Designation: ~~E3370 – 22~~ E3370 – 23

Standard Practice for Matrix Array Ultrasonic Testing of Composites, Sandwich Core Constructions, and Metals ~~Used in Aerospace Applications~~[1]

This standard is issued under the fixed designation E3370; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 This practice ~~establishes~~covers procedures for matrix array ultrasonic testing (MAUT) of monolithic composites, composite sandwich constructions, and metallic test articles. These procedures can be used throughout the life cycle of a part during product and process design optimization, on line process control, post-manufacturing inspection, and in-service inspection.

1.2 In general, ultrasonic testing is a common volumetric method for detection of embedded or subsurface discontinuities. This practice includes general requirements and procedures which may be used for detecting flaws and for making a relative or approximate evaluation of the size of discontinuities and part anomalies. The types of flaws or discontinuities detected include ~~delamination,~~ interply delaminations, foreign object ~~debris,~~ debris (FOD), inclusions, disbond/un-bond, fiber debonding, fiber fracture, porosity, voids, impact damage, thickness variation, and corrosion.

1.3 Typical test articles include monolithic composite ~~lay-ups~~layups such as uniaxial, cross ply and angle ply laminates, sandwich constructions, bonded structures, and filament windings, as well as forged, wrought and cast metallic parts. Two techniques can be considered based on accessibility of the inspection surface: namely, pulse echo inspection for one-sided access and through-transmission for two-sided access. As used in this practice, both require the use of a pulsed straight-beam ultrasonic longitudinal wave followed by observing indications of either the reflected (pulse-echo) or received (through transmission) wave.

1.4 This practice provides two ultrasonic test procedures. Each has its own merits and requirements for inspection and shall be selected as agreed upon in a contractual document.

1.4.1 *Test Procedure A, Pulse Echo (non-contacting and contacting)* is at a minimum a single matrix array transducer transmitting and receiving longitudinal waves in the range of ~~0.5 to 20 MHz~~ 0.5 MHz to 20 MHz (see Fig. 1). This procedure requires access to only one side of the specimen. This procedure can be conducted by automated or manual means. Automated and manual test results may be analyzed in real time or recorded and analyzed later.

1.4.2 *Test Procedure B, Through Transmission (non-contacting and contacting)* is a combination of two transducers. One transmits a longitudinal wave and the other receives the longitudinal wave in the range of ~~0.5~~0.5 MHz to 20 MHz (see Fig. 2). This procedure requires access to both sides of the specimen. ~~This~~ Typically, the signal transmitting and signal receiving transducers are perpendicularly aligned with each other. This is normally achieved using a yoke transducer holder arrangement, which attaches the two transducers to a single point but deploys them on opposite sides of the structure. Through transmission inspections are also permitted without the use of a yoke transducer holder. This is due to the capacity for improved manual alignment via the matrix

[1] This practice is under the jurisdiction of ASTM Committee E07 on Nondestructive Testing and is the direct responsibility of Subcommittee E07.06 on Ultrasonic Method.
Current edition approved ~~Dec. 1, 2022~~July 1, 2023. Published ~~January 2023~~August 2023. Originally approved in 2022. Last previous edition approved in 2022 as E3370 – 22. DOI: ~~10.1520/E3370-22.~~10.1520/E3370-23.

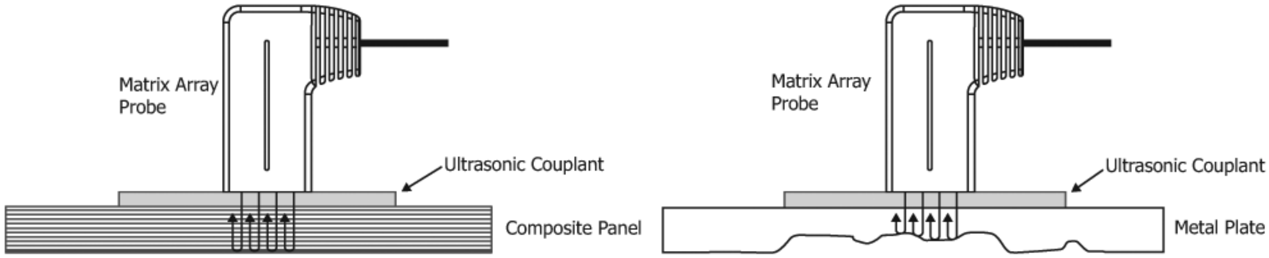

FIG. 1 Test Procedure A, Pulse Echo Apparatus Set-up for a Composite Panel (Left) and Metal Plate (Right) Using One-sided Access

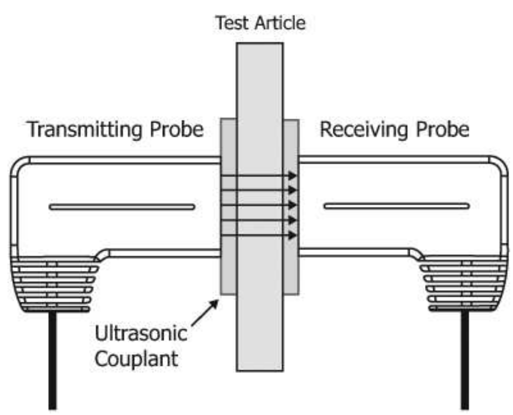

FIG. 2 Test Procedure B, Through Transmission Apparatus Set-up using Two-sided Access

array transducers, whereby the live C-scan display enables visual confirmation of accurate alignment, and facilitates re-alignment if needed. This procedure can be conducted by automated or manual means. Automated and manual test results may be imaged or recorded.

1.5 Other contact methods such as angle-beam techniques using shear waves to characterize welds, or surface-beam techniques using Lamb waves to detect impact damage in composite panel structures are not covered.

1.6 This practice does not specify accept-reject criteria.

1.7 *Units*—The values stated in SI units are to be regarded as standard. The values given in parentheses after SI units are provided for information only and are not considered standard.

1.8 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety, health, and environmental practices and determine the applicability of regulatory limitations prior to use.*

1.9 *This international standard was developed in accordance with internationally recognized principles on standardization established in the Decision on Principles for the Development of International Standards, Guides and Recommendations issued by the World Trade Organization Technical Barriers to Trade (TBT) Committee.*

2. Referenced Documents

2.1 *ASTM Standards:*[2]

D3878 Terminology for Composite Materials
D5687/D5687M Guide for Preparation of Flat Composite Panels with Processing Guidelines for Specimen Preparation
E114 Practice for Ultrasonic Pulse-Echo Straight-Beam Contact Testing
E127 Practice for Fabrication and Control of Flat Bottomed Hole Ultrasonic Standard Reference Blocks
E494 Practice for Measuring Ultrasonic Velocity in Materials by Comparative Pulse-Echo Method
E543 Specification for Agencies Performing Nondestructive Testing

[2] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

E797/E797M Practice for Measuring Thickness by Manual Ultrasonic Pulse-Echo Contact Method
E1001 Practice for Detection and Evaluation of Discontinuities by the Immersed Pulse-Echo Ultrasonic Method Using Longitudinal Waves
E1434 Guide for Recording Mechanical Test Data of Fiber-Reinforced Composite Materials in Databases (Withdrawn 2015)[3]
E1901 Guide for Detection and Evaluation of Discontinuities by Contact Pulse-Echo Straight-Beam Ultrasonic Methods
E1316 Terminology for Nondestructive Examinations
E2375 Practice for Ultrasonic Testing of Wrought Products
E2491 Guide for Evaluating Performance Characteristics of Phased-Array Ultrasonic Testing Instruments and Systems
E2580 Practice for Ultrasonic Testing of Flat Panel Composites and Sandwich Core Materials Used in Aerospace Applications

2.2 *SAE Standards:*[4]
ARP 5605 Solid Composite Laminate NDI Reference Standards
ARP 5606 Composite Honeycomb NDI Reference Standards
ARP 5089 Composite Repair NDT/NDI Handbook

2.3 *AIA Standard:*[5]
NAS-410 NAS Certification & Qualification of Nondestructive Test Personnel

2.4 *ASNT Documents:*[6]
SNT-TC-1AANSI/ASNT CP-189 Recommended Practice for Personnel Standard for Qualification and Certification inof Nondestructive Testing Personnel
ANSI/ASNT CP-189SNT-TC-1A Standard for Recommended Practice for Personnel Qualification and Certification orin Nondestructive Testing Personnel
Nondestructive Testing Handbook, Ultrasonic Testing, 2nd Edition, Vol. 7

2.5 *ISO Standard:*[7]
ISO 9712 NDT–Qualification and Certification of NDT Personnel in the Applicable Product Sector "Aerospace"

2.6 *European Committee for Standardization Document:*[8]
EN 4179 Aerospace Series - Qualification and Approval of Personnel for Non-destructive Testing

2.7 *FAA Circular Advisory:*[9]
AC-65-31B Training, Qualification, and Certification of Nondestructive Inspection Personnel

2.8 *MIL Document:*[10]
MIL-HDBK-1823 Nondestructive Evaluation System Reliability Assessment

3. Terminology

3.1 *Definitions*—Terminology in accordance with Terminologies E1316 and D3878 shall be used where applicable.

3.2 *Definitions of Terms Not Specific to This Standard:*

3.2.1 *defect, n*—see Terminology E1316.

3.2.2 *delamination, n*—see Terminology D3878.

3.2.3 *disbond, n*—see Terminology D3878.

3.2.4 *distance amplitude correction (DAC), n*—see Terminology E1316.

3.2.5 *flaw, n*—see Terminology E1316.

3.2.6 *matrix array probes,transducers, n*—these probestransducers have an active area divided in two dimensions in different elements. This division can, for example, be in the form of a checkerboard, or sectored rings. Matrix array probestransducers may either be phased or nonphased. Nonphased matrix array probestransducers tend not to have discrete piezoelectric elements that

[3] The last approved version of this historical standard is referenced on www.astm.org.
[4] Available from SAE International (SAE), 400 Commonwealth Dr., Warrendale, PA 15096, http://www.sae.org.
[5] Available from Aerospace Industries Association (AIA), 1000 Wilson Blvd., Suite 1700, Arlington, VA 22209, http://www.aia-aerospace.org.
[6] Available from American Society for Nondestructive Testing (ASNT), P.O. Box 28518, 1711 Arlingate Ln., Columbus, OH 43228-0518, http://www.asnt.org.
[7] Available from International Organization for Standardization (ISO), ISO Central Secretariat, Chemin de Blandonnet 8, CP 401, 1214 Vernier, Geneva, Switzerland, https://www.iso.org.
[8] Available from CEN-CENELEC Management Centre, Rue de la Science 23, B-1040 Brussels.
[9] Available from U.S. Department of Transportation Federal Aviation Administration 800 Independence Ave SW, Washington, DC 20591.
[10] Available from Standardization Documents Order Desk, Bldg. 4 Section D, 700 Robbins Ave., Philadelphia, PA 19111-5094, Attn: NPODS.

pulse and receive individually. They instead achieve a matrix array aperture by either using a crossed electrode architecture or by pulsing from a large single crystal and receiving on a separate two-dimensional array. Due to this architecture, ~~the~~ matrix array ~~probes do~~transducers may not allow beam steering. They are thus typically used for straight beam applications such as inspection of composites and corrosion mapping. Such nonphased matrix array ~~probes typically~~ transducers use live C-scan displays, highlighting the inspection region directly beneath the ~~probe.~~transducers.

3.2.6.1 *Discussion—*
For the purpose of this practice, the matrix array ~~probes~~transducers used are nonphased.

3.2.7 *phased array transducer, n*—see Terminology E1316.

3.2.8 *pulse echo method, n*—see Terminology E1316.

3.2.9 *sandwich construction, n*—see Terminology D3878.

3.2.10 *through transmission technique, n*—see Terminology E1316.

3.3 *Definitions of Terms Specific to This Standard:*

3.3.1 *flat panel composite, n*—any fiber reinforced composite lay-up consisting of laminate (plies) with one or more orientations with respect to some reference direction that are consolidated by press or autoclave to yield a two-dimensionally flat article of finite thickness.

3.3.2 *time-corrected gain (TCG), n*—time-corrected gain is a method of compensating for a reduction in signal amplitude with increasing range from reflectors of equal area. This is achieved by increasing the system gain with time so that the signals appear of equal amplitude. TCG achieves the same objective as a DAC.

3.3.2.1 *Discussion—*
Calibration using TCG is required to ensure that indications have uniform amplitude with depth and position.

4. Summary of Practice

4.1 This practice describes two procedures for detecting bulk defects in monolithic composites, composite sandwich constructions, and metallic parts using ultrasonic longitudinal waves emitted from a two-dimensional matrix array ~~probe~~transducer and coupled by contact. Equipment, reference blocks, examination procedures, data evaluation procedures, and documentation are described in detail

4.2 This practice focuses on the advantages and limitations of two-dimensional matrix arrays. Characteristics of phased array ~~probes~~transducers such as linear, annular, and "rho-theta" are not discussed.

5. Significance and Use

5.1 The procedures described in this practice have proven utility in the inspecting (*1*) monolithic polymer matrix composites (laminates) for bulk defects, (*2*) metals for corrosion during the service life of the part of interest, (*3*) thickness checks, (*4*) adhesive bonding of metals, composites, and sandwich core constructions, (*5*) coatings, and (*6*) composite filament windings. Both unpressurized, and with suitable precautions, pressurized materials and components are inspected.

5.2 This practice provides guidelines for the application of longitudinal wave examination to the detection and quantitative evaluation of damage, discontinuities, and thickness variations in materials.

5.3 This practice is intended primarily for the testing of parts to acceptance criteria most typically specified in a purchase order or other contractual document, and for testing of parts in-service to detect and evaluate damage.

5.4 MAUT search units provide near-surface resolution and detection of small discontinuities comparable to phased array ~~probes.~~transducers. They may or may not be capable of beam steering. The advantage of MAUT for straight-beam longitudinal wave inspections is the ability to provide real-time C-scan data, which facilitates data interpretation and shortens inspection time. Depending on inspection needs, data can be displayed as A-, B- or C-scans, or three-dimensional renderings. Toggling between pulse-echo and through transmission ultrasonic (TTU) modes without having to use another system or changing transducers is also possible.

5.5 The MAUT technique has proven utility in the inspection of multi-ply carbon-fiber reinforced laminates used in primary aircraft structures.[11]

5.6 For ultrasonic ~~testing, the flat panel~~ testing of laminate composites and sandwich core materials using conventional UT equipment consult Practice E2580. Consult Practice E114 for ultrasonic testing of materials by the pulse-echo method using straightbeam longitudinal waves introduced by a piezoelectric element (transducer) with diameters of ~~3.2~~3.2 mm to 28.6 mm ~~(⅛~~(⅛ in. to 1⅛ in.) in contact with the material being examined and usually presented in an A-scan display.

5.7 This practice is directed towards the evaluation of discontinuities detectable at normal beam incidence. If discontinuities or material integrity at other orientations are of concern such as through cracks and welds, alternate scanning techniques are required.

5.8 *Test Procedure A, Pulse Echo*—Pulsed energy is transmitted into materials, travels in a direction normal to the contact surface, and is reflected back to the search unit by discontinuity or boundary interfaces, which are parallel or near parallel to the contacted surface. These echoes return to the search unit, where they are converted from mechanical to electrical energy and are amplified by a receiver. The amplified echoes (signals) are displayed as A-, B- or C-scans, or three-dimensional renderings. Types of information that may be obtained from the pulsed-echo straight-beam practice are (*1*) apparent discontinuity size, (*2*) depth location of discontinuities, (*3*) material properties such as velocity of sound in the material, and similarly, the thickness of a material, and (*4*) the extent of bond and unbond (or fusion and lack of fusion) between two ultrasonic conducting materials if geometry and materials permit. In addition to detecting volumetric discontinuities such as delaminations (Fig. 3), ultrasonic thickness measurements can be made with MAUT search units in pulse-echo mode on basic shapes and products of many materials, and on precision machined parts, to determine wall thinning in process equipment caused by corrosion and erosion (Fig. 4).

5.9 *Test Procedure B, Through Transmission*—In TTU, a ~~probe~~transducer on one side of a part transmits an ultrasonic pulse to an aligned receiving ~~probe~~transducer on the other side (Fig. 2). Alignment between the two ~~probes~~transducers is often accomplished by automation. Attenuation or absence of the pulse coming to the receiving ~~probe~~transducer indicates the presence of a defect. Advantages of TTU over pulse-echo include less attenuation of sound energy, absence of ~~probe~~transducer ringing, and less of an

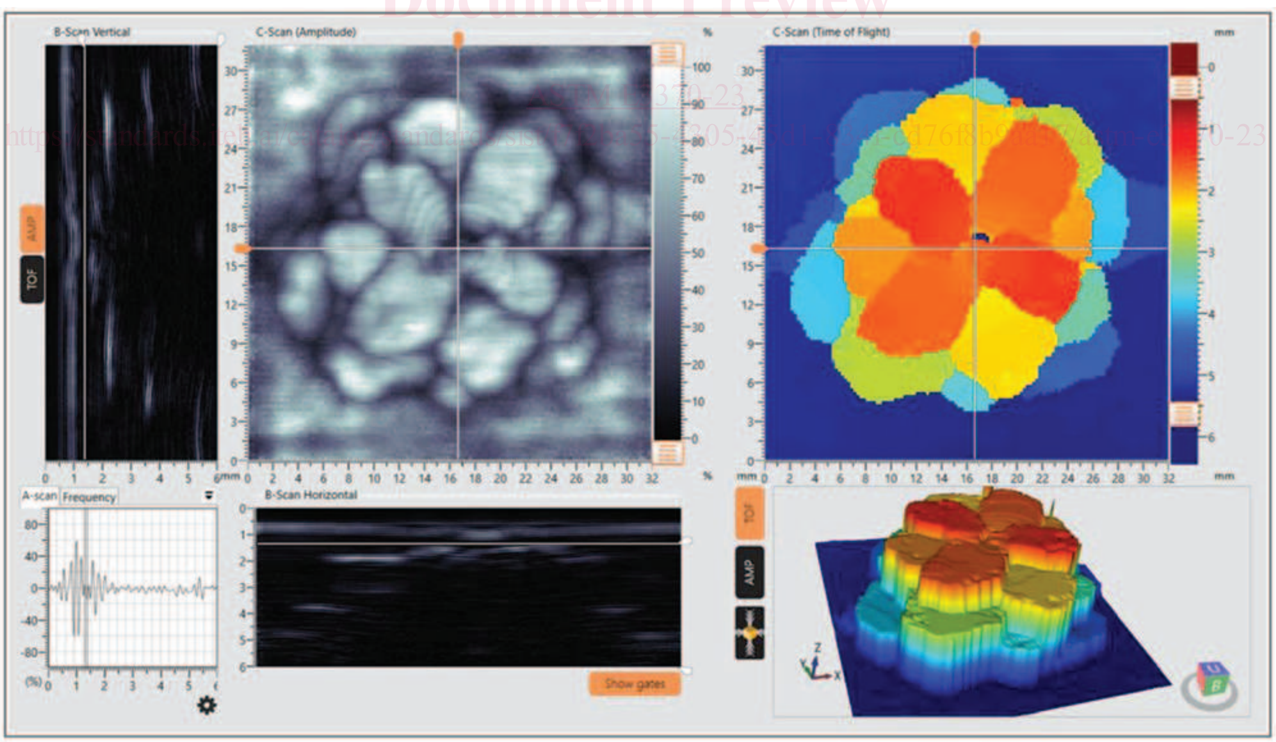

FIG. 3 Detection of Delamination in Flat Panel Carbon-fiber Reinforced Composite Using Matrix Array Ultrasonic Testing Showing Typical A-, B- and C-Scans and A Three-dimensional Rendering (Pulse-Echo Method)

[11] The Boeing Company, *787 Nondestructive Test Manual Part 4 – Ultrasonic*, Dec. 30, 2015, P.O. Box 3707, Seattle, Washington 98124.

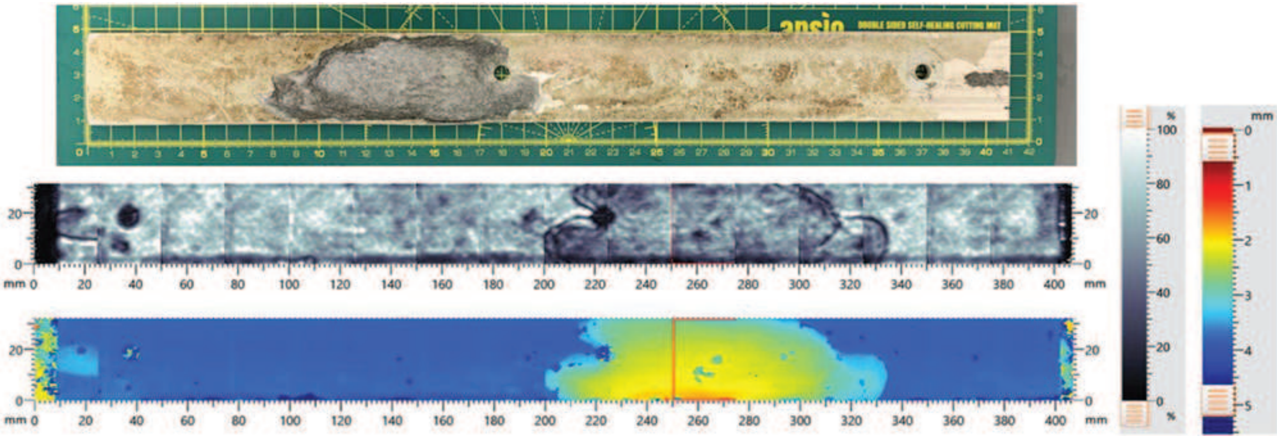

FIG. 4 Detection of Wall Thinning Corrosion in 3.5 mm Thick Aluminum Plate Using Matrix Array Ultrasonic Testing (Pulse-Echo Method)

effect of defect orientation on transmitted signal. However, two-sided access is necessary, and like pulse-echo, vertical defects such as through cracks are difficult to detect. Applications include inspection of plate and bar stock after manufacturing, and detection of disbonds in materials with high attenuation properties that hinder sound propagation, such as multiple bond layers, honeycomb cores (Fig. 5), and foam cores.

5.10 This practice does not discuss nonlinear resonant ultrasonic spectroscopy, ultrasonic spectral analysis, use of angle beams, transverse waves, and guided waves that can be used to assist in bond characterization in composites or sandwich constructions.[12] Air coupled ultrasonic inspection using MAUT search units to detect skin-to-core disbonds in sandwich constructions is also not discussed.

6. Basis of Application

6.1 *Timing of Examination*—The timing of examination shall be in accordance with 9.1 and 9.2 in this practice, unless specified otherwise.

6.2 *Extent of Examination*—The extent of examination (coverage) shall be in accordance with 9.4 in this practice, unless specified otherwise.

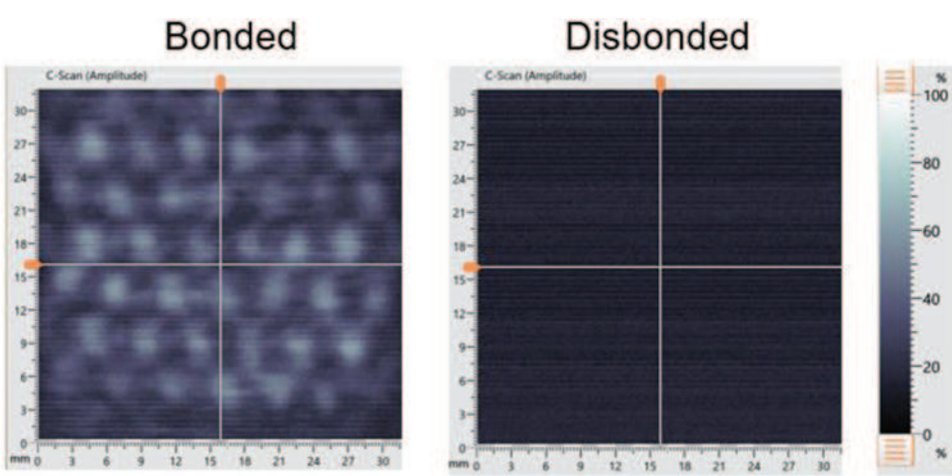

FIG. 5 Detection of Disbond in A Sandwich Construction Consisting of A Graphite Fiber Reinforced Facesheet and An Aluminum Honeycomb Core Using Matrix Array Ultrasonic Testing (Through-Transmission Mode)

[12] Hsu, D. K., Bossi, R. H., and Roach, D. P., *Bond Testing, Part 2. Bond Testing Methods, Chapter 14*, American Society of Nondestructive Testing, 2014.

6.3 *Reporting Criteria/Acceptance Criteria*—Reporting criteria for the examination results shall be in accordance with 9.8 and Section 12, unless otherwise specified. Since acceptance criteria (for example, for reference sonograms) are not specified in this practice, they shall be specified in the contractual agreement.

6.4 *Reexamination of Repaired/Reworked Items*—Reexamination of repaired/reworked items is not addressed in this practice and if required shall be specified in the contractual agreement. For guidance to assist inspectors on where to inspect repaired composite and metal bonded parts on the aircraft, to understand the capabilities of current NDT methods, and to aid interpretation of inspection results, consult ARP 5089. ARP 5089 does not override any instructions that may be issued within a manufacturer's or operator's published documentation.

6.5 *Probability of Detection (POD)*—Detailed instruction for assessing the reliability of NDT data using POD with composite, sandwich core and metallic test articles is beyond the scope of this practice. More detailed instruction for assessing the capability of an NDT method by determining the POD as a function of flaw size can be found in MIL-HDBK-1823. Specific performance of NDT methods applied to composite laminate and composite honeycomb structures can be found elsewhere.[13]

7. Quality Assurance Provisions

7.1 There are areas in this practice that require agreement between the cognizant engineering organization and the supplier, or specific direction from the cognizant engineering organization.

7.2 The following items are subject to contractual agreement between the parties using or referencing this practice.

7.3 *Personnel Qualification*—If specified in the contractual agreement, personnel performing examinations to this practice shall be qualified in accordance with a nationally or internationally recognized NDT personnel qualification practice or standard such as ANSI/ASNT-CP-189, SNT-TC-1A, NAS-410, ISO 9712, FAA CA-65-31B or similar document and certified by the employer or certifying agency, as applicable. The practice or standard used, and its applicable revision, shall be identified in the contractual agreement between the using parties.

7.4 *Qualification of Nondestructive Agencies*—If specified in the contractual agreement, NDT agencies shall be qualified and evaluated as described in Specification E543. The applicable edition of Specification E543 shall be specified in the contractual agreement.

7.5 *System Performance*—As a minimum requirement, system performance should be verified in accordance with the following schedule (if mutually agreed upon, more stringent or frequent checks may be specified): (*1*) Gain settings and distance amplitude relationships should be checked after any interruption of power, change of operating personnel, replacement of a system component, or adjustment of any electrical or mechanical control which cannot be returned exactly to its previous position and (*2*) verification should also be made at such interim periods as are needed to assure that any material previously inspected can be recovered and reinspected. To evaluate performance characteristics of phased array ~~probes~~transducers consisting of a series of individually wired elements that are activated separately using a programmable time delay pattern, and where it is possible to vary the beam angle, focal distance, or beam dimensions, consult Practice E2491.

7.6 *Wetting Agent Control*—When wetting agent solution is used, check the agent concentration in the solutions after initial solution makeup and at ~~90-day~~90 day intervals. Wetting agents are used to deaerate the couplant and enhance adherence of the couplant to the material and search unit. The ability of the wetting agents used as a couplant should be verified during normal system calibration activities carried out just prior to conducting an inspection.

8. Apparatus and Materials

8.1 *Apparatus*

8.1.1 *Operation*—Test equipment shall be capable of providing uniform, repeatable, and controlled operation.

[13] Roach, D, Rice, T., "A Quantitative Assessment of Advanced Nondestructive Inspection Techniques for Detecting Flaws in Composite Laminate Aircraft Structures," U.S. Dept. of Transportation Report DOT/FAA/TC-15/4, March, 2016.