Office of the NASA Chief Engineer

NASA TECHNICAL STANDARD

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METRIC/SI (ENGLISH)

NONDESTRUCTIVE EVALUATION REQUIREMENTS FOR FRACTURE-CRITICAL METALLIC COMPONENTS

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DOCUMENT HISTORY LOG

Status	Document Revision	Change Number	Approval Date	Description
Interim			2006-09-11	Interim Release
Baseline			2008-04-07	Baseline Release
Revision	A		2018-06-19	Significant changes were made to this NASA Technical Standard. It is recommended that it be reviewed in its entirety before implementation. Key changes were: Calibration of Eddy Current, factors to consider for CR and DR application, sensitivity level 3 or 4 penetrant choice.
Revision	B		2019-05-08	Added requirement e. in section 4.5.2 that was approved in the Baseline but inadvertently omitted from Revision A. Inserted Tables 1 and 2 and Figure 1 from the Baseline to correct formatting issues.
Revision	C		2023-08-03	Significant changes were made to this NASA Technical Standard. It is recommended that it be reviewed in its entirety before implementation. Key changes were: Re-organized to bring “standard NDE” to the front, followed by “special NDE” then the sections of “Documenting” to help reduce redundant shall statements. Added note that the Standard is not applicable to additive manufactured metals. Deleted sections on digital radiography and added that standard NDE only applies to film X-ray. Corrected and added several definitions and applicable documents. For “special NDE,” added sections on three possible

Status	Document Revision	Change Number	Approval Date	Description
				POD approaches. Added discussions on the history of NASA-STD-5009, Tables 1 and 2 reliably detected flaw sizes. Added discussions on similarity and transfer functions. Added lower limits of plate thickness for penetrant and eddy current. Added guidelines for mapping reliably detectable dye penetrant crack size at external corners with fillet radii. Added guidelines for determining x-ray shots for inspection of cylindrical parts. Eliminated the requirement to have the proper authority disposition all crack-like flaws. Updated to current template.

FOREWORD

This NASA Technical Standard is published by the National Aeronautics and Space Administration (NASA) to provide uniform engineering and technical requirements for processes, procedures, practices, and methods endorsed as standard for NASA programs and projects, including requirements for selection, application, and design criteria of an item.

This Standard establishes the nondestructive evaluation (NDE) requirements for any NASA system or component, flight or ground, where fracture control and a quantitative demonstration of probability of detection (POD) are a requirement. This Standard specifically defines requirements for nondestructive evaluation in support of NASA-STD-5019A with Changes, Fracture Control Requirements for Spaceflight Hardware.

Submit requests for information via "Email Feedback" at https://standards.nasa.gov. Submit requests for changes to this Standard via Marshall Space Flight Center (MSFC) Form 4657, Change Request for a NASA Engineering Standard, or the "Suggest a Change to this Standard" link on the Standard's Summary Page at https://standards.nasa.gov.

Original Signed By	8/3/2023
Joseph W. Pellicciotti NASA Chief Engineer	Approval Date

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1. SCOPE

1.1 Purpose

This NASA Technical Standard establishes the nondestructive evaluation (NDE) requirements for any NASA system or component, flight or ground, where fracture control and a quantitative demonstration of probability of detection (POD) are required. This Standard defines the primary requirements for NDE in support of NASA-STD-5019A with Changes, Fracture Control Requirements for Spaceflight Hardware. NDE applied in-process for purposes of process control and NDE of damage-tolerant composites are not addressed in this Standard.

It is the policy of NASA to produce aerospace flight systems with a high degree of reliability and safety. This is accomplished through good design, manufacturing, test, and operational practices, including the judicious choice of materials, detailed analysis, appropriate factors of safety, rigorous testing and control of hardware, and reliable inspection. NASA fracture control requirements stipulate that all human-rated aerospace flight systems be subjected to fracture control procedures to preclude catastrophic failure. Those procedures frequently rely on NDE to ensure that the potential failure initiation of relevant crack-like flaws is not present in critical areas.

Programs that are not human-rated may choose to impose these requirements on a mission or hardware to increase the robustness of a structural design or to serve as a stepping-stone for human-rating.

1.2 Applicability

1.2.1 This Standard is applicable to the fracture control of metal components (e.g., aluminum, steel, titanium, and nickel alloys) for any NASA system or component, flight or ground, where fracture control is a requirement.

For additively manufactured (AM) components, refer to NASA-STD-6030, Additive Manufacturing Requirements for Spaceflight Systems.

The requirements described herein apply to fracture-critical hardware developed for NASA applications by NASA Field Centers, international partners, contractors, and outside organizations. NDE processes are required to meet the requirements in this Standard to screen hardware reliably for the presence of crack-like flaws.

1.2.2 This Standard is approved for use by NASA Headquarters and NASA Centers and Facilities, and applicable technical requirements may be cited in contract, program, and other Agency documents. This language applies to the Jet Propulsion Laboratory (a Federally Funded Research and Development Center), other contractors, recipients of grants, cooperative agreements, or other agreements only to the extent specified or referenced in the applicable contracts, grants, or agreements.

1.2.3 References to "this Standard" refer to NASA-STD-5009C; references to other documents state the specific document information.

1.2.4 Verifiable requirement statements are designated by the acronym NER (Nondestructive Evaluation Requirement), numbered, and indicated by the word "shall." This Standard contains 74 requirements. To facilitate requirements selection by NASA programs and projects, a Requirements Identification Matrix is provided in Appendix A.

1.2.5 Explanatory or guidance text is indicated in italics beginning in section 4. The terms "may" or "can" denote discretionary privilege or permission, "should" denotes a good practice and is recommended but not required, "will" denotes expected outcome, and "are/is" denotes descriptive material or a statement of fact.

1.3 Tailoring

Tailoring of the requirements in this Standard for application to a specific program or project is acceptable when formally approved by the delegated NASA Technical Authority in accordance with NPR 7120.5, NASA Space Flight Program and Project Management Requirements, and documented in program or project requirements.

2. APPLICABLE DOCUMENTS

2.1 General

2.1.1 Documents listed in this section contain provisions constituting requirements of this Standard as cited in the text. Latest issuances of cited documents apply unless specific versions are designated. Obtain approval from the delegated NASA Technical Authority to use a version other than as designated.

2.1.2 Access applicable documents at https://standards.nasa.gov or obtain documents directly from the Standards Developing Body or other document distributors, and from information provided or linked.

Note: *Refer to Appendix C for reference documents.*

2.2 Government Documents

Department of Defense

MIL-HDBK-1823A, Nondestructive Evaluation System Reliability Assessment

NASA

NPR 1441.1, NASA Records Management Program Requirements

NPR 7120.5, NASA Space Flight Program and Project Management Requirements

NASA-STD-5019A with Changes, Fracture Control Requirements for Spaceflight Hardware

NASA/TM−20210018515 (Corrected Copy), NESC-TI-20-01545, Guidebook for Limited Sample Probability of Detection (LS-POD) Demonstration for Signal-Response Nondestructive Evaluation (NDE) Methods

2.3 Non-Government Documents

Aerospace Industries Association (AIA)/National Aerospace Standards (NAS)

NAS 410, NAS Certification and Qualification of Nondestructive Test Personnel

American Society for Nondestructive Testing

Materials Evaluation (ME), Volume 40, No. 9, 1982, Recommended Practice for a Demonstration of Nondestructive Evaluation (NDE) Reliability on Aircraft Production Parts, Ward D. Rummel (Authorized NASA Users Only: https://sharepoint.msfc.nasa.gov/sites/agency/1539nasaen/Shared%20Documents/Forms/AllItems.aspx?RootFolder=%2Fsites%2Fagency%2F1539nasaen%2FShared%20Documents%2FNASA%2DSTD%2D5009C%2FNASA%2DSTD%2D5009%20%2D%20Applicable%20Documents&FolderCTID=0x01200095DB05AE97665D40A79F36C31E990E4C&View=%7B2F7691A6%2D3B60%2D4654%2DBA21%2D8F169BC3D21F%7D; other users may request from The American Society for Nondestructive Testing [https://www.asnt.org])

ASTM International

ASTM E164, Standard Practice for Contact Ultrasonic Testing of Weldments

ASTM E1417/E1417M, Standard Practice for Liquid Penetrant Testing

ASTM E1444/E1444M, Standard Practice for Magnetic Particle Testing for Aerospace

ASTM E1742/E1742M, Standard Practice for Radiographic Examination

ASTM E2375, Standard Practice for Ultrasonic Testing of Wrought Products

SAE International

SAE AMS2647, Fluorescent Penetrant Inspection Aircraft Structures and Engine Component Maintenance

SAE ARP4402, Eddy Current Inspection of Open Fastener Holes in Aluminum Aircraft Structure

SAE AS4787, Eddy Current Inspection of Circular Holes in Nonferrous Metallic Aircraft Engine Hardware

2.4 Order of Precedence

2.4.1 The requirements and standard practices established in this Standard do not supersede or waive existing requirements and standard practices found in other Agency documentation, or in applicable laws and regulations unless a specific exemption has been obtained by the Office of the NASA Chief Engineer.

2.4.2 Conflicts between this Standard and other requirements documents will be resolved by the delegated NASA Technical Authority.

3. ACRONYMS, ABBREVIATIONS, SYMBOLS, AND DEFINITIONS

3.1 Acronyms, Abbreviations, and Symbols

β	For a cylindrical shape with a crack perpendicular to the side wall running in the axial direction (length of the tube), the local direction of the radiation beam to that crack
%	percent
=	equals
≥	greater than or equal to
≤	less than or equal to
±	plus or minus
AIA	Aerospace Industries Association
AM	Additive Manufactured
AMS	Aerospace Materials Specification
ARP	Aerospace Recommended Practice
AS	Aerospace Standard

CR	Computed Radiography
DR	Digital Radiography
EDM	electrical discharge machining
ESA	European Space Agency
HDBK	Handbook
IACS	International Annealed Copper Standard
in	inch
JSC	Johnson Space Center
LS-POD	Limited Sample Probability of Detection
ME	Materials Evaluation
MIL	Military
mm	millimeter
MRB	Material Review Board
MSFC	Marshall Space Flight Center
NAS	National Aerospace Standard
NASA	National Aeronautics and Space Administration
NAVAIR	Naval Air Systems Command
NDE	Nondestructive Evaluation
NER	Nondestructive Evaluation Requirement
NPR	NASA Procedural Requirements
PEM	Point Estimate Method
POD	Probability of Detection
POF	Probability of False-Calls
PRC	Procedure
PTC	partly through crack
QQI	Quantitative Quality Indicator
RFCB	Responsible Fracture Control Board
SAE	SAE International (formerly Society of Automotive Engineers)
SI	The International System of Units (commonly known as the Système Internationale)
STD	Standard
TM	Technical Memorandum
USN	United States Navy

3.2 Definitions

Applicable Documents: Documents cited in the body of the standard that contain provisions or other pertinent requirements directly related and necessary to the performance of the activities specified by the standard.

Capability Demonstration Specimens: A set of specimens made from material similar to the material of the hardware to be inspected with known flaws used to estimate the capability of flaw detection, i.e., Probability of Detection.

Certification: A written statement by an employer that an individual has met the applicable requirements of this Standard. (Source: NAS 410)

Contrast: The difference between the average signal value in a specific region and the average signal value in a neighboring region.

Cracks or Crack-Like Flaws: A discontinuity assumed to behave like a crack for assessment of material or structural integrity.

Flaw: An imperfection or discontinuity that may be detectable by nondestructive testing and is not necessarily rejectable. Examples of flaws in metallic materials include cracks, deep scratches and sharp notches that behave like cracks, material inclusions, forging laps, welding incomplete fusion, penetration, and slag or porosity with a crack-like tail.

Fracture Control: The rigorous application of those branches of design engineering, quality assurance, manufacturing, and operations dealing with the analysis and prevention of crack propagation leading to catastrophic failure.

Fracture-Critical Hardware, Component, or Part: Fracture control classification that identifies a part whose individual failure, caused by the presence of a crack, is a catastrophic hazard and that requires safe-life analysis or other fracture control assessment to be shown acceptable for flight. A part is fracture critical unless it can be shown that there is no credible possibility for a flaw to cause failure during its lifetime or the part failure does not result in a credible catastrophic hazard. Assessments for fracture critical parts include damage tolerance analysis, damage tolerance test, or defined approaches for specific categories. Parts under this classification receive flaw screening by NDE, proof test, or process control and are subjected to traceability, materials selection and usage, documentation, and engineering drawing requirements.

Hardware Developer: The organization, NASA or prime contractor, responsible for the design, development, and manufacturing of hardware that is subject to fracture control.

Instrument Standardization: Adjustment of an NDE instrument response using an appropriate reference standard with known size discontinuities such as electro-discharged machined slots and flat bottom holes, to obtain or establish a known and reproducible response. This is usually done prior to an examination but can be carried out anytime there is concern about the examination or instrument response. It is also commonly known as calibration prior to initiating an NDE procedure.

Material Review Board: After non-conforming material has been identified, this board reviews it and determines whether or not the material should be returned, reworked, used as-is, or scrapped. Note: The Material Review Board (MRB) consists of representatives across many disciplines, including manufacturing engineering, materials engineering, quality, etc.

Naturally Occurring Flaw: A flaw that is present in a component as a result of the normally occurring manufacturing processes or usage of the component as compared to NDE simulated flaws such as electrical discharge machining (EDM) notches, flat bottom holes, engineered cracks, etc.

NDE Plan: A plan that describes the process for establishment, implementation, and control of NDE of aerospace flight hardware during design, manufacturing, and its operational life.

NDE Procedure: A written plan providing detailed information on "how-to" perform a hardware-specific inspection.

NDE Reference Standard: A material or object for which all relevant chemical and physical characteristics are known and measurable, used as a comparison for, or standardization of, equipment or instruments used for nondestructive testing.

90/95 Probability of Detection (POD 90/95): Refers to 90% probability of flaw detection with a 95% lower confidence bound.

Nondestructive Evaluation: The development and application of technical methods to examine materials or components in ways that do not impair future usefulness and serviceability to detect, locate, measure, and evaluate flaws; to assess integrity, properties, and composition; and to measure geometrical characteristics. This is to include nondestructive inspection and testing.

Pie Gauge: A tool for quickly verifying the direction of magnetic flux on a surface. Pie gauges are not acceptable for measuring field intensities.

Qualification: The skills, training, knowledge, examinations, experience, and visual capability required for personnel to properly perform to a particular level.

Quantitative Quality Indicator: Magnetic particle test pieces with artificial flaws used to verify proper field direction and adequate field strength.

Reference Document: Written, printed, or electronic matter that is useful as background information for the reader to help in understanding the subject matter but does not constitute technical requirements of the Standard.

Reliably Detectable Flaw Size: The size of a crack-like flaw that can be detected with at least 90% POD with 95% confidence (i.e., 90/95 POD). For Standard NDE, reliably detectable flaw sizes are provided in Tables 1 and 2. For Special NDE, the reliably detectable flaw size must be demonstrated through POD testing using the methods cited within this Standard. When determined using the MIL-HDBK-1823A, Nondestructive Evaluation System Reliability Assessment, POD method, this flaw size will be the minimum reliably detectable flaw size, denoted $a_{90/95}$. Reliably detectable flaw sizes are assumed to exist in a part for the purpose of performing a damage tolerance safe-life analysis of the part, component, or assembly.

Responsible Fracture Control Board (RFCB): The designated board at the NASA Center or sponsoring institution responsible for fracture control methodology that can interpret fracture control requirements.

Responsible NASA Center: A group of designated multi-discipline representatives as designated by the responsible program office that has the authority to develop, interpret, and approve fracture control requirements and the responsibility for overseeing and approving the technical adequacy of all fracture control activities.

Responsible NDE Engineering: The NDE engineering organization of the hardware developer or the sustaining engineering organization responsible for the engineering aspect of fracture-critical NDE during manufacturing or operations and maintenance.

Sensitivity Level: A scale used to assess the quality of a penetrant of radiographic inspection.

Similarity: The case where it has been established either by engineering judgement or quantitative data analysis that a one-to-one transfer function exists between the original NDE POD study and the specific NDE inspection situation at hand. Differences between the inspection configurations that might be assessed in similarity analysis include factors such as surface finish, accessibility, material type, geometry, and orientation.

Simulated Fabricated Flaw: A flaw that is intentionally placed in a component for the purpose of generating an NDE signal response. These can be produced by a variety of material removal processes (e.g., cutting, drilling, EDM, laser notching, plasma focused ion beam notching) or additive material-forming processes.

Simulated Induced Flaw: A flaw that is intentionally placed in a component for the purpose of generating an NDE signal response. Induced flaws are produced by intentional loading (thermal, mechanical, etc.) to induce damage (e.g., cracks, delaminations, disbonds).

Special NDE: Nondestructive inspections of fracture-critical hardware that are capable of detecting cracks or crack-like flaws smaller than those assumed detectable by Standard NDE or do not conform to the requirements for Standard NDE as set forth in this Standard. Special NDE methods are not limited to fluorescent penetrant, radiography, ultrasonic, eddy current, and magnetic particle.

Standard NDE: NDE methods for which conservative reliably detectable flaw sizes were established by POD demonstration testing performed by multiple inspectors. For the Standard

NDE flaw sizes, it is assumed that qualified inspectors can provide the required 90/95 POD without additional POD demonstration testing. Current Standard NDE methods include fluorescent penetrant, radiographic (film), ultrasonic, eddy current, and magnetic particle testing.

Sustaining Engineering: The organization, NASA or prime contractor, responsible for operation and maintenance of hardware that is subject to fracture control.

Technical Authority: A representative delegated by the contracting agency to address technical matters and who is responsible for the interpretation and implementation of the requirements set forth in this Standard.

4. NDE REQUIREMENTS

The requirements set forth in this Standard are the minimum NDE requirements for metallic fracture-critical hardware. The application of Standard and Special NDE per the requirements of this Standard does not exempt fracture-critical hardware from routine NDE performed during manufacturing. The fracture control NDE procedures cited herein may exceed the requirements for NDE procedures that are routinely performed for purposes such as configuration control and process control. NASA-STD-5019A with Changes provides the definition of fracture-critical hardware for all spaceflight systems.

4.1 Standard NDE

[NER 1] Standard NDE **shall** consist of nondestructive inspections of traditional (non-AM) metal components (e.g., aluminum, steel, titanium, and nickel alloys) using the NDE methods cited in Table 1, Reliably Detectable Flaw Sizes for Fracture Analysis Based on Standard NDE Methods (Millimeters), or Table 2, Reliably Detectable Flaw Sizes for Fracture Analysis Based on Standard NDE Methods (Inches), or additional methods that have been demonstrated by section 4.1.5 in this Standard and approved by the RFCB or delegated NASA Technical Authority.

The Reliably Detectable Flaw Sizes shown in Table 1 and Table 2 can be assumed as starting points in the damage tolerance fracture analyses and are applicable only for metals (not to include AM metals). The crack geometries for the cracks in Table 1 or Table 2 are shown in Figure 3, Assumed Flaw Geometries.

4.1.1 Standard NDE Crack Sizes

[NER 2] Nondestructive inspections of fracture-critical hardware **shall** detect the initial crack sizes used in the damage tolerance fracture analyses with a capability of minimum 90% probability of detection at a 95% confidence level, known as 90/95.

The Standard NDE flaw sizes for eddy current, penetrant, magnetic particle, radiography, and ultrasonic techniques are shown in Table 1 and Table 2. The table entries are based primarily on

NDE capability studies conducted on flat specimens with open surface, partially through, etched fatigue cracks that were evaluated by multiple inspectors from multiple contractors early in the Space Shuttle Program. See Bishop (1973). The studies were performed on wrought steel for the magnetic particle method and on 2219-T87 aluminum panels for the other NDE methods. Bishop's detectable flaw sizes for the penetrant method were the basis of the Shuttle Orbiter Fracture Control Plan's (King and Johnson [1974]) definition of Standard NDE flaw sizes since it was the predominant NDE method in use at the time. Bishop's POD estimates were averaged over a range of aspect ratio cracks. The translation of Bishop's study results to the Standard NDE flaw sizes was based on both quantitative and qualitative analysis of the data. These original Orbiter Standard NDE flaw sizes evolved into later NASA Standards, including MSFC-STD-1249, Standard NDE Guidelines and Requirements for Fracture Control Programs, and eventually in this Standard through the consideration of additional POD studies and engineering judgement as well as structural analysis of additional crack configurations. The Standard NDE flaw sizes in Tables 1 and 2 are considered to meet the 90/95 capability requirement. A more detailed history can be found in NASA/TM−20220013820, NESC-TI-21-01657, A Survey of NASA Standard Nondestructive Evaluation (NDE).

Since the Standard NDE flaw sizes were derived from a single flaw type and limited specimen parameters, the application of these flaw sizes to other geometries, materials, material forms, and material processes is based on a rationale of similarity to a specific fracture critical component. Similarity can be established by POD studies, using the method described in NASA/TM−20220003648, Guidebook for Assessing Similarity and Implementing Empirical Transfer Functions for Probability of Detection (POD) Demonstrations for Signal Based Nondestructive Evaluation (NDE) Methods, or engineering rationale approved by the RFCB. For example, a flat panel may be considered representative of a component with a large diameter curvature. Also, it may be considered reasonable to use the Standard NDE flaw sizes for most aerospace wrought alloys. Conversely, the Standard NDE flaw sizes may not apply to thick-section components; threaded parts; weldments; compressively loaded structures; double wall radiography; and other unique material, structural, or inspection applications.

If similarity to Standard NDE flaw sizes cannot be established, the Standard NDE flaw sizes may also be transferred to estimate the detectable flaw size in a specific flight component using NASA/TM−20220003648, specifically, the inverse transfer function method.

If similarity to Standard NDE cannot be established and an inverse transfer function cannot be applied, a Special NDE demonstration can be performed using naturally occurring flaws in flight component geometry to demonstrate 90/95 capability (see section 4.2 in this Standard). For example, a Special NDE demonstration using penetrant to evaluate the capillary action in fatigue cracks on a curved flight-representative component may confirm similarity of using penetrant on a curved part compared to a flat specimen.

If a sufficient number of naturally occurring flaws in flight component geometry are not available for a Special NDE demonstration, a representative flaw type, flaw size, and specimen can be established using the NASA/TM−20220003648 forward method. It is recommended that

Special NDE demonstrations be performed with simulated induced flaws (e.g., fatigue cracks) rather than fabricated flaw (e.g., EDM notches) to better represent flaw-to-flaw variability.

4.1.2 Standard NDE Classification Justification

[NER 3] The justification to classify an NDE procedure as a Standard NDE procedure **shall** be documented and approved by NDE engineering and the delegated NASA Technical Authority.

4.1.3 Demonstration of Standard NDE Capability

[NER 4] Instrument standardization **shall** be performed.

Implementation of Standard NDE methods in accordance with the requirements in section 4.1.4 in this Standard will not require a POD crack detection capability demonstration.

4.1.4 Standard NDE Methods

4.1.4.1 Eddy Current

Standard eddy-current inspection was only applied to nonmagnetic, nonferromagnetic, and conductive metals in our early capability databases. With approval from NDE Engineering or the delegated NASA Technical Authority, inspection of some ferromagnetic materials can be considered Standard.

4.1.4.1.1 [NER 5] Eddy-current inspections **shall** be in accordance with SAE ARP4402, Eddy Current Inspection of Open Fastener Holes in Aluminum Aircraft Structure; SAE AS4787, Eddy Current Inspection of Circular Holes in Nonferrous Metallic Aircraft Engine Hardware; or NASA fracture control and NASA NDE Engineering-approved contractor internal specifications with the following additional requirements:

a. [NER 6] For part conductivities less than 10% International Annealed Copper Standard (IACS), the reference standard **shall** have a conductivity of ±2% IACS with a minimum reference standard conductivity of 0.8% IACS.

As given in SAE ARP4402, pay special attention to ensure that the conductivity of the reference standard matches the conductivity of the part to be inspected within ±15% of the IACS.

b. [NER 7] Reference standard notches used for standardization **shall** be no larger than ½ the length and ½ the depth of the target crack size with a maximum width of 0.127 mm (0.005 in):

The shape of surface and through artificial notches can be anywhere between semi-circular "thumb nail" to rectangular. The shape for corner notches can be anywhere between semi-circular to triangular.

c. [NER 8] Noise levels on the component **shall** be less than 25% of the reference notch response.

d. [NER 9] Any indication greater than 50% of the reference notch response **shall** be reported to, and receive disposition by, the proper engineering authority.

4.1.4.1.2 [NER 10] The influence of coatings and lift-off variations on the reliability of an eddy current Standard NDE inspection process **shall** be evaluated for application-specific suitability and documented in the NDE Summary Report.

4.1.4.2 Fluorescent Penetrant

[NER 11] Fluorescent Penetrant inspection **shall** be in accordance with ASTM E1417/E1417M, Standard Practice for Liquid Penetrant Testing; SAE AMS2647, Fluorescent Penetrant Inspection Aircraft Structures and Engine Component Maintenance; or NASA fracture control and NASA NDE Engineering-approved contractor internal specifications.

4.1.4.2.1 Penetrant System

[NER 12] The penetrant system used **shall** be a fluorescent penetrant of sensitivity level 3 or 4.

(See NASA/TM-2011-215869, A Comparison of the Capability of Sensitivity Level 3 and Sensitivity Level 4 Fluorescent Penetrants to Detect Fatigue Cracks in Various Metals.)

4.1.4.2.2 Mechanically Disturbed Surfaces

[NER 13] Mechanically disturbed or wire EDM surfaces **shall** be etched or electropolished prior to the penetrant inspection and at an appropriate time in the manufacturing flow.

The final penetrant inspection can be performed prior to metal finishing operations such as buffing or sanding that do not by themselves produce flaws. It should be noted that these final finishing operations may create a mechanically disturbed surface that could impede subsequent (nonconformance resolution and/or service life) penetrant inspections and thus require etching.

4.1.4.2.3 Etching/Electropolishing Procedure

a. [NER 14] An etching/electropolishing procedure **shall** be developed, approved, and controlled to prevent part damage.

b. [NER 15] The etching/electropolishing procedure **shall** specify the minimum amount of material to be removed to ensure that smeared metal does not mask cracks.

(1) [NER 16] Non-ferrous materials such as aluminum and titanium alloys **shall** be etched/electropolished to remove a minimum of 0.01 mm (0.0004 in) of material.

(2) [NER 17] Corrosion resistant steel and nickel-based alloys **shall** be etched/electropolished to remove a minimum of 0.005 mm (0.0002 in) of material.

For NER 16 and NER 17, reference JSC PRC-5010C, Process Specification for Pickling, Etching, and Descaling of Metals.

Take care to use an etchant or electropolish and process parameters which will preserve the surface finish.

c. [NER 18] If etching/electropolishing is not feasible or the minimum depths are not attainable, it **shall** be demonstrated and documented that the required flaw size can be reliably detected following current machining processes.

When very close tolerances are required, critical surfaces should be machined near final dimensions, etched and inspected, then finish machined and dye penetrant inspected without further etch.

4.1.4.2.4 Special Considerations

Tables 1 and 2 reliably detectable flaw sizes do not specify a minimum part thickness or edge or hole crack sizes when a fillet radius is present.

[NER 19] Interpretation of reliably detectable flaw sizes for thin parts with thickness less than 0.64 mm (0.025 in) or edges and holes with a fillet radius **shall** require approval by the RFCB.

Refer to NASA/TM-20230000318, Guidelines for Mapping Reliably Detectable Dye Penetrant Crack Size at External Corners with Fillet Radii, for estimating reliably detectable flaw sizes on external corners.

4.1.4.3 Magnetic Particle

[NER 20] Magnetic particle inspections **shall** be in accordance with ASTM E1444/E1444M, Standard Practice for Magnetic Particle Testing for Aerospace, or NASA fracture control and NASA NDE Engineering-approved contractor internal specifications.

4.1.4.3.1 [NER 21] The magnetic particle inspection **shall** be the wet, fluorescent, continuous, or multi-mag method.

4.1.4.3.2 [NER 22] A Quantitative Quality Indicator (QQI) **shall** be used to validate the local field intensities.

4.1.4.3.3 [NER 23] Type CX-230 or CX4-230 QQIs **shall** be used on curved or complex surfaces where the Type CX-430 or CX4-430 QQIs cannot conform to the part in the area of interest.

Cut Type CX4-230 and CX4-430 QQIs into four individual QQIs. Ensure QQIs are in intimate contact with the inspection surface with the notches facing down and the "+" notches aligned with the required magnetization directions.

Hall probes are acceptable provided they are verified with a QQI. Pie gauges are not acceptable for measuring field intensities.

4.1.4.4 Radiography (X-Ray)

Table 1 or Table 2 minimum detectable crack size for standard radiographic processes is based solely on film x-ray radiography and represents NASA's past radiographic capability demonstrations on metallic specimens. With the conversion to digital radiographic techniques and methods, it is essential to assess the capability of such systems to meet the Tables 1 and 2 requirements.

4.1.4.4.1 [NER 24] A POD study **shall** be used to establish the capability of digital radiographic techniques, including computed radiography, digital radiography, and computed tomography which at this time are considered to be Special NDE.

4.1.4.4.2 [NER 25] A POD study **shall** be used to establish the capability of Gamma radiation source inspections which are considered special NDE.

For radiographic inspections, surface cracks are assumed to be oriented normal to the surface unless otherwise indicated in the inspection callouts.

4.1.4.4.3 [NER 26] Film radiographic inspections, with capabilities shown in Table 1 or Table 2, **shall** be in accordance with ASTM E1742/E1742M, Standard Practice for Radiographic Examination, or NASA fracture control and NASA NDE Engineering-approved contractor internal specifications with the following additional requirements:

a. [NER 27] The minimum radiographic inspection sensitivity level **shall** be 2-1T.

The requirement for sensitivity level 2-1T is in accordance with industry specifications for similar applications, namely NAVAIR 01-1A-34, Aeronautical Equipment Welding, and European Space Agency ECSS-E-ST-32-01C, Fracture Control.

b. [NER 28] Film density **shall** be 2.5 to 4.0.

The requirement for 2.5 to 4.0 film density, while more stringent than the requirements of ASTM E1742/E1742M, is intended to optimize contrast for flaw detection for most films used in aerospace hardware inspection. This is because the gradient values of these films (change in density in response to a small change in exposure values caused by flaw conditions) are generally highest in the required density range.

c. [NER 29] The local x-ray axis of the radiation beam **shall** be within ±5 degrees of the assumed crack plane orientation.

For flat parts only, with the center axis of the beam perpendicular to the part, the area of the film that falls within a ±5-degree cone of radiation (10-degree total solid angle, i.e., 2 $\boldsymbol{\theta}$, apex at the radiation source, central axis of the cone equal to the central axis of the radiation beam) will be considered valid for interpretation. See Figure 1, Flat Part X-ray Shot Geometry.

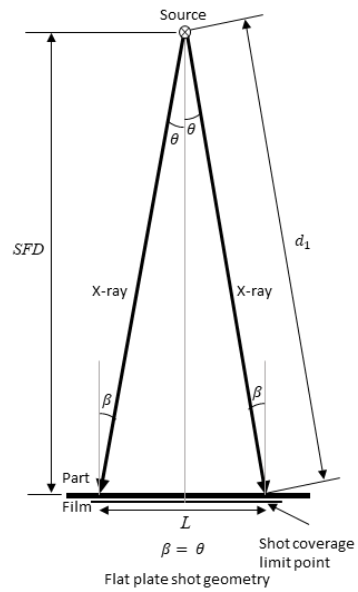

Figure 1—Flat Part X-ray Shot Geometry

For a cylindrical shape with a crack perpendicular to the side wall running in the axial direction (length of the tube), the local direction of the radiation beam to that crack would be defined as "$\boldsymbol{\beta}$" as shown in Figure 2, Curved Part X-ray Shot Geometry.

Refer to NASA/TM-20230000324, "Guidelines for Determining X-ray Shots for Inspection of Cylindrical Parts, to determine shot coverage and number of shots for inspection of girth weld on cylindrical or spherical parts."

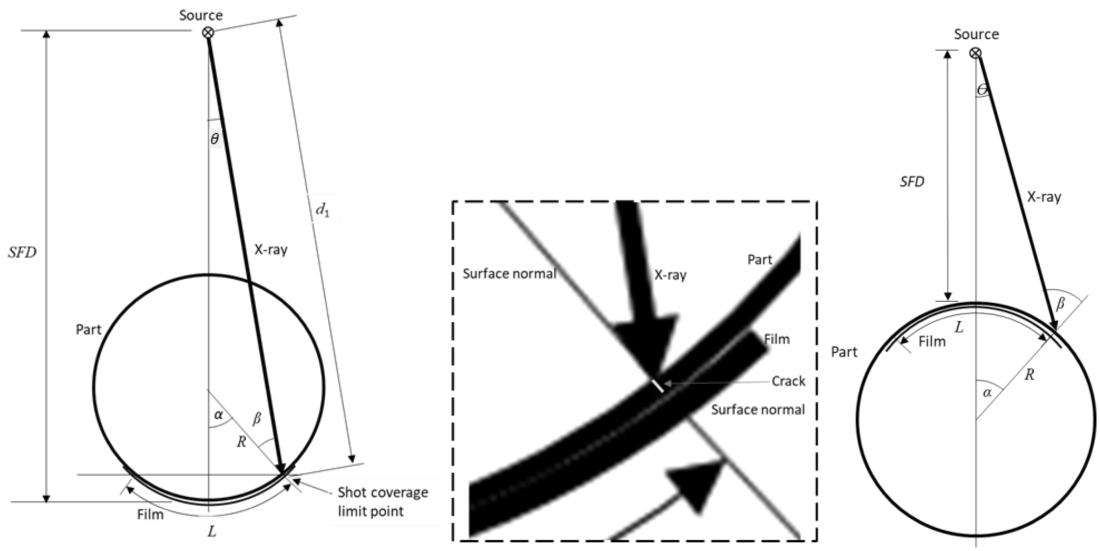

Figure 2—Curved Part X-ray Shot Geometry

4.1.4.5 Ultrasonics

[NER 30] Utrasonic inspections for wrought products **shall** be in accordance with ASTM E2375, Standard Practice for Ultrasonic Testing of Wrought Products; ASTM E164, Standard Practice for Contact Ultrasonic Testing of Weldments; or NASA fracture control and NASA NDE Engineering-approved contractor internal specifications with the following additional requirements:

a. [NER 31] Any single discontinuity with a response greater than 50% of the response from a 1.98-mm (0.078-in) diameter flat bottom hole (or equivalent surface notch or side drilled hole) at the estimated discontinuity depth (or sound path) **shall** be reported.

Rationale: This requirement is different from that in ASTM E2375 where response greater than the response from a 1.98-mm (0.078-in) diameter flat-bottom hole or equivalent notch at the estimated discontinuity depth and the discontinuity size given is not acceptable. Such requirement only provides 50% POD in detection of the 1.98-mm (0.078-in) diameter flat-bottom hole equivalent reflector which is the Standard ultrasonic testing flaw size flaw. Therefore, a lower response or the decision threshold at 50% of the response from a 1.98-mm (0.078-in) diameter flat-bottom hole or equivalent is used to provide targeted POD/Confidence of minimum 90/95.

b. [NER 32] Multiple discontinuities with indications greater than the response from a 1.19-mm (0.047-in) diameter flat bottom hole (or equivalent surface notch or side drilled hole) at the estimated discontinuity depth (or sound path) **shall** be reported if the centers of any two such indications are separated by less than 25.4 mm (1 in).

c. [NER 33] Any linear discontinuity (i.e., cracks or crack-like flaws such as stringers, incomplete fusion, or incomplete penetration) with a response equal to or greater than the response from a 1.19-mm (0.047-in) diameter flat bottom hole (or equivalent surface notch or side drilled hole) at the estimated discontinuity depth (or sound path) **shall** be reported regardless of length.

4.1.5 Method for Introducing New Standard NDE Flaw Sizes

4.1.5.1 [NER 34] A Standard NDE POD study **shall** consist of a MIL-HDBK-1823A-compliant POD study that is conducted by a minimum of 10 inspectors that form a representative sample from a specific population of inspectors.

4.1.5.2 [NER 35] Individual inspector analyses **shall** be performed in accordance with MIL-HDBK-1823A methods and reported.

4.1.5.3 [NER 36] Individual inspector probability of false-calls (POF) **shall** be reported and are recommended to not exceed 1% POF with 50% confidence.

4.1.5.4 [NER 37] The Standard NDE flaw size **shall** be estimated as a function of the average and standard deviation of individual inspector $a_{90/95}$ flaw sizes and represent the flaw size that 90% of inspectors are expected to demonstrate at least 90/95 detection capability.

4.1.5.5 [NER 38] Approval of the study design, execution, and analysis, or waivers from these parameters, **shall** be subject to review and approval of the RFCB.

Adding Standard NDE flaw sizes for other techniques not included in Tables 1 and 2 or revisions to flaw sizes can be established based on the requirements of this section. MIL-HDBK-1823A is the primary reference for the design, execution, and analysis of the individual inspector POD studies conducted within a NASA Standard NDE study. Additional guidance that augments and adapts MIL-HDBK-1823A for Standard NDE is contained in NASA/TM−20220013822, NESC-TI-21-01657, Guidebook for the Design and Analysis of a NASA Standard Nondestructive Evaluation (NDE) Probability of Detection (POD) Study. It exploits the advantage of having prior POD studies in planning a Standard NDE POD study and provides considerations in how to define the inspector population and sampling strategies for selecting inspectors. NASA/TM−20220013822 recommends an approach to estimate the Standard NDE flaw size that provides 90% coverage of the inspector population.

4.1.6 Inability to Meet Standard NDE Inspection Process Requirements

[NER 39] If the requirements of section 4.1 of this Standard cannot be met or smaller cracks or crack-like flaws than those shown in Table 1 or Table 2 have to be detected, the inspection processes **shall** be considered Special NDE, and the Special NDE requirements of section 4.2 of this Standard apply.

4.2 Special NDE

4.2.1 General

Special NDE consists of nondestructive inspections that are capable of detecting crack-like flaws smaller than those detectable by Standard NDE (Table 1 or Table 2) or those that do not conform to the requirements for Standard NDE given in section 4.1 of this Standard.

Special NDE methods are not limited to fluorescent penetrant, radiography, ultrasonic, eddy current, and magnetic particle methods.

Special NDE provides minimum 90/95 POD/Confidence in detection capability.

[NER 40] All Special NDE certification processes of NASA partners, contractors, sub-contractors, and suppliers **shall** be approved by RFCB.

4.2.2 Special NDE Crack Sizes

[NER 41] Special NDE inspections **shall** require the approval of the RFCB and the delegated NASA Technical Authority.

The Special NDE crack size can be any demonstrated size.

4.2.3 Demonstration of Special NDE Capability

a. [NER 42] A 90/95% flaw detection capability **shall** be demonstrated before a Special NDE inspection can be performed for fracture-critical part screening.

The demonstration of the Special NDE inspection at a given crack size qualifies the Special NDE for implementation for the detection of cracks at the demonstrated size and larger.

b. [NER 43] The capability tests **shall** be designed and conducted based on the MIL-HDBK-1823A POD Method (section 4.2.3.1 of this Standard), the Binomial Point Estimate POD Method (section 4.2.3.2 of this Standard), the Limited-Sample POD method (section 4.2.3.3 of this Standard), or other method approved by the RFCB.

Use the MIL-HDBK-1823A POD Method to demonstrate the smallest flaw size that the NDE method and inspector can demonstrate with the required 90/95 POD/Confidence. A large number of flawed specimens are recommended when using the POD methods (i.e., 40-60). The Binomial Point Estimate and Limited-Sample POD Methods are to be used when it is only necessary to demonstrate that the NDE method and inspector can provide at least 90/95 POD/Confidence for a specific target flaw size. The Binomial Point Estimate POD Method can be applied to either hit-miss NDE data or signal response NDE data that have been converted to *hit/miss and require a minimum of 29 flawed specimens. The Limited-Sample POD method can only be used for signal response NDE data and requires a minimum of ten flawed specimens.*

4.2.3.1 NDE Qualification Using the MIL-HDBK-1823A POD Methods

[NER 44] NDE qualification using the MIL-HDBK-1823 POD methods **shall** be performed in accordance with MIL-HDBK-1823A.

This method requires a range of flaw sizes that span the targeted qualification flaw size. The large number of flaws required by this method is intended to allow estimation of the reliably detectable flaw size, $a_{90/95}$ *and the complete POD curve (or model). Qualification by this method demonstrates that the procedure and the individual operator are capable of reliably detecting flaws larger than or equal to the estimated* $a_{90/95}$ *flaw size.*

ASTM E2862-18, Standard Practice for Probability of Detection Analysis for Hit/Miss Data, and ASTM E3023-21, Standard Practice for Probability of Detection Analysis for â Versus a Data, define procedures for performing the statistical analysis of hit/miss data and signal-response data, respectively, to estimate the demonstrated POD based on MIL-HDBK-1823A's methodology.

4.2.3.2 NDE Qualification Using Binomial Point Estimate POD Method

[NER 45] NDE qualification using the Binomial Point Estimate Method (PEM) **shall** be performed in accordance with Materials Evaluation (ME), Vol. 40, No. 9, pp 922-932, 1982, adapted for a single flaw size interval, and the target flaw size is equal to or larger than the maximum flaw size in the set or a flaw set approved by the RFCB.

This method qualifies that an individual inspector achieves at least 90/95 detection capability for a specified target flaw size. The Binomial PEM method assumes that flaw detection capability increases with flaw size in the neighborhood of the target flaw size.

The Binomial PEM does not estimate the minimum flaw size that provides 90/95 detection, which differs from the objective of the ME (1982). This method adapts the guidance in ME (1982) to one flaw size interval containing a minimum of 29 flaws with a maximum flaw size equal to the target flaw size. If the maximum flaw size exceeds the target, then basing the demonstration on the average of the flaw sizes could be considered if the average is not larger than the target size. The range of flaw sizes in the set is small enough to accept the assumption that the POD function is either concave in the region or does not markedly depart from being linear. The number of unflawed inspection sites (or opportunities) is recommended to be a minimum of three times the number of flawed sites in accordance with MIL-HDBK-1823A, which is an increase from the ME (1982) guidance. Therefore, a minimum of 29 flawed and 87 unflawed inspection sites are to be randomly presented to each inspector. Per MIL-HDBK-1823A, an unflawed inspection site need not be a separate specimen. There should be at least one blank specimen in the set when using the Binomial Point Estimate Method. There should be no indication of a specimen's flaw state *(i.e., flawed or unflawed) or flaw location(s) on the specimen that may enhance detection capability. Successful demonstration of 90/95 detection capability requires that all 29 flaw opportunities are detected with an acceptably low false call rate.*

If there are no more than 1 missed detection of the 29 flaws, a continuation of the demonstration activity may be warranted by adding 17 flaws to the inspection set, resulting in a total of 46 flaws. Successful demonstration of 90/95 detection capability requires that 45 of the 46 flaws are detected with an acceptably low false call rate.

The demonstration specimens should be representative or conservative relative to the operational components to be inspected, including material, surface finish, flaw type, flaw location, and flaw spatial frequency and proximity. If similarity (i.e., a 1-1 transfer function) cannot be justified, a transfer function may be developed according to NASA/TM−20220003648.

4.2.3.3 NDE Qualification Using Limited Sample POD Method

[NER 46] NDE qualification using the limited sample probability of detection (LS POD) method **shall** be performed in accordance with NASA/TM−20210018515/Corrected Copy, NESC-TI-20-01545, Guidebook for Limited Sample Probability of Detection (LS-POD) Demonstration for Signal-Response Nondestructive Evaluation (NDE) Methods.

This method is also applicable to a single target flaw size but is limited to NDE methods that produce a signal response correlated to flaw size. The LS POD method assumes that the capability of flaw detection increases with the size of flaws in the neighborhood of the target flaw size. In addition to signal response data from flawed specimens, noise data (i.e., signals from specimens or inspection opportunities where no flaw exists) are necessary for this method. Qualification by this method demonstrates that the procedure and operator are capable of reliably detecting flaws larger than or equal to the target flaw size.

4.2.4 NDE Capability Demonstration Specimens

[NER 47] Special NDE demonstration specimen design **shall** be justified and approved by the RFCB or the delegated NASA Technical Authority based on the similarity or transfer function between the test hardware and the demonstration specimen and documented in the NDE Summary Report.

Ideally, Special NDE capability demonstrations would be performed with naturally occurring flaws of the type and size specified by the fracture control plan in representative specimens of the actual component geometry and field inspection access restrictions. Seldom are enough specimens available with flaw sizes that are independently verified for a Special NDE capability demonstration. Historically, simulated flaws have been used in component representative or simplified specimens, such as plates, cylinders, or tubes. Simulated flaws may be induced, such as cracks induced by fatigue or thermal loading, or fabricated by material removal methods such as EDM machining or laser notching, or by AM methods. Simulated induced flaws such as *fatigue cracks should be used for Special NDE capability demonstration as they are typically conservative to naturally occurring flaws with respect to flaw features such as crack opening that affect the signal response produced by NDE methods. In special cases, other flaws such as simulated fabricated flaws that are more representative of the naturally occurring flaws for the specific application may be used for the demonstration with the approval of the RFCB and the delegated NASA Technical Authority. The preparation and control of demonstration specimens and how to administer demonstration tests should meet the intent of MIL-HDBK-1823A, PEM, or LS-POD.*

4.3 NDE Procedures, Standards, and Methods

a. [NER 48] NDE procedures, standards, methods, and acceptance criteria **shall** be defined, validated, documented, approved, and implemented for all phases of the life cycle such as manufacturing, operation, and maintenance of each fracture-critical part.

b. [NER 49] Updates to any of the NDE procedures, standards, methods, or acceptance criteria **shall** be validated, documented, and approved by the RFCB or the delegated NASA Technical Authority.

c. [NER 50] All NDE inspections **shall** be conducted by certified NDE inspectors (see section 4.5 in this Standard).

d. [NER 51] The fracture-critical NDE inspection procedure(s) **shall** be clearly defined for each type of part.

e. [NER 52] All identified part areas **shall** be inspected.

f. [NER 53] Unless specified otherwise by the delegated NASA Technical Authority, inspection procedures **shall** be designed to detect volumetric and surface cracks and crack-like flaws in all orientations.

4.3.1 Material Review Board (MRB)

[NER 54] The acceptance of cracks of any size in a fracture-critical part **shall** require an MRB action and the approval of the RFCB and the delegated NASA Technical Authority.

4.3.2 NDE Drawing Callouts

a. [NER 55] NDE inspection requirements for all fracture-critical parts **shall** be clearly identified on all drawings.

b. [NER 56] The drawings **shall** clearly identify each inspection requirement by zone when different zones require different NDE inspection requirements and acceptance criteria.

c. [NER 57] The drawings **shall** be updated when NDE inspection requirements are updated.

4.3.3 NDE Process Documentation Control

a. [NER 58] A written procedure for each fracture-critical part **shall** be developed that complies with the relevant specification for the NDE method selected.

b. [NER 59] Documentation control by revision or date **shall** be maintained current for the following:

(1) Personnel Qualification.
(2) Personnel Certification.
(3) NDE Specification.
(4) NDE Reference Standards.
(5) NDE Method.
(6) NDE Part-Specific Procedures.

All NDE process changes require approval by the responsible NDE organization and the delegated NASA Technical Authority.

4.3.4 Capability Demonstration Specimens

a. [NER 60] NDE capability demonstration specimens **shall** be used for determining the detection capability for all Special NDE applications and may be used to validate the capabilities of Standard NDE procedures.

b. [NER 61] Specimens **shall** be representative of the material to be inspected and the critical inspection area for the applicable hardware and of the flaw size (length, width and depth), type, location, and orientation.

Specimens may be borrowed from NASA or other Government departments when available.

c. [NER 62] If appropriate demonstration specimens are not available, specimens **shall** be built or procured that meet both specimen requirements and specific engineering drawing requirements.

d. [NER 63] Specimens used **shall** be documented as a part of the NDE procedures and personnel skill qualifications.

4.3.5 Organizational Guidelines and Documentation

It is recommended that a document be developed that meets the intent of the responsibilities and authorities described in Appendix B of this Standard.

4.4 NDE Documentation

4.4.1 NDE Plan

[NER 64] An NDE plan **shall** be developed that addresses the following, as a minimum:

a. Applicable specifications and documented standards.
b. Calibration artifact traceability.
c. Inspector training, qualification, and certification.
d. Method selection, application, and process control.
e. Acceptance criteria.
f. Application of requirements during manufacturing, maintenance, and operations.
g. NDE applied to fracture-critical hardware.
h. Standard NDE selection, application, and control.
i. Special NDE selection, equipment, application, and configuration control.

4.4.2 NDE Summary/Inspection Report

4.4.2.1 [NER 65] An NDE Summary Report **shall** be developed and include, but not be limited to, the following:

a. Identification of the fracture-critical part number.
b. Critical zones inspected.
c. NDE methods applied and procedures used.
d. Classification and justification of Standard NDE or Special NDE inspections.
e. Acceptance, rejection, or summary of critical data.
f. Inspectors' names and inspection dates.
g. Evaluation of special conditions that affect Standard NDE.
h. Descriptions, locations, and sizes for flaws that do not meet acceptance criteria.
i. Non-conformances and problems encountered during the inspection.
j. Descriptions, locations, and sizes for all detected cracks or crack-like flaws, regardless of size.

4.4.2.2 [NER 66] An NDE inspection report **shall** be generated for every part acceptance NDE operation by NDE personnel involved in the NDE operation and signed by cognizant NAS-410, NAS Certification and Qualification of Nondestructive Test Personnel, Level 2 or 3.

4.4.2.3 [NER 67] NDE reports and digital records from NDE techniques that produce digital data (e.g., ultrasonic C-scans, radiographs, shearography images) used for part acceptance **shall** be traceable through the NDE Summary Report.

4.4.3 Supporting Data and Record Retention

4.4.3.1 [NER 68] All certification records, NDE reports, and associated paperwork **shall** be retained per current NASA requirements for records management as specified in NPR 1441.1, NASA Records Management Program Requirements.

It is recommended that electronic and digital data be stored in common file formats that are not lost via equipment-unique data storage or limited proprietary formats.

4.4.3.2 [NER 69] Responsible NDE engineering **shall** acquire and retain all records during a change to a different contractor, including but not limited to, the following:

(1) Controlling NDE specifications and document standards.
(2) Calibration artifact traceability.
(3) Part-specific NDE procedures.
(4) Special NDE 90/95% capability demonstration data.
(5) Supporting data used to justify Standard NDE.
(6) Standard and Special NDE inspector qualification and certification documents.
(7) Standard and Special NDE process changes and approval documents.
(8) The hardware acceptance, inspection, and summary reports.
(9) Other supporting data, including inspector identifications, inspection dates, detailed and zoned drawings, acceptance criteria, and NDE problem reports and resolutions.
(10) NDE reports.

4.5 Personnel Qualification and Certification

4.5.1 [NER 70] Personnel performing Standard or Special NDE of fracture-critical hardware **shall** be, at a minimum, qualified and certified Level II in accordance with NAS 410.

Successful demonstration of 90/95 POD on the NDE capability demonstration specimens qualifies the specific written procedure and inspector performing the inspection for detecting the demonstrated flaw size and larger.

4.5.2 [NER 71] If there is a failure to demonstrate capability, then proof of improved inspector skills **shall** be presented to the responsible NDE organization or the delegated NASA Technical Authority prior to a retest.

Examples are additional training and education.

4.5.3 [NER 72] Qualification for Special NDE **shall** be specific to the procedure and the inspector.

4.5.4 [NER 73] Special NDE inspection **shall** not be transferable to another procedure or inspector.

4.5.5 [NER 74] The period of Special NDE certification **shall** be 3 years.

Table 1—Reliably Detectable Flaw Sizes for Fracture Analysis Based on Standard NDE Methods (Millimeters) (See Section 4.1 of this Standard for applicability.)

Système Internationale Units (millimeters)

Crack Location	**Part Thickness, t**	**Crack Type**	**Crack Dimension, a***	**Crack Dimension, c***
Eddy Current NDE				
Open Surface	0.381 ≤ t ≤ 1.27 t > 1.27	Through PTC[1]	t 0.51 1.27	1.27 2.54 1.27
Edge or Hole	0.381 ≤ t ≤ 1.91 t > 1.91	Through Corner	t 1.91	2.54 1.91
Penetrant NDE				
Open Surface	0.64 ≤ t ≤ 1.27 1.27<t <1.91 t > 1.91	Through Through PTC	t t 0.64 1.91	2.54 3.81 – t 3.18 1.91
Edge or Hole	0.64 ≤ t ≤ 2.54 t > 2.54	Through Corner	t 2.54	3.81 3.81
Magnetic Particle NDE				
Open Surface	t ≤ 1.91 t > 1.91	Through PTC	t 0.97 1.91	3.18 4.78 3.18
Edge or Hole	t ≤ 1.91 t > 1.91	Through Corner	t 1.91	6.35 6.35
Radiographic NDE				
Open Surface	t ≤2.72 t > 2.72	PTC PTC Embedded	0.7t 0.7t 2a=0.7t	1.91 0.7t 0.7t
Ultrasonic NDE Comparable to a Class A Quality Level (ASTM E-2375)				
Open Surface	t ≥ 2.54	PTC Embedded**	0.76 1.65 0.43 0.99	3.81 1.65 2.21 0.99

[1] PTC – Partly through crack (Surface Crack)
* See Figure 3 for definitions of “a” and “c” for different geometries.
** Equivalent area is acceptable, ASTM E-2375, Class A.

Table 2—Reliably Detectable Flaw Sizes for Fracture Analysis Based on Standard NDE Methods (Inches) (See Section 4.1 of this Standard for applicability.)

U. S. Customary Units (inches)

Crack Location	Part Thickness, t	Crack Type	Crack Dimension, a*	Crack Dimension, c*
Eddy Current NDE				
Open Surface	0.015 ≤ t ≤ 0.050 t > 0.050	Through PTC[1] PTC	t 0.020 0.050	0.050 0.100 0.050
Edge or Hole	0.015 ≤ t ≤ 0.075 t > 0.075	Through Corner	t 0.075	0.100 0.075
Penetrant NDE				
Open Surface	0.025 ≤ t ≤ 0.050 0.050<t <0.075 t > 0.075	Through Through PTC	t t 0.025 0.075	0.100 0.150 - t 0.125 0.075
Edge or Hole	0.025 ≤ t ≤ 0.100 t > 0.100	Through Corner	t 0.100	0.150 0.150
Magnetic Particle NDE				
Open Surface	t ≤ 0.075 t > 0.075	Through PTC	t 0.038 0.075	0.125 0.188 0.125
Edge or Hole	t ≤ 0.075 t > 0.075	Through Corner	t 0.075	0.250 0.250
Radiographic NDE				
Open Surface	t ≤0.107 t > 0.107	PTC PTC Embedded	0.7t 0.7t 2a=0.7t	0.075 0.7t 0.7t
Ultrasonic NDE Comparable to a Class A Quality Level (ASTM E-2375)				
Open Surface	t ≥ 0.100	PTC Embedded**	0.030 0.065 0.017 0.039	0.150 0.065 0.087 0.039

[1] PTC - Partly through crack (Surface Crack)
* See Figure 3 for definitions of “a” and “c” for different geometries.
** Equivalent area is acceptable, ASTM E-2375, Class A.

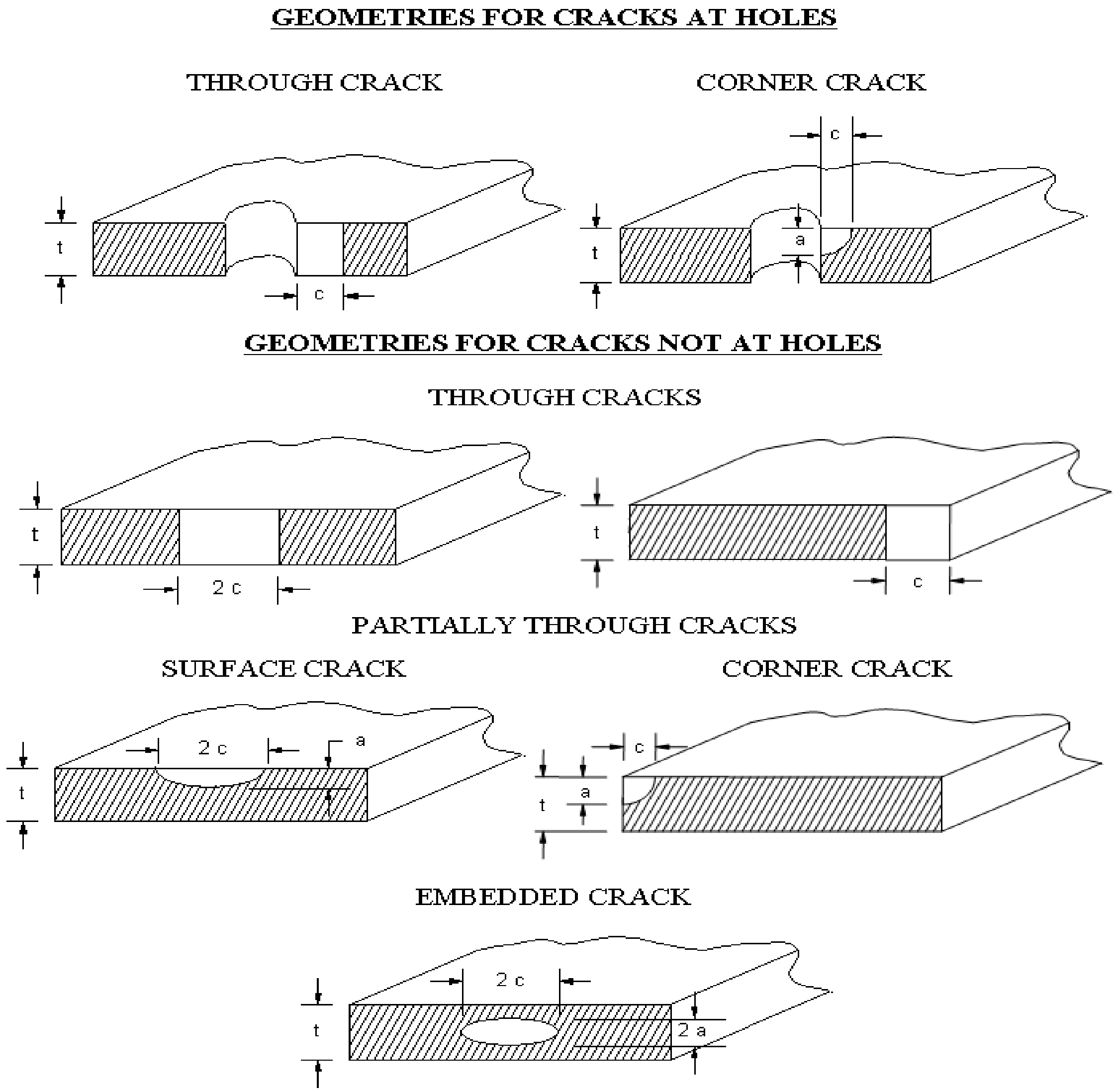

Figure 3—Assumed Flaw Geometries

APPENDIX A: REQUIREMENTS IDENTIFICATION MATRIX

A.1 PURPOSE

Due to the complexity and uniqueness of space flight, it is unlikely that all of the requirements in a Standard will apply. The Requirements Identification Matrix below contains this Standard's technical authority requirements and may be used by programs and projects to indicate requirements that are applicable or not applicable. Enter "Yes" in the "Applicable" column if the requirement is applicable to the program or project or "No" if the requirement is not applicable to the program or project. The "Comments" column may be used to provide specific instructions on how to apply the requirement, specify proposed tailoring, or provide an explanation/justification when not applicable.

Table 3—Requirements Identification Matrix

NASA-STD-5009C				
Section	**Description**	**Requirement in this Standard**	**Applicable (Enter Yes or No)**	**Comments**
4. NDE Requirements				
4.1	Standard NDE	[NER 1] Standard NDE **shall** consist of nondestructive inspections of traditional (non-AM) metal components, (e.g., aluminum, steel, titanium, and nickel alloys) using the NDE methods cited in Table 1, Reliably Detectable Flaw Sizes for Fracture Analysis Based on Standard NDE Methods (Millimeters), or Table 2, Reliably Detectable Flaw Sizes for Fracture Analysis Based on Standard NDE Methods (Inches), or additional methods that have been demonstrated by section 4.1.5 in this Standard and approved by the RFCB or delegated NASA Technical Authority.		

Table 1—Reliably Detectable Flaw Sizes for Fracture Analysis Based on Standard NDE Methods (Millimeters) (See Section 4.1 of this Standard for applicability.)

Système Internationale Units (millimeters)

Crack Location	Part Thickness, t	Crack Type	Crack Dimension, a*	Crack Dimension, c*
Eddy Current NDE				
Open Surface	0.381≤ t ≤ 1.27 t > 1.27	Through PTC[1]	t 0.51 1.27	1.27 2.54 1.27
Edge or Hole	0.381≤ t ≤ 1.91 t > 1.91	Through Corner	t 1.91	2.54 1.91
Penetrant NDE				
Open Surface	0.64 ≤ t ≤ 1.27 1.27<t <1.91 t > 1.91	Through Through PTC	t t 0.64 1.91	2.54 3.81 – t 3.18 1.91
Edge or Hole	0.64 ≤ t ≤ 2.54 t > 2.54	Through Corner	t 2.54	3.81 3.81
Magnetic Particle NDE				
Open Surface	t ≤ 1.91 t > 1.91	Through PTC	t 0.97 1.91	3.18 4.78 3.18
Edge or Hole	t ≤ 1.91 t > 1.91	Through Corner	t 1.91	6.35 6.35
Radiographic NDE				
Open Surface	t ≤2.72 t > 2.72	PTC PTC	0.7t 0.7t	1.91 0.7t

NASA-STD-5009C				
Section	**Description**	**Requirement in this Standard**	**Applicable (Enter Yes or No)**	**Comments**
		(table continued below)		

		Embedded	2a=0.7t	0.7t
Ultrasonic NDE Comparable to a Class A Quality Level (ASTM E-2375)				
Open Surface	t ≥ 2.54	PTC	0.76 1.65	3.81 1.65
		Embedded**	0.43 0.99	2.21 0.99

[1] PTC – Partly through crack (Surface Crack)
* See Figure 3 for definitions of “a” and “c” for different geometries.
** Equivalent area is acceptable, ASTM E-2375, Class A.

Table 2—Reliably Detectable Flaw Sizes for Fracture Analysis Based on Standard NDE Methods (Inches) (See Section 4.1 of this Standard for applicability.)

U. S. Customary Units (inches)

Crack Location	Part Thickness, t	Crack Type	Crack Dimension, a*	Crack Dimension, c*
Eddy Current NDE				
Open Surface	0.015 ≤ t ≤ 0.050 t > 0.050	Through PTC[1] PTC	t 0.020 0.050	0.050 0.100 0.050
Edge or Hole	0.015 ≤ t ≤ 0.075 t > 0.075	Through Corner	t 0.075	0.100 0.075
Penetrant NDE				
Open Surface	0.025 ≤ t ≤ 0.050 0.050<t <0.075 t > 0.075	Through Through PTC	t t 0.025 0.075	0.100 0.150 - t 0.125 0.075
Edge or Hole	0.025 ≤ t ≤ 0.100 t > 0.100	Through Corner	t 0.100	0.150 0.150
Magnetic Particle NDE				
Open Surface	t ≤ 0.075 t > 0.075	Through PTC	t 0.038 0.075	0.125 0.188 0.125
Edge or Hole	t ≤ 0.075 t > 0.075	Through Corner	t 0.075	0.250 0.250
Radiographic NDE				
Open Surface	t ≤0.107 t > 0.107	PTC PTC	0.7t 0.7t	0.075 0.7t

<table>
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<tr><td colspan="5"><u>Ultrasonic NDE</u>
Comparable to a Class A Quality Level (ASTM E-2375)</td></tr>
<tr><td>Open Surface</td><td>t ≥ 0.100</td><td>PTC

Embedded**</td><td>0.030
0.065
0.017
0.039</td><td>0.150
0.065
0.087
0.039</td></tr>
</table>
[1] PTC - Partly through crack (Surface Crack)
* See Figure 3 for definitions of “a” and “c” for different geometries.
** Equivalent area is acceptable, ASTM E-2375, Class A.
</td><td></td><td></td></tr>
<tr><td>4.1.1</td><td>Standard NDE Crack Sizes</td><td>[NER 2] Nondestructive inspections of fracture-critical hardware shall detect the initial crack sizes used in the damage tolerance fracture analyses with a capability of minimum 90% probability of detection at a 95% confidence level, known as 90/95.</td><td></td><td></td></tr>
<tr><td>4.1.2</td><td>Standard NDE Classification Justification</td><td>[NER 3] The justification to classify an NDE procedure as a Standard NDE procedure shall be documented and approved by NDE engineering and the delegated NASA Technical Authority.</td><td></td><td></td></tr>
<tr><td>4.1.3</td><td>Demonstration of Standard NDE Capability</td><td>[NER 4] Instrument standardization shall be performed.</td><td></td><td></td></tr>
<tr><td>4.1.4.1.1</td><td>Eddy Current</td><td>[NER 5] Eddy-current inspections shall be in accordance with SAE ARP4402, Eddy Current Inspection of Open Fastener Holes in Aluminum Aircraft Structure; SAE AS4787, Eddy Current Inspection of Circular Holes in Nonferrous Metallic Aircraft Engine Hardware; or NASA fracture control and NASA NDE Engineering-approved contractor internal specifications with the following additional requirements:</td><td></td><td></td></tr>
<tr><td>4.1.4.1.1a</td><td>Eddy Current</td><td>[NER 6] For part conductivities less than 10% International Annealed Copper Standard (IACS), the reference standard shall have a conductivity of ±2% IACS with a minimum reference standard conductivity of 0.8% IACS.</td><td></td><td></td></tr>
<tr><td>4.1.4.1.1b</td><td>Eddy Current</td><td>[NER 7] Reference standard notches used for standardization shall be no larger than ½ the length and ½ the depth of the target crack size with a maximum width of 0.127 mm (0.005 in).</td><td></td><td></td></tr>
</table>

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Section	**Description**	**Requirement in this Standard**	**Applicable (Enter Yes or No)**	**Comments**
4.1.4.1.1c	Eddy Current	[NER 8] Noise levels on the component **shall** be less than 25% of the reference notch response.		
4.1.4.1.1d	Eddy Current	[NER 9] Any indication greater than 50% of the reference notch response **shall** be reported to, and receive disposition by, the proper engineering authority.		
4.1.4.1.2	Eddy Current	[NER 10] The influence of coatings and lift-off variations on the reliability of an eddy current Standard NDE inspection process **shall** be evaluated for application-specific suitability and documented in the NDE Summary Report.		
4.1.4.2	Fluorescent Penetrant	[NER 11] Fluorescent Penetrant inspection **shall** be in accordance with ASTM E1417/E1417M, Standard Practice for Liquid Penetrant Testing; SAE AMS2647, Fluorescent Penetrant Inspection Aircraft Structures and Engine Component Maintenance; or NASA fracture control and NASA NDE Engineering-approved contractor internal specifications.		
4.1.4.2.1	Penetrant System	[NER 12] The penetrant system used **shall** be a fluorescent penetrant of sensitivity level 3 or 4.		
4.1.4.2.2	Mechanically Disturbed Surfaces	[NER 13] Mechanically disturbed or wire EDM surfaces **shall** be etched or electropolished prior to the penetrant inspection and at an appropriate time in the manufacturing flow.		
4.1.4.2.3a	Etching/Electropolishing Procedure	[NER 14] An etching/electropolishing procedure **shall** be developed, approved, and controlled to prevent part damage.		
4.1.4.2.3b	Etching/Electropolishing Procedure	[NER 15] The etching/electropolishing procedure **shall** specify the minimum amount of material to be removed to ensure that smeared metal does not mask cracks.		
4.1.4.2.3b(1)	Etching/Electropolishing Procedure	[NER 16] Non-ferrous materials such as aluminum and titanium alloys **shall** be etched/electropolished to remove a minimum of 0.01 mm (0.0004 in) of material.		
4.1.4.2.3b(2)	Etching/Electropolishing Procedure	[NER 17] Corrosion resistant steel and nickel-based alloys **shall** be etched/electropolished to remove a minimum of 0.005 mm (0.0002 in) of material.		
4.1.4.2.3c	Etching/Electropolishing Procedure	[NER 18] If etching/electropolishing is not feasible or the minimum depths are not attainable, it **shall** be demonstrated and documented that the required flaw size can be reliably detected following current machining processes.		
4.1.4.2.4	Special Considerations	[NER 19] Interpretation of reliably detectable flaw sizes for thin parts with thickness less than 0.64 mm (0.025 in) or edges and holes with a fillet radius **shall** require approval by the RFCB.		

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Section	**Description**	**Requirement in this Standard**	**Applicable (Enter Yes or No)**	**Comments**
4.1.4.3	Magnetic Particle	[NER 20] Magnetic particle inspections **shall** be in accordance with ASTM E1444/E1444M, Standard Practice for Magnetic Particle Testing for Aerospace, or NASA fracture control and NASA NDE Engineering-approved contractor internal specifications.		
4.1.4.3.1	Magnetic Particle	[NER 21] The magnetic particle inspection **shall** be the wet, fluorescent, continuous, or multi-mag method.		
4.1.4.3.2	Magnetic Particle	[NER 22] A Quantitative Quality Indicator (QQI) **shall** be used to validate the local field intensities.		
4.1.4.3.3	Magnetic Particle	[NER 23] Type CX-230 or CX4-230 QQIs **shall** be used on curved or complex surfaces where the Type CX-430 or CX4-430 QQIs cannot conform to the part in the area of interest.		
4.1.4.4.1	Radiography (X-Ray)	[NER 24] A POD study **shall** be used to establish the capability of digital radiographic techniques, including computed radiography, digital radiography, and computed tomography which at this time are to be considered to be NDE.		
4.1.4.4.2	Radiography (X-Ray)	[NER 25] A POD study **shall** be used to establish the capability of Gamma radiation source inspections which are considered special NDE.		
4.1.4.4.3	Radiography (X-Ray)	[NER 26] Film radiographic inspections, with capabilities shown in Table 1 or Table 2, **shall** be in accordance with ASTM E1742/E1742M, Standard Practice for Radiographic Examination, or NASA fracture control and NASA NDE Engineering-approved contractor internal specifications with the following additional requirements:		
4.1.4.4.3a	Radiography (X-Ray)	[NER 27] The minimum radiographic inspection sensitivity level **shall** be 2-1T.		
4.1.4.4.3b	Radiography (X-Ray)	[NER 28] Film density **shall** be 2.5 to 4.0.		
4.1.4.4.3c	Radiography (X-Ray)	[NER 29] The local x-ray axis of the radiation beam **shall** be within ±5 degrees of the assumed crack plane orientation.		
4.1.4.5	Ultrasonics	[NER 30] Utrasonic inspections for wrought products **shall** be in accordance with ASTM E2375, Standard Practice for Ultrasonic Testing of Wrought Products, ASTM E164, Standard Practice for Contact Ultrasonic Testing of Weldments, or NASA fracture control and NASA NDE Engineering-approved contractor internal specifications with the following additional requirements:		
4.1.4.5a	Ultrasonics	[NER 31] Any single discontinuity with a response greater than 50% of the response from a 1.98 mm (0.078-in) diameter flat bottom hole (or equivalent		

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Section	**Description**	**Requirement in this Standard**	**Applicable (Enter Yes or No)**	**Comments**
		surface notch or side drilled hole) at the estimated discontinuity depth (or sound path) **shall** be reported.		
4.1.4.5b	Ultrasonics	[NER 32] Multiple discontinuities with indications greater than the response from a 1.19 mm (0.047-in) diameter flat bottom hole (or equivalent surface notch or side drilled hole) at the estimated discontinuity depth (or sound path) **shall** be reported if the centers of any two such indications are separated by less than 25.4 mm (1 in).		
4.1.4.5c	Ultrasonics	[NER 33] Any linear discontinuity (i.e., cracks or crack-like flaws such as stringers, incomplete fusion, or incomplete penetration) with a response equal to or greater than the response from a 1.19-mm (0.047-in) diameter flat bottom hole (or equivalent surface notch or side drilled hole) at the estimated discontinuity depth (or sound path) **shall** be reported regardless of length.		
4.1.5.1	Method for Introducing New Standard NDE Flaw Sizes	[NER 34] A Standard NDE POD study **shall** consist of a MIL-HDBK-1823A-compliant POD study that is conducted by a minimum of 10 inspectors that form a representative sample from a specific population of inspectors.		
4.1.5.2	Method for Introducing New Standard NDE Flaw Sizes	[NER 35] Individual inspector analyses **shall** be performed in accordance with MIL-HDBK-1823A methods and reported.		
4.1.5.3	Method for Introducing New Standard NDE Flaw Sizes	[NER 36] Individual inspector probability of false-calls (POF) **shall** be reported and are recommended to not exceed 1% POF with 50% confidence.		
4.1.5.4	Method for Introducing New Standard NDE Flaw Sizes	[NER 37] The Standard NDE flaw size **shall** be estimated as a function of the average and standard deviation of individual inspector $a_{90/95}$ flaw sizes and represent the flaw size that 90% of inspectors are expected to demonstrate at least 90/95 detection capability.		
4.1.5.5	Method for Introducing New Standard NDE Flaw Sizes	[NER 38] Approval of the study design, execution, and analysis, or waivers from these parameters, **shall** be subject to review and approval of the RFCB.		
4.1.6	Inability to Meet Standard NDE Inspection Process Requirements	[NER 39] If the requirements of section 4.1 of this Standard cannot be met or smaller cracks or crack-like flaws than those shown in Table 1 or Table 2 have to be detected, the inspection processes **shall** be considered Special NDE, and the Special NDE requirements of section 4.2 of this Standard apply.		
4.2.1	Special NDE - General	[NER 40] All Special NDE certification processes of NASA partners, contractors, sub-contractors, and suppliers **shall** be approved by the RFCB.		
4.2.2	Special NDE Crack Sizes	[NER 41] Special NDE inspections **shall** require the approval of the RFCB and the delegated NASA Technical Authority.		

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Section	**Description**	**Requirement in this Standard**	**Applicable (Enter Yes or No)**	**Comments**
4.2.3a	Demonstration of Special NDE Capability	[NER 42] A 90/95% flaw detection capability **shall** be demonstrated before a Special NDE inspection can be performed for fracture-critical part screening.		
4.2.3b	Demonstration of Special NDE Capability	[NER 43] The capability tests **shall** be designed and conducted based on the MIL-HDBK-1823A POD Method (section 4.2.3.1 of this Standard), the Binomial Point Estimate POD Method (section 4.2.3.2 of this Standard), the Limited-Sample POD method (section 4.2.3.3 of this Standard), or other method approved by the RFCB.		
4.2.3.1	NDE Qualification Using the MIL-HDBK-1823A POD Method	[NER 44] NDE qualification using the MIL-HDBK-1823 POD methods **shall** be performed in accordance with MIL-HDBK-1823A.		
4.2.3.2	NDE Qualification Using Binomial Point Estimate POD Method	[NER 45] NDE qualification using the Binomial Point Estimate Method (PEM) **shall** be performed in accordance with Materials Evaluation (ME), Vol. 40, No. 9, pp 922-932, 1982, adapted for a single flaw size interval, and the target flaw size is equal to or larger than the maximum flaw size in the set or a flaw set approved by the RFCB.		
4.2.3.3	NDE Qualification Using Limited Sample POD Method	[NER 46] NDE qualification using the limited sample probability of detection (LS POD) method **shall** be performed in accordance with NASA/TM−20210018515/Corrected Copy, NESC-TI-20-01545, Guidebook for Limited Sample Probability of Detection (LS-POD) Demonstration for Signal-Response Nondestructive Evaluation (NDE) Methods.		
4.2.4	NDE Capability Demonstration Specimens	[NER 47] Special NDE demonstration specimen design **shall** be justified and approved by the RFCB or the delegated NASA Technical Authority based on the similarity or transfer function between the test hardware and the demonstration specimen and documented in the NDE Summary Report.		
4.3a	NDE Procedures, Standards, and Methods	[NER 48] NDE procedures, standards, methods, and acceptance criteria **shall** be defined, validated, documented, approved, and implemented for all phases of the life cycle such as manufacturing, operation, and maintenance of each fracture-critical part.		
4.3b	NDE Procedures, Standards, and Methods	[NER 49] Updates to any of the NDE procedures, standards, methods, or acceptance criteria **shall** be validated, documented, and approved by the RFCB or the delegated NASA Technical Authority.		
4.3c	NDE Procedures, Standards, and Methods	[NER 50] All NDE inspections **shall** be conducted by certified NDE inspectors (see section 4.5 in this Standard).		

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Section	**Description**	**Requirement in this Standard**	**Applicable (Enter Yes or No)**	**Comments**
4.3d	NDE Procedures, Standards, and Methods	[NER 51] The fracture-critical NDE inspection procedure(s) **shall** be clearly defined for each type of part.		
4.3e	NDE Procedures, Standards, and Methods	[NER 52] All identified part areas **shall** be inspected.		
4.3f	NDE Procedures, Standards, and Methods	[NER 53] Unless specified otherwise by the delegated NASA Technical Authority, inspection procedures **shall** be designed to detect volumetric and surface cracks and crack-like flaws in all orientations.		
4.3.1	Material Review Board (MRB)	[NER 54] The acceptance of cracks of any size in a fracture-critical part **shall** require an MRB action and the approval of the RFCB and the delegated NASA Technical Authority.		
4.3.2a	NDE Drawing Callouts	[NER 55] NDE inspection requirements for all fracture-critical parts **shall** be clearly identified on all drawings.		
4.3.2b	NDE Drawing Callouts	[NER 56] The drawings **shall** clearly identify each inspection requirement by zone when different zones require different NDE inspection requirements and acceptance criteria.		
4.3.2c	NDE Drawing Callouts	[NER 57] The drawings **shall** be updated when NDE inspection requirements are updated.		
4.3.3a	NDE Process Documentation Control	[NER 58] A written procedure for each fracture-critical part **shall** be developed that complies with the relevant specification for the NDE method selected.		
4.3.3b	NDE Process Documentation Control	[NER 59] Documentation control by revision or date **shall** be maintained current for the following: (1) Personnel Qualification. (2) Personnel Certification. (3) NDE Specification. (4) NDE Reference Standards. (5) NDE Method. (6) NDE Part-Specific Procedures.		
4.3.4a	Capability Demonstration Specimens	[NER 60] NDE capability demonstration specimens **shall** be used for determining the detection capability for all Special NDE applications and may be used to validate the capabilities of Standard NDE procedures.		
4.3.4b	Capability Demonstration Specimens	[NER 61] Specimens **shall** be representative of the material to be inspected and the critical inspection area for the applicable hardware and of the flaw size (length, width and depth), type, location, and orientation.		

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Section	**Description**	**Requirement in this Standard**	**Applicable (Enter Yes or No)**	**Comments**
4.3.4c	Capability Demonstration Specimens	[NER 62] If appropriate demonstration specimens are not available, specimens **shall** be built or procured that meet both specimen requirements and specific engineering drawing requirements.		
4.3.4d	Capability Demonstration Specimens	[NER 63] Specimens used **shall** be documented as a part of the NDE procedures and personnel skill qualifications.		
4.4.1	NDE Plan	[NER 64] An NDE plan **shall** be developed that addresses the following, as a minimum: a. Applicable specifications and documented standards. b. Calibration artifact traceability. c. Inspector training, qualification, and certification. d. Method selection, application, and process control. e. Acceptance criteria. f. Application of requirements during manufacturing, maintenance, and operations. g. NDE applied to fracture-critical hardware. h. Standard NDE selection, application, and control. i. Special NDE selection, equipment, application, and configuration control.		
4.4.2.1	NDE Summary/Inspection Report	[NER 65] An NDE Summary Report **shall** be developed and include, but not be limited to, the following: a. Identification of the fracture-critical part number. b. Critical zones inspected. c. NDE methods applied and procedures used. d. Classification and justification of Standard NDE or Special NDE inspections. e. Acceptance, rejection, or summary of critical data. f. Inspectors' names and inspection dates. g. Evaluation of special conditions that affect Standard NDE. h. Descriptions, locations, and sizes for flaws that do not meet acceptance criteria. i. Non-conformances and problems encountered during the inspection. j. Descriptions, locations, and sizes for all detected cracks or crack-like flaws, regardless of size.		
4.4.2.2	NDE Summary/Inspection Report	[NER 66] An NDE inspection report **shall** be generated for every part acceptance NDE operation by NDE personnel involved in the NDE operation and signed by		

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Section	**Description**	**Requirement in this Standard**	**Applicable (Enter Yes or No)**	**Comments**
		cognizant NAS-410, NAS Certification and Qualification of Nondestructive Test Personnel, Level 2 or 3.		
4.4.2.3	NDE Summary/Inspection Report	[NER 67] NDE reports and digital records from NDE techniques that produce digital data (e.g., ultrasonic C-scans, radiographs, shearography images) used for part acceptance **shall** be traceable through the NDE Summary Report.		
4.4.3.1	Supporting Data and Record Retention	[NER 68] All certification records, NDE reports, and associated paperwork **shall** be retained per current NASA requirements for records management as specified in NPR 1441.1, NASA Records Management Program Requirements.		
4.4.3.2	Supporting Data and Record Retention	[NER 69] Responsible NDE engineering **shall** acquire and retain all records during a change to a different contractor, including but not limited to, the following: (1) Controlling NDE specifications and document standards. (2) Calibration artifact traceability. (3) Part-specific NDE procedures. (4) Special NDE 90/95% capability demonstration data. (5) Supporting data used to justify Standard NDE. (6) Standard and Special NDE inspector qualification and certification documents. (7) Standard and Special NDE process changes and approval documents. (8) The hardware acceptance, inspection, and summary reports. (9) Other supporting data, including inspector identifications, inspection dates, detailed and zoned drawings, acceptance criteria, and NDE problem reports and resolutions. (10) NDE reports.		
4.5.1	Personnel Qualification and Certification	[NER 70] Personnel performing Standard or Special NDE of fracture-critical hardware **shall** be, at a minimum, qualified and certified Level II in accordance with NAS 410.		
4.5.2	Personnel Qualification and Certification	[NER 71] If there is a failure to demonstrate capability, then proof of improved inspector skills **shall** be presented to the responsible NDE organization or the delegated NASA Technical Authority prior to a retest.		
4.5.3	Personnel Qualification and Certification	[NER 72] Qualification for Special NDE **shall** be specific to the procedure and the inspector.		
4.5.4	Personnel Qualification and Certification	[NER 73] Special NDE inspection **shall** not be transferable to another procedure or inspector.		

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Section	**Description**	**Requirement in this Standard**	**Applicable (Enter Yes or No)**	**Comments**
4.5.5	Personnel Qualification and Certification	[NER 74] The period of Special NDE certification **shall** be 3 years.		

APPENDIX B: EXAMPLE OF AN NDE ORGANIZATION ("SHALLS" ARE FOR EXAMPLE ONLY)

This Appendix provides an example of an NDE organization with clearly defined roles, responsibilities, and implementation. This is not a requirement and may be used as an organizational model.

NOTE: The "shalls" used below are for example purposes only and are not requirements related to this Standard.

B.1 IMPLEMENTATION AND RESPONSIBILITIES

B.1.1 Oversight Responsibility

The responsible NASA Center shall provide an NDE oversight function and approval of the hardware developer's NDE plan and program for the inspection of fracture-critical hardware.

a. The NASA oversight function shall establish periodic reviews of the hardware developer's NDE program.

b. The NDE oversight function shall be responsible for establishing the personnel certification system for Special NDE procedures when NASA conducts the certification tests.

c. NDE standards and procedures for fracture-critical hardware shall be approved by the responsible NASA Center.

d. In general, all plans, data, documentation, reference standards, and reliability demonstration specimens generated under contract from NASA to its contractors, subcontractors, and suppliers in fulfillment of these requirements during hardware development, manufacturing, operations, and maintenance shall be subject to examination, evaluation, and inspection by and delivery to the NDE oversight function or designated representatives of the responsible NASA Center.

B.1.2 Responsibility of Hardware-Specific NDE Requirements

a. The hardware developer, in concurrence with the RFCB and delegated NASA Technical Authority, shall establish and provide hardware-specific NDE requirements to its in-house NDE inspection organizations, suppliers, subcontractors, and vendors to accomplish the NDE during manufacturing.

b. The hardware developer, in concurrence with the RFCB and delegated NASA Technical Authority, shall provide the hardware-specific NDE requirements for operations and maintenance to the responsible NASA Center or its designated sustaining engineering organization.

c. The sustaining engineering organization, in concurrence with the RFCB and the delegated NASA Technical Authority, shall be responsible for maintaining, changing, and establishing new hardware-specific fracture control requirements.

d. The hardware developer or sustaining engineering organization shall perform a drawing review process that identifies fracture-critical parts, identifies all areas of the parts requiring NDE, and identifies the appropriate type of NDE during manufacturing, maintenance, and operations.

e. The review process shall include NDE engineering.

f. NDE engineering shall ensure that the identified areas are inspectable and that efficient and reliable NDE methods are selected.

B.1.3 Responsibility of NDE Standards, Procedures, and Reference Standards During Hardware Development and Manufacturing

a. The hardware developer’s responsible NDE engineering shall be responsible for establishing and approving NDE method standards, NDE procedures, and NDE reference standards and for ensuring that all NDE processes are implemented through approved written NDE procedures.

b. The NDE procedures shall be performed by the hardware developer’s NDE inspection organization or by an approved external NDE organization, provided that the NDE procedures approved by responsible NDE engineering are used by personnel certified for fracture-critical NDE.

c. NDE engineering shall be responsible for administering Special NDE certification tests and approving certification of the NDE personnel.

B.1.4 Responsibility of NDE Standards, Procedures, and Reference Standards for Operations and Maintenance NDE

a. During hardware development, the hardware developer shall be responsible for establishing, approving, and providing operations and maintenance NDE requirements, method standards, NDE procedures, and NDE reference standards to the sustaining engineering organization designated by the responsible NASA Center.

b. During operations and maintenance, the sustaining engineering organization, in concurrence with the RFCB and the delegated NASA Technical Authority, shall be responsible for maintaining or changing existing NDE requirements, standards, and procedures as well as establishing and maintaining new hardware-specific NDE requirements, standards, and procedures. *NDE procedures may be performed by an in-house NDE inspection organization or* *by an external NDE inspection organization provided that the NDE procedures approved by NDE engineering are used by the personnel certified for fracture-critical NDE.*

c. NDE engineering shall be responsible for administering Special NDE certification tests and approving certification of the NDE personnel.

B.1.5 NDE Drawing Callouts

a. The hardware developer's responsible NDE engineering shall review the zoned drawings, the NDE inspection methods, procedures, and acceptance criteria.

b. Where there are different inspection requirements for different areas of a component, the drawing shall indicate separate inspection requirements for each zone.

B.1.6 NDE Process and Configuration Control

a. A written NDE procedure that complies with the relevant specification for the NDE method selected for the part is required for NDE inspection of each fracture-critical part.

b. Configuration control by revision or date shall be maintained for the personnel qualifications and certifications and for the NDE specifications, standards, and part-specific procedures.

c. Certifications shall remain current with revisions.

d. NDE engineering shall approve NDE process changes.

e. The RFCB and the delegated NASA Technical Authority shall have final approval for NDE process changes that affect the reliability of fracture-critical NDE.

B.1.7 Capability Demonstration Specimens

a. NDE engineering shall be responsible for designing, approving, and providing Special NDE capability demonstration specimens.

b. If possible, NDE engineering shall borrow the specimens from NASA or other government departments.

c. If appropriate demonstration specimens are not available, the hardware developer or the sustaining engineering organization shall build or procure the demonstration specimens in concurrence with the RFCB and the delegated NASA Technical Authority.

d. Capability artifacts used in NDE procedure application shall be traceable to those used in the capability demonstration of the NDE procedure.

B.1.8 Responsibilities of NDE Inspection Organization

a. The NDE inspection organization shall be responsible for training, qualification, and facilitating NDE certification of its inspection personnel.

b. The NDE inspection organization shall be responsible for maintaining and operating NDE equipment and facilities used in the NDE inspection of fracture-critical hardware.

c. The NDE inspection organization shall be responsible for retention of certification records, NDE reports, and associated paperwork through the life of the program.

APPENDIX C: REFERENCE DOCUMENTS

C.1 PURPOSE

This Appendix provides information of a general or explanatory nature but does not contain requirements. The latest issuances of reference documents apply unless specific versions are designated. Access reference documents at https://standards.nasa.gov or obtain documents directly from the Standards Developing Body, other document distributors, or information provided or linked.

C.2 GOVERNMENT DOCUMENTS

NASA-STD-6030, Additive Manufacturing Requirements for Spaceflight Systems

NASA/TM−2011-215869, A Comparison of the Capability of Sensitivity Level 3 and Sensitivity Level 4 Fluorescent Penetrants to Detect Fatigue Cracks in Various Metals, Parker, January 2011

NASA/TM−20220003648, NESC-TI-21-01657, Guidebook for Assessing Similarity and Implementing Empirical Transfer Functions for Probability of Detection (POD) Demonstrations for Signal Based Nondestructive Evaluation (NDE) Methods

NASA/TM−20220013820, NESC-TI-21-01657, A Survey of NASA Standard Nondestructive Evaluation (NDE)

NASA/TM−20220013822, NESC-TI-21-01657, Guidebook for the Design and Analysis of a NASA Standard Nondestructive Evaluation (NDE) Probability of Detection (POD) Study

NASA/TM−20230000318, Guidelines for Mapping Reliably Detectable Dye Penetrant Crack Size at External Corners with Fillet Radii, for estimating reliably detectable flaw sizes on external corners

NASA/TM−20230000324, Guidelines for Determining X-ray Shots for Inspection of Cylindrical Parts, to determine shot coverage and number of shots for inspection of girth weld on cylindrical or spherical parts.

Bishop, C. R. (1973): "Nondestructive Evaluation of Fatigue Cracks," Space Division Rockwell International, SD 73-SH-0219, NASA Contractor Report NAS9-14000, 1973 (https://ntrs.nasa.gov/citations/20220005353)

King, J. P.; and Johnson, K. R. (1974): "Space Shuttle Orbiter Fracture Control Plan," Space Division Rockwell International SD73-SH-0082A, 1974 (Document ID 20220017997)

NAVAIR 01-1A-34, Aeronautical Equipment Welding (http://everyspec.com/USN/NAVAIR/NAVAIR_01-1A-34_2009_30232/)

ECSS-E-ST-32-01C, European Space Agency, Fracture Control (http://everyspec.com/ESA/ECSS-E-ST-32-01C_REV-1_48193/)

JSC PRC-5010C, Process Specification for Pickling, Etching, and Descaling of Metals

MSFC-STD-1249, Standard NDE Guidelines and Requirements for Fracture Control Programs

C.3 NON-GOVERNMENT DOCUMENTS

ASTM E2862-18, Standard Practice for Probability of Detection Analysis for Hit/Miss Data

ASTM E3023-21, Standard Practice for Probability of Detection Analysis for â Versus a Data