Process Specification for Ultrasonic Inspection of Composites

Engineering Directorate

Structural Engineering Division

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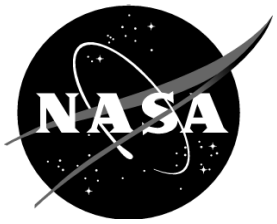

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REVISIONS		
VERSION	**DESCRIPTION**	**DATE**
Baseline	Original version	5/27/1997
A	Modified Section 3.1 "Levels" to replace MIP's with inspection points; modified Section 6.5 "Reference Standards" to eliminate +/-4 dB requirement; clarified report requirements for work performed at JSC facilities in Section 6.13 "Inspection Report."	8/28/1998
B	Modified the porosity acceptance criteria in Section 7.3 to account for part thickness and test frequency variations.	8/11/2000
C	Reviewed document per QMS requirements. Updated division name, organization codes, and document numbers.	
D	Revised applicable documents and inspection methods	01/04/2010
E	Revised applicable documents and inspection methods	06/29/2011
F	Added NASA-STD-5009 to para. 4.0. Deleted MIL-STD-2154 from para. 5.0, and added ASTM E2375. Deleted Term "Material Data Sheet" from para. 6.4 and 6.12 for clarity.	05/06/2014
G	Revised paragraph 9.0 for uniformity across all NOE PRCs. Revised para. 6.2, and definitions. Added NASA-HDBK-5010 which provides recommended requirements for ultrasonic testing of composite materials.	01/07/2020

1.0 SCOPE

This document establishes the minimum requirements for ultrasonic inspection of laminated composites, bonded laminates, and adhesively bonded honeycomb composite materials.

2.0 APPLICABILITY

This specification shall be applicable whenever ultrasonic inspection is invoked per Section 3.0, "Usage". This specification is applicable to in-process, final, and in-service ultrasonic inspections to detect discontinuities in composite materials described in para. 1.0. Ultrasonic inspection is intended to detect disband and delaminations between layers of laminated material and laminated and bonded materials like honeycomb or metal typically more or less parallel to the closest surface or mold line.

3.0 USAGE

This specification shall be invoked by including an inspection note in the applicable drawing or by reference in a Process Specification, Task Performance Sheet, Discrepancy Report/Material Review Record or other appropriate work authorizing document as exemplified in Fig. 1.

ULTRASONICALLY INSPECT PER JSC PRC-6501, Level 1

3.1 LEVELS

The "Level" designator governs the extent to which quality assurance provisions are applied and shall be specified in the inspection note on the basis of the following definitions:

a. Level 1 - Level 1 inspections are those generally applied to Class I or Class II hardware. The procedures for Level 1 inspections shall have inspection points for the calibration of the ultrasonic test equipment and for evaluation of flaw indications. Traceable records for all inspection points shall be maintained as a permanent quality record.

b. Level 2 - Level 2 inspections are those generally applied to Class Ill hardware or ground support equipment (GSE). There are no special process verification requirements for Level 2 inspections.

3.2 ACCEPTANCE CRITERIA

Unless otherwise stated on the drawing, the standard acceptance criteria in Section 7.0 shall be applicable. If alternate acceptance criteria are desired, then the criteria shall be added to the inspection note as exemplified in Fig. 2. The acceptance criteria specified in the inspection note supersedes the standard acceptance criteria in their entirety.

ULTRASONICALLY INSPECT PER JSC PRC-6501, Level 1, DELAMINATIONS,

DISBONDS, AND POROSITY GREATER THAN 1 INCH DIAMETER OR EQIVALENT AREA ARE REJECTABLE

4.0 APPLICABLE DOCUMENTS

The following specifications, standards, and handbooks form a part of this document to the extent specified herein. All documents listed are assumed to be the current revisions unless a specific revision is listed. In the case of conflict between this specification and the technical requirements cited in other referenced documents, the requirements of this document take precedence unless a deviation to the document has been authorized by appropriate engineering authority.

ASTM E 317	*Practice for Evaluating the Performance Characteristics of Ultrasonic Pulse-Echo Testing Systems without the Use of Electronic Measurement Instruments*
NAS 410	NAS *Certification & Qualification of Nondestructive Test Personnel*
NASA-STD-5009	*Nondestructive Evaluation Requirements for Fracture- Critical Metallic Components*
SNT-TC-1A	*Personnel Qualification and Certification in Nondestructive Testing*
NASA-HDBK-5010	*Fracture Control Implementation Handbook for Spaceflight Hardware*

5.0 REFERENCED DOCUMENTS

SOP-007.1	*Preparation and Revision of Process Specifications (PRC's)*
ASTM E2375	*Standard Practice for Ultrasonic Evaluation of Wrought Products*

6.0 PROCESS REQUIREMENTS

6.1 WRITTEN PROCEDURE

All inspections shall be performed in accordance with a detailed written procedure. The procedure shall meet the requirements of this specification and include the following:

a. Reference to this PRC by number and title.

b. Manufacturer and model numbers of all instrumentation.

c. Type, size, and frequency of the transducers used as well as a description of any wedges, shoes, bubblers, or squirters.

d. Description of any couplant additives.

e. Description of scanning equipment and method for determining scan speeds and indexes.

f. Scan plan.

g. Description of the calibration procedure and reference standards.

h. Discontinuity evaluation procedure.

i. Any other pertinent data.

For work performed at JSC facilities, written procedures shall consist of Detailed Process Instructions (DPIs) selected for use from the DPI-6501-XX series of work instructions.

6.2 INSPECTION METHOD

6.2.1 Assumptions

AC-scan is used to display data produced by raster scanning. Techniques are assumed to be Ultrasonic (Phased-array/ pulse-echo/ through-transmission) in zero degree longitudinal wave mode. If other techniques are used small changes to the requirements may be needed. The techniques assume square pixels i.e. scan step equals index step. Requirements are assumed to provide high POD and low POF without full POD demonstration. POD and POF will not be quantified. Noise is measured in an area outside flaw indication as standard deviation of gray level or signal response. For a given flaw type domain, six flaws of target size; or 3 flaws of target size along with 3 flaws of sub-target size are assumed to provide adequate measure of scatter in signal response for NOE validation.

6.2.2 Reference Standard Requirements

NOE reference standard shall be representative of the part and shall have known size representative flaws (programmed delaminations or disbands) at various depths (z coordinate) and spatial (x, y coordinates) locations. Representative flaws in the laminate sections shall be located at minimum 3 depths providing adequate coverage for flaws within the laminate thickness. Typically, in laminates, flaws shall be on nearside, middle and farside. Nearside and farside flaws may be between ply 2-3 from the respective nearside and farside laminate surfaces. For thinner laminate thicknesses, where more than 2- 3 plies of separation between flaw depths is not possible, less than three depths of flaws may be used. Representative disbands shall be located on both sides of (film or paste) adhesive for bonded parts. Pull tabs may be used for core structures. The representative flaws shall be spaced so that they do not overlap in (x, y) coordinates. Minimum 6 target size flaws and minimum 6 sub-target size flaws are recommended for each flaw type domain. Flaws used for validation of NOE procedure may be located on a single or several physical test

standards.

6.2.3 Flaws Used for Validation and/or Calibration/Standardization

Both target and sub-target flaws shall provide adequate and uniform flaw detectability (indication size and signal response). Flaws with out-of-family flaw indications caused by either bonding of flaw partially or wholly shall not be used in the validation. Flaws with out-of-family flaw indications that are larger than the expected area of the indications shall not be used in the validation.

6.2.4 NOE Procedure Validation Requirements

Requirements of either Criteria 1 or 2 shall be met for NOE procedure validation.

Criteria 1: Based on minimum of 6 target size flaws following requirements shall be met for each of the six target size flaws for each flaw type domain in the standard.

a. CNR shall be ≥ 2.5. Minimum 40 pixels shall be used for noise measurement.
b. Aperture or beam size shall be ≤ target flaw size.*
c. There shall be minimum 50% overlapping i.e. step size ≤ 0.5 aperture size*.

Criteria 2: Based on minimum of 3 target size flaws and 3 sub- target size flaws following requirements shall be met.

a. For each of the three target size flaws for each flaw type domain in the standard.
b. CNR shall be ≥ 2.5. Minimum 40 pixels shall be used for noise measurement.
c. Aperture or beam size shall be ≤ target flaw size*
d. There shall be minimum 50% overlapping i.e. step size ≤ 0.5 aperture size*.
e. For each of the three sub-target size flaws for each flaw type domain in the standard.
f. CNR shall be ≥ 2.5. Minimum 40 pixels shall be used for noise measurement.

For manual pulse-echo inspections using A-scan, reference target size flaws shall be detected with signal response 6 dB above noise level measured as maximum of peak responses from non-indication area or background outside an indication (~99 percentile noise).

6.2 EQUIPMENT

The equipment used shall be capable of performing inspections to the requirements of this specification. Transducer frequencies and sizes shall be selected to provide optimum detection of unacceptable flaws in the structure inspected. Electronic equipment, when used with the appropriate transducers, shall be capable of operating in the frequency range of at least 1 to 10 MHz. The horizontal and vertical linearity of the equipment shall be checked annually using the procedures in ASTM E 317.

6.3 COUPLANT

When water is used as a couplant, deionized water shall be used for level inspections. The water shall be free of air bubbles and other foreign matter which could interfere with the inspection. Corrosion inhibitors and wetting agents may be added, if necessary, to inhibit corrosion and prevent the formation of bubbles. However, any such additives must be approved by the responsible design authority.

Use of couplants other than deionized water for contact inspection of rough surfaces shall be approved by the responsible design authority. Parts subject to subsequent bonding operations shall be cleaned after inspection in accordance with approved cleaning procedures to ensure removal of all residual couplant.

6.4 REFERENCE STANDARDS

Reference standards with a physical configuration and acoustic properties similar to the part under test shall be used to establish the ultrasonic test parameters. The thickness of the reference standard shall be within 1O percent or 2 plies, whichever is greater, of the thickness of the part. Laminated composite reference standards shall have a porosity content of less than 0.2 percent by volume as verified by cross sectioning and optical analysis of a separate co- cured test coupon or a sacrificial area of the actual standard. Attenuation shall not vary more than± 2 dB across the reference standard.

The reference standard shall contain reference flaws representative of the types of defect which must be detected. Reference flaws used to establish the ultrasonic test parameters shall be equal to or smaller than the smallest unacceptable defect.

6.5 CALIBRATION

In addition to annual linearity checks, the inspection system shall be calibrated against the appropriate reference standard at the beginning and end of each inspection shift and every four hours in between. The system shall also be calibrated after any power interruption or system shutdown and before scanning any part where changes in part thickness of more than 10 percent have occurred. A C-scan of the reference standard clearly showing the relevant reference flaws shall be produced as part of the calibration procedure. All of the calibration C-scans shall be maintained as part of the inspection record.

6.6 SURFACE PREPARATION

The surface of the laminate or honeycomb structure under test shall be free of any dirt, oil, or grease which may interfere with the inspection. Honeycomb structures with exposed core or facesheet penetrations shall be sealed prior to inspection to prevent water from entering the structure. All sealing materials added for inspection shall be removed from parts immediately after inspection.

6.7 SCANNING SPEED AND INDEXING INCREMENT

The scanning speed and indexing increment shall not exceed the maximum values which provide for detection of all relevant flaws in the reference standards used to set up the test.

6.8 COVERAGE

Unless otherwise specified by the responsible design authority, all parts shall be 100 percent inspected.

6.9 LOCATION MARKERS

If a part must be inspected in a series of two or more separate scans, then location markers, such as self-adhesive lead tape, shall be placed on the surface of the part. The location markers shall be placed to aid in verifying that individual scans cover all of the intended inspection area and to aid in assembling separate scans into a single mosaic. The size of the markers shall be less than the smallest unacceptable flaw in order to avoid masking unacceptable defects.

6.10 FLAW EVALUATION

Defect indications shall be verified with manual A-scan techniques. Verified defects larger than allowable shall be labeled with the appropriate defect type, i.e., delamination, disband, or porosity, on the c-scan recording and their location shall be marked on the surface of the part. In addition to the defect type, the estimated depth of delaminations shall be noted on the C-scan.

6.11 POST INSPECTION CLEANING

Parts shall be thoroughly cleaned and dried immediately following inspection in accordance with approved cleaning procedures.

6.12 INSPECTION REPORT

An inspection report shall be prepared for each part or group of parts. The report shall indicate compliance with this specification, reference the appropriate written procedure or DPI, and include the name and equivalent NOT Level of the personnel performing the inspection. The report shall identify each part by part number and serial number and indicate whether each part was accepted or rejected. The flaws in all rejected parts shall be noted and a hard copy of the C- scan showing the defective areas shall be attached to the report along with the relevant calibration C-scans. For work performed at JSC facilities, the inspection report shall consist of the completed JSC Form 1262, "Manufacturing Process Record" and, if applicable, a JSC Form 2176, "Discrepancy Report/Material

Review Record". Inspection reports shall be retained as a permanent quality record and a copy provided to the responsible design authority.

7.0 STANDARD ACCEPTANCE CRITERIA

7.1 DELAMINATIONS, VOIDS, FOREIGN MATERIAL, AND LAMINATE-TO-LAMINATE DISBONDS

Any single delamination, void, foreign material inclusion, or laminate-to-laminate disband with a length of 0.25 in. or greater shall be rejected. Any single delamination, void, foreign material inclusion, or laminate-to-laminate disband with an area of 0.049 $in.^2$ or greater shall be rejected. The length and area requirements are separate requirements and must be evaluated individually. Indications meeting either requirement shall be rejected.

Multiple delaminations, voids, foreign material inclusions, or laminate-to-laminate disbands with individual lengths less than 0.25 in. and areas less than 0.049 $in.^2$ but separated by less than 1 inch shall be rejected.

7.2 LAMINATE-TO-CORE DISBONDS

Any single laminate-to-core disband with a length of 1 in. or greater shall be rejected. Any single laminate-to-core disband with an area of 0.785 $in.^2$ or greater shall be rejected. The length and area requirements are separate requirements and must be evaluated individually. Indications meeting either requirement shall be rejected.

Multiple laminate-to-core disbands with individual lengths less than 1 in. and areas less than 0.785 $in.^2$ but separated by less than 6 in. shall be rejected.

7.3 POROSITY

Any area of porosity with a length of 0.5 in. or greater or an area of 0.196 $in.^2$ or greater and producing a signal drop relative to the appropriate reference standard equal to or greater than the dB value given in the following table shall be rejected.

Part Thickness (in.)	Pulse-Echo		Through Transmission	
	2.25 MHz	5.0 MHz	2.25 MHz	5.0 MHz
0.005 -0.064	*NIA*	7 dB	*NIA*	3 dB
0.065 -0.135	4dB	10 dB	3dB	5 dB
0.136 -0.210	7 dB	13 dB	3dB	7 dB
0.211 -0.285	10 dB	16 dB	5 dB	8 dB

8.0 DISPOSITION OF UNACCEPTABLE PARTS

A Discrepancy Report (DR) shall be initiated in accordance with standard operating procedures for each part containing unacceptable flaws. A copy of the inspection report shall be made a part of the DR.

9.0 TRAINING AND CERTIFICATION OF PERSONNEL

Personnel performing acceptance inspections of Class I, 11, IIIW and GSE hardware shall be qualified and certified, at a minimum, to Level 2 in accordance with NAS 410. Personnel performing acceptance inspections requiring Special NOE shall also be qualified and certified for Special NOE in accordance with NASA-STD-5009.

Personnel performing acceptance inspections of Class 111, STE/D, mockup, and facility hardware shall be qualified and certified in accordance with either NAS 410 or SNT-TC-1A. Personnel making accept/reject decisions shall, at a minimum, be certified to Level 2. Level 3 personnel making accept/reject decisions shall have successfully completed a hands-on practical examination equivalent to the examination required for Level 2. Level 1 personnel may perform acceptance inspections under the direct supervision of a Level 2 but shall not make accept/reject decisions.

10.0 DEFINITIONS

Adhesively Bonded Honeycomb Composite - a composite structure consisting of metallic or nonmetallic facesheets adhesively bonded to a metallic or nonmetallic honeycomb core.

A-scan	A method of data presentation utilizing a horizontal base line indicating distance, or time, and a vertical deflection from the base line indicating amplitude.
Class I Hardware	Hardware acceptable for flight use.
Class II Hardware	Hardware acceptable for use in ground test or training in a hazardous environment.
Class Ill Hardware	Hardware acceptable for nonhazardous training or display purposes. This hardware is uncontrolled.
Contact Testing	A technique in which the search unit makes contact directly with the test piece through a thin layer of couplant.
Contrast	Average amplitude sampled from indication area minus the same from non-indication area or background outside indication area.
Couplant	A substance used between the search unit and test surface

	to permit or improve transmission of ultrasonic energy.
C-scan	An ultrasonic data presentation which provides a plan view of the test object and discontinuities therein.
Delamination	A separation of laminated composite plies from each other.
Disbond	A separation at the adhesive layer of a laminate-to-laminate or laminate-to-core bond.
Flaw Size	Diameter of round flaw (programmed delamination or disband) or side of a square flaw.
Flaw Type	Each flaw type is defined by unique combination of flaw location, depth and part cross section containing the flaw.
Flaw Type Domain	A group of similar flaw types so that flaw detectability within the group (envelope or range) is assumed to be monotonic with the major variable of the group other than flaw size i.e. depth. For example, flaws of the same size but at different depths may belong to same flaw detectability domain for ultrasonic through-transmission inspection, although POD flaw size may be different for flaws in different material thicknesses.
Foreign Material	Any object contained within the laminated composite, bonded laminate or adhesively bonded honeycomb composite that is not specified on the engineering drawing.
Ground Support Equipment (GSE)	Equipment acceptable for the control, handling, and testing of Class I and Class II hardware.
Laminated Composite	A composite material made up of several bonded layers or plies each consisting of unidirectional or woven reinforcement fibers in a polymer matrix.
Noise	Noise is measured as standard deviation of amplitude sampled from non-indication area or background outside indication area. Noise sample shall have at least 40 measurements.
POD	Probability of Detection.
POF	Probability of False Positive.
Porosity	Small gas pores or air pockets within the matrix and/or

	bondline of a laminated composite or bonded panel.
Pulse-Echo Method	An inspection method in which the ultrasonic pulse is emitted and received by a single transducer. The presence and position of a flaw are indicated by the amplitude and time-of-flight of the ultrasonic energy reflected from the flaw.
Step Size or Pixel Size	Stepping Interval in scan or index direction at which a signal data is acquired.
Sub Target Flaw Size	Flaw size that provides less than minimum 20% of signal response compared to the target flaw or is smaller by minimum 20% compared to the target size flaw.
Target Size Flaw	Flaw size used in acceptance criteria.
Through Transmission Method	An inspection method in which the ultrasonic pulse is emitted by one transducer and received by another at the opposite surface of the material examined. The presence of a flaw is indicated by a decrease in the amplitude of the transmitted ultrasonic energy.
Transducer Aperture or Beam Diameter	Aperture refers to size (or diameter) of area sampled by the transducer a time. For focused transducer, it will be smaller than the transducer piezoelectric element. For unfocused transducers in immersion mode, it will be same as the receiving transducer diameter. For squirter systems, it will be equal to the water jet diameter.
Void	A relatively large localized gas pore or air pocket within the matrix and/or bondline of a laminated composite or bonded panel.