Tue Apr 28 13:53:42 2009

Holes Sorted by Assending hole X - Location

Hole #	X Loc	Y Loc	HOLE Qual CALL	LARGE AREA CALL	SOFT Above CALL	SOFT Below CALL
11	9.707	0.578	POOR	NO	NO	NO
12	10.578	0.588	GOOD	NO	NO	NO
13	11.407	0.554	GOOD	NO	WEAK	NO
14	12.283	0.560	GOOD	NO	NO	NO
15	13.081	0.575	GOOD	NO	NO	NO
16	13.961	0.628	POOR	NO	NO	NO

Table 1 User configurable automated test report

Test results on four 2-layer test panels:

The test panels are cut from original P3 wing skins and were dismantled; EDM notches were induced and reassembled. The EDM notches were cut into the 1^{st} and 2^{nd} layers at various sizes and lengths emanating out of the faster hole. The notches were from 0.035” to 0.210” in size and induced at 6 different notch angles (12:00, 1:30, 4:30, 6:00 7:30, 10:30 o’clock) around the fastener hole. Ultrasonic shearwave inspection was performed at 45^{o} 5MHz phased array transducer using the FlawInspecta. Four scans were performed using different skew angles (0^{o}, 180^{o}, 30^{o}, 150^{o}). The test panels have the same appearance as *Figure 1* shown previously.

The UT inspection was performed on 90 fastener holes with 68 induced notches at the four skew angles. Some notches were not ultrasonically detectible due to notches being filled with sealant or the 2^{nd} layer was not bonded to the 1^{st} layer.

AFCS analysis results:
360 holes inspected (90 x 4 skew angles)
Detected 100% visible (in the data) notches equal to or greater than 0.100”
Detected ~50% notches under 0.100”
The AFCS made 2 false calls.
The false calls were reviewed by looking at the image data and it was determined no notch signals were in the data.

Conclusions and future work:

The AFCS technology has great potential to speed data evaluation and reporting. The total inspection time can be reduced significantly. Human errors during the inspection and data review can be reduced or nearly eliminated. AFCS can be tuned to specific applications and is procedure driven. AFCS can be set to evaluate indications in the same manner as the reviewer does. The AFCS is designed to assist the inspector/evaluator not replace them. The AFCS program is the next logical step to increase the Probability of Detection of defect indication in large data sets. AFCS can evaluate image data from several data acquisition platforms and more platforms are being considered. It is a relatively simple process to import a new platform’s image data. AFCS is paving the way for rapid inspection of large areas of aircraft structure without sacrificing inspection quality.

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