Recommended Practice for a Demonstration of Nondestructive Evaluation (NDE) Reliability on Aircraft Production Parts

Prepared by the American Society for Nondestructive Testing (ASNT) and approved by the ASNT National Board of Directors

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Introduction to the Guidelines

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Background and Summary

Catastrophic failure of major systems (i.e., Liberty Ships, Threasher and F-111); a major engineering project (i.e., the military space race, the national space program, nuclear reactor programs and the Alaska pipeline); and development of a new materials application (i.e., composite materials) or a new engineering design/analysis technology (i.e., finite element analysis and fracture mechanics analysis) have evolved as major forcing functions in the development and application of nondestructive testing technology.

The introduction of linear elastic fracture mechanics in engineering design has been a major forcing function in nondestructive testing technology development during the past decade. Introduction of linear elastic fracture mechanics caused refocus of nondestructive testing practices from the traditional "How small a flaw can be detected?" to "How large a flaw might be missed?" The guidelines document was initiated and completed to provide a common baseline for demonstrating flaw detection capabilities in aircraft production. The importance and controversial nature of the document has resulted in long and laborious efforts on the part of many individuals to get a common agreement for publication. The published results constitute a consensus of some of the most distinguished members of the aerospace community.

History of the Document

The need for the document was identified by W. H. Lewis, Chairman of the Airframe Subcommittee of the ASNT Aerospace Committee, in March 1973. A concurrent effort for information exchange was initiated by the American Society for Metals (ASM) and the Air Force Materials Laboratory in a "Materials Design Forum Series on Prevention of Structural Failure Using NDT/Fracture Mechanics." This forum was held in 1973, 1974, 1975 and was cosponsored by ASNT in 1976.

The need was addressed to compliance with MIL-STD-1530, "Aircraft Structural Integrity Program, Airframe Requirements," dated September 1, 1972. A one-day working session of the Airframe Subcommittee was called by Lewis at Wright Patterson Air Force Base, OH, on July 10, 1973. Assignments were made to the 13 attendees for draft of the respective sections of the document for review and comment at the Aerospace meeting October 17, 1973. A final draft of the document was issued in January 1974. A second draft was issued in July 1974 that incorporated committee comments. This draft was submitted to the ASNT Technical Council for publication. Comments from the Technical Council were incorporated into a third draft, dated February 1975, and were submitted to the ASNT Board of Directors. A corrected copy of the third draft with Board of Directors' comments incorporated was submitted for publication in February 1976. This is essentially the form of the document in this final publication.

Credits for drafts, comments and pursuit of the final publication by members of the Aerospace Committee include:

Bill Bennett	Bill Shelton
Ward Rummel	Bob Roehrs
Rich Meyer	Don Pettit
Bill Sproat	Joe Moyzis
Nate Tupper	Bill Sturrock
Bernie Boisvert	Lee Crockett
Roy Wolford	J. L. Parker
Jim Moore	D. J. Hagemaier
Stanley Klima	P. F. Packman
M. L. Stellabotte	R. T. Anderson

Use of the Document

It is intended that the final document be used as a guideline for the preparation of specific reliability demonstration plans. It is, by nature, a living document and will continue to be a focal point for technology development in the aerospace community.

*Rummel was Chairman of the ASNT Airframe Subcommittee and of the Aerospace Committee during the initial drafts of the guidelines document.

Definition of Terms

Term	Definition
Defect Surface Length	Length of the defect measured on the surface of the specimen.
Defect Depth	Maximum measured depth below the surface of the specimen. For an elliptical surface flaw or part-through crack, this is the minor axis dimension.
Flaw Population	The total number of intentionally induced defects.
Flaw Size Group	A series of arbitrary groupings of flaw sizes, each group containing all cracks of a specified size range.
Test Specimens	Samples of the test material containing intentionally induced defects.
Inspection Procedure	Written document prepared following calibration studies which detail all steps in the inspection procedure for a given method of inspection.
Reliability	The probability of detecting a crack in a given size group under the inspection conditions and procedures specified in the inspection procedure document.
Statistical Sensitivity	A measure of the defect size which can be detected by a given NDE method and procedure. For the purpose of this document, the sensitivity will be defined in terms of a minimum detectable flaw size, i.e., the largest size crack that can escape detection at a given level of statistical probability and confidence level.
Nondestructive Evaluation	The act of determining mechanical, physical, or geometrical properties of a material, component, or structure without alteration of functional capabilities.

1. Purpose and Scope

1.1 *Purpose*

The purpose of this document is to promulgate a recommended practice for developing repeatable data for fracture mechanics applications. Such a practice is designed to demonstrate the capability of various NDE methods to detect flaws in specific materials or parts under routine production inspection conditions. The intent is to define the limiting flaw size which can be *detected* with a given probability of detection and with a given percent confidence in that probability. This document *does not* address the subject of NDE flaw size resolution once a flaw has been detected. (Flaw size measurement is conducted by those who are involved with data analysis.)

1.2 *Scope*

This document contains information necessary for the development of a valid, repeatable NDE demonstration program which may be utilized internally by a manufacturer to assess or improve both design and quality control or it may be imposed by a customer or regulatory body as necessary. The methods, specimen selection and choice of operating parameters should be specifically documented and mutually agreed upon between the requester and the organization demonstrating performance. This initial document suggests specimen designs using fatigue cracked, flat coupons because of their ease of fabrication and control. Subsequent revisions will address programs designed for the advancing technology and other product forms and/or other flaw types and geometries.

2. Applicability

Results of the recommended demonstration program outlined herein are intended for application to design and quality control functions under a variety of conditions. At this time, no quantitative means exist to translate results from the demonstration to one or several cases. Judgment can be applied to form estimates. There is no intent, however, to translate results from one method to another, e.g., eddy current to ultrasonic. The following items are factors that must be considered in forming estimates. These factors are listed under three general categories for convenience.

Factors to Consider when making Estimates

2.1 *Relation Between Test Specimens and Production Parts*

2.1.1 Production Part Similarity
- a. Production form (castings, forgings, assemblies, etc.)
- b. Material or alloy and heat treat
- c. Condition (coatings, surface finish, stressed, etched, etc.)
- d. Type of defect
- e. Location and orientation of typical flaws including interfering geometry
- f. Cleaning preparation

2.1.2. Test Samples
- a. Similarity to production parts
- b. Induced flaw geometry compared to type of defect expected

2.2 *Inspection Process Variables*

2.2.1 Type of Process (automatic, semiautomatic, manual)

2.2.2 Equipment and Materials
- a. Manufacturer and model
- b. Calibration, set-up and standards

2.2.3 Flaw Detection and/or Recognition Method (recording, alarm, visual interpretation)

2.2.4 Production or Inspection Rate (number or quantity of parts to be inspected per unit time)

2.2.5 Inspection Time (total elapsed time a group of parts is examined)

2.3 *Personnel and Environment Variables*

2.3.1 Personnel Training and Experience

2.3.2 Knowledge of Inspection Intent
- a. Probable flaw location
- b. Anticipated results

2.3.3 Inspection Location Convenience
- a. Area and space
- b. Optimum lighting
- c. Operator comfort
- d. Availability of auxilliary equipment (microscope, hand tools, polishing paper, etc.)

2.3.4 *Management and Periodic Surveillance of Operator/Area, Discipline and Conformance to Procedures*

2.3.5 Size of Parts and Handling Fixtures

3. Operational Requirements

3.1 *General*

The objective is to acquire a representative, unbiased sample of nondestructive inspection capabilities on aircraft parts in a production environment. An unbiased sampling process requires safeguards against preferential treatment. The work shall be conducted in facilities identified as regular production nondestructive inspection locations.

3.2 *Equipment*

A report of all equipment used in performing the NDE demonstration shall be made. This report shall identify the equipment by name, manufacturer, model number, the manufacturer's designation, and the owner's identification number(s). All pertinent operating parameters used in the demonstration shall be included with the equipment report. A list of parameters is provided in Appendix A.

3.3 *Personnel*

The production NDE personnel who conduct the NDE demonstration shall be identified by level of proficiency as defined by the American Society for Nondestructive Testing Document SNT-TC-1A, "Recommended Practice for Qualification and Certification of Nondestructive Testing Personnel," and/or Military Standard MIL-STD-410D, "Nondestructive Testing Personnel Qualification and Certification." Personnel shall be selected at random and identified by code. It is emphasized that this NDE demonstration program is not intended to grade or contrast individual personnel capabilities. Proficiency level identification is intended only as a part of the documentation of the overall NDE function.

An analysis of variance may be performed on the test data to assess whether or not the results are operator independent. This document, however, does not include details for performing this option.

3.4 *Specimens*

Typical specimen designs for metallic parts are provided in Appendix C. The demonstration specimens shall be constructed to closely resemble production parts where possible, and shall carry identification marks compatible with the production practices of the demonstrating concern. Delivery and transmittal of specimens shall be conducted within the routine practices exercised in transmittal of production parts into and out of NDE.

A sufficient number of flaw-free (control) specimens must be randomly mixed with the flawed specimens prior to initiation of a reliability investigation. Sufficient in this case means that as a minimum, the number of control specimens be equal in number to the flawed specimens.

3.5 *NDE Procedures*

Definitive and complete instructions for the calibration and performance of the NDE task on all specimens shall be documented and supplied as procedures to all affected personnel. Such procedures shall be supplied to the performing NDE personnel in the routine format used in the performance of NDE on regular production parts. Calibration standards as required shall be furnished as part of the necessary equipment to perform the NDE. Prior to the demonstration, a thorough and complete trial of NDE procedures on the completed specimens should be conducted to assure that a valid demonstration can be conducted.

3.6 *Reports*[a]

Reports for defect identification and location shall be formated in the routine manner used in the identification of defects in regular production parts and all defect indications shall be reported. An NDE operator's estimate or measure of defect size is not required. The intent is to assess detection probability for given flaws; not size resolution of those found.

4. Acquisition and Reduction of Data

4.1 *General*

A statistical treatment of flaw detection successes and failures is required to establish detection probabilities. A description of the statistical treatment is provided in Appendix B. A useful result of this treatment is a histogram of detection probabilities measured for selected flaw size intervals as depicted in Figure 4-1.

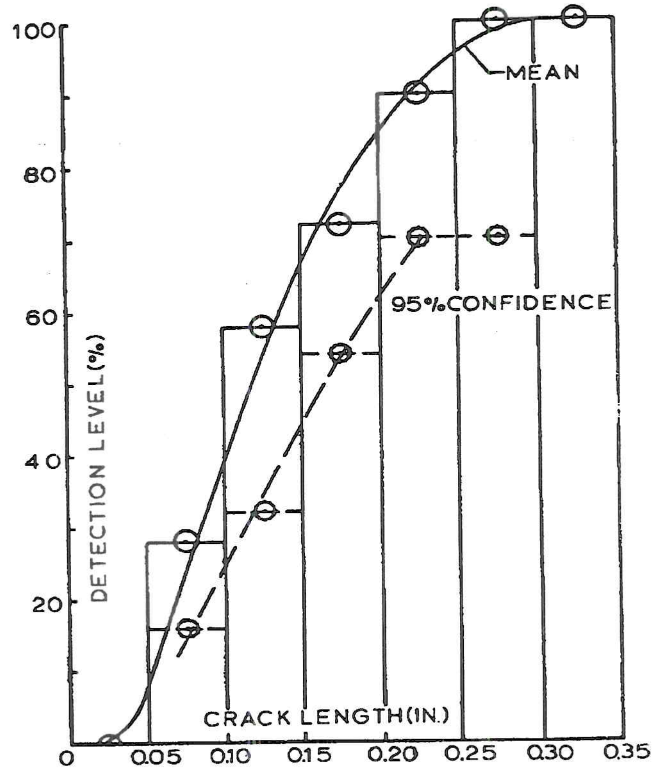

Figure 4-1—Crack detection probability, ultrasonic, NDE. (Note: This figure is provided solely to demonstrate the method of plotting data.)

4.2 *Procedure*

The flow diagram is depicted in Figure 4-2.

4.2.1 Decide upon the physical flaw parameter against which the inspection procedure is to be tested for reliability (crack length, depth, etc.)

4.2.2 Decide upon the flaw parameter size range to be investigated and the number and width of the intervals into which that range is to be divided

AND

Determine the number of [b]flawed specimens required for the reliability study. The number of flawed specimens per flaw size interval will be 29, 46, 61, 85 or 103 for the 90% reliability, 95% confidence level case (henceforth designated 90-95); 7, 17, 27, 37, 47, 57, 67, 77, 87, or 97 for the 90% reliability, 50% confidence level case (henceforth designated 90-50).

4.2.3 Randomly mix 29 (90-95 case) or 7 (90-50 case) flawed

[a]Care must be exercised in planning the demonstration such that discrepancy reports from this program do not enter the normal production inspection documents.

[b]It may be economically necessary to cycle repeated NDE on a selected number of flawed specimens to acquire the required volume of data.

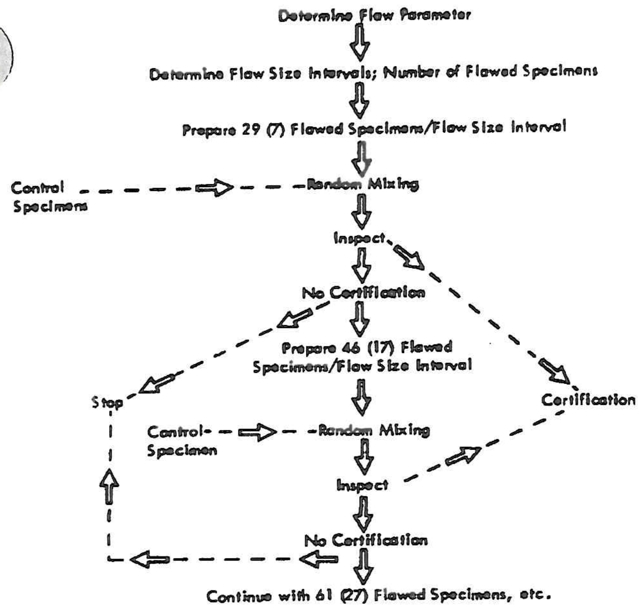

Figure 4-2—Procedure flow chart.

specimens for each flaw size interval with the unflawed control specimens and inspect per the procedure being investigated for reliability. Tabulate the results in a Table I format.

4.2.4 Decide upon certification.

4.2.4.1 If all 29 (90–95) or 7 (90–50) flawed specimens have been detected in a flaw size interval and in all larger flaw size intervals, the procedure is to be considered certified at the smallest such flaw size interval.

4.2.4.2 If no flaw size interval is certified after 29 (90–95) or 7 (90–50) flawed specimens have been inspected, a decision must be made as to whether it is economically feasible to continue the certification attempt. The maximum probability graphs, Figures 4-3 and 4-4, have been constructed to aid in this decision. (See Appendix B for a discussion of how these graphs are constructed). These graphs and Table

TABLE I CERTIFICATION DATA

Certification Level		______ Percent Reliability ______ Percent Confidence	
Flaw Size Interval	Number of Flawed Specimens	Flawed Samples Found by Inspection	Certified (Yes) or (No)

(Check One)

Decision Certified
Not Certified
Continue
Terminate

Reason (Give reason for continuing or terminating if inspection procedure is not verified at this stage)

Notes Number of Inspectors ______
Number of False Flaw Indications ______

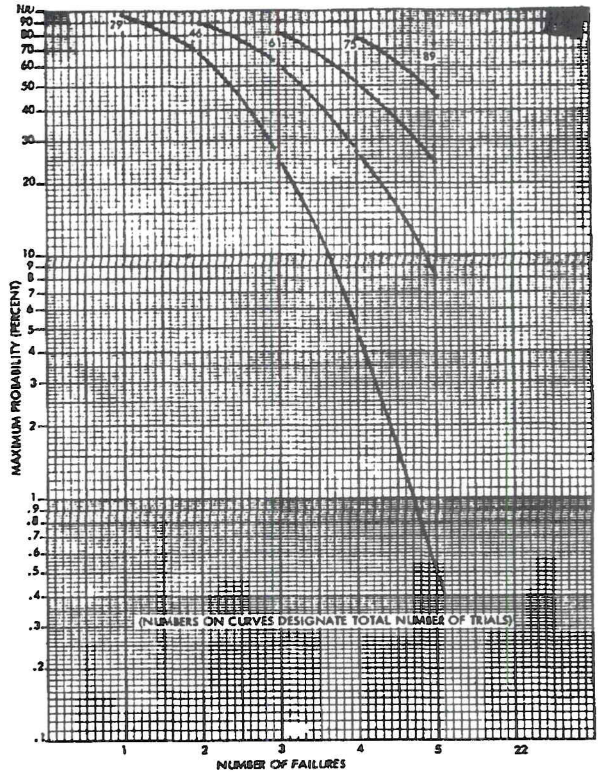

Figure 4-3—Maximum probabilities—90% reliability; 95% confidence.

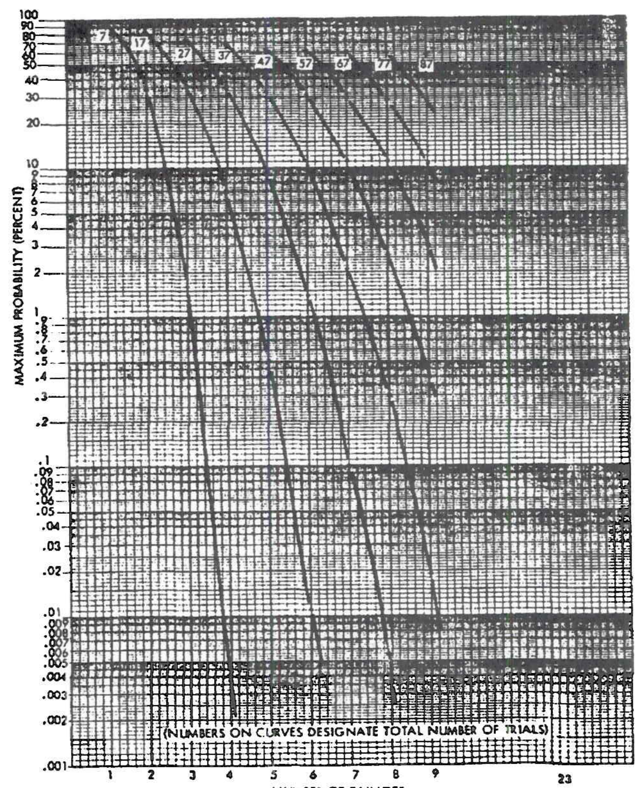

Figure 4-4—Maximum probabilities—90% reliability; 50% confidence.

II give an upper limit, dependent upon the inspection results to that point, to the probability that certification will be achieved if the investigation is continued.

For example, in the 90–95 case, if two of the 29 flawed specimens in a given flaw size interval are not found, it will be necessary to successfully find the next 32 flaws in this flaw size interval to achieve certification at 59 of 61 flaws. The question to be answered is whether it is likely that the next 32 flaws will actually be detected when 2 of 29 have already been missed. Figure 4-2 indicates that the maximum probability of finding the next 32 flaws is 68% and the decision to continue or not should be based upon this eventual success probability.

It is expected that, prior to the certification attempt, the investigators will select a predetermined maximum probability level and terminate the attempt when the maximum probability falls below that level. Thus, if the maximum probability level is set at 50%, one would continue if only 1 or 2 of 29 flawed specimens were not detected but terminate if 3 or more flawed specimens were not detected.

4.2.5 If a decision has been made to continue the certification attempt, 46 (90–95) or 17 (90–17) flawed specimens in each remaining flaw size interval will be collected, mixed randomly with the appropriate number of control specimens, and the inspection procedure will be performed on this set of specimens. The result will be tabulated in a Table I format.

NOTE: The original 29 (or 7) flawed specimens can be used as part of the 46 (or 17) flawed specimens if the previous inspection has not caused identifiable NDE marking of the specimens. Thus, in a test of penetrant reliability, all traces of penetrant must be removed from the original 29 specimens before they are combined with more specimens to create the 46 specimen sample needed for further investigation.

4.2.6 If certification is not accomplished after 46 (17) flawed specimens per flaw size interval have been inspected, a decision, based on successful probabilities defined in Appendix B, must be made to continue or terminate.

4.2.7 Repeat the procedure outlined above at the number of flawed specimens per flaw size interval (mixed with the appropriate control specimens) required to obtain 90–95 or 90–50 reliability - confidence until either the inspection procedure is certified or the attempt at certification is abandoned. Abandonment will be due either to a low maximum probability, in all flaw size intervals, of continuing the certification attempt or to exceeding the number of flawed specimens available.

TABLE II MAXIMUM PROBABILITY TABLES

II-A 90 RELIABILITY - 95 CONFIDENCE LEVEL

Number of Trials	Number of Successes	Minimum Number of Trials Needed for Certification	Maximum Probability of Achieving Certification (Percent)
29	28	46	96.6
29	27	61	68.0
29	26	75	25.8
29	25	89	4.9
29	24	103	0.5
46	44	61	90.0
46	43	75	60.8
46	42	89	27.0
46	41	103	8.2
61	58	75	82.1
61	57	89	52.1
61	56	103	24.4
75	71	89	77.5
75	70	103	46.5
89	84	103	73.2

II-B 90 RELIABILITY - CONFIDENCE LEVEL

Number of Trials	Number of Successes	Minimum Number of Trials Needed for Certification	Maximum Probability of Achieving Certification (Percent)
7	6	17	93.2
7	5	27	33.7
7	4	37	1.6
7	3	47	3.7×10^{-3}
17	15	27	80.9
17	14	37	35.8
17	13	47	7.0
17	12	57	0.5
17	11	67	1.1×10^{-2}
27	24	37	73.0
27	23	47	34.4
27	22	57	9.3
27	21	67	1.4
27	20	77	0.1
27	19	87	3.6×10^{-3}
37	33	47	67.9
37	32	57	32.3
37	31	67	10.3
37	30	77	2.1
37	29	87	0.3
37	28	97	1.9×10^{-2}
47	42	57	63.2
47	41	67	30.9
47	40	77	11.0
47	39	87	2.6
47	38	97	0.4
57	51	67	61.8
57	50	77	29.6
57	49	87	11.0
57	48	97	3.0
67	60	77	59.9
67	59	87	28.4
67	58	97	10.6
77	69	87	58.6
77	68	97	27.8
87	78	97	56.8

5. Requalification Procedures

After completion of the Demonstration Procedure, the specific inspection process documentation, e.g., specifications, standards, work tickets or instructions in accordance with which the demonstration was performed, may not normally be changed without customer approval. Where required by the customer, such changes must be accompanied by a requalification program. Where the customer identifies the changes as minor, the requalification program shall consist of a demonstration in the flaw size range previously demonstrated. If the single flaw size range demonstration is unsuccessful, a new complete Demonstration Program shall be required. Where the customer identifies the changes as major, a new complete Demonstration Program shall be required.

6. Subcontractors, Suppliers and Vendors

Demonstration in accordance with this document of any NDI capability by subcontractors, suppliers and vendors, shall be accomplished by one or more of the following:

1. the subcontractor, supplier or vendor
2. the prime contractor in the subcontractor, vendor or supplier's plant
3. an outside agency

as determined by mutual agreement. The Demonstration Plan shall be approved by the prime contractor in writing prior to the start of testing.

APPENDIX A—OPERATING PARAMETERS

I. Ultrasonic Testing

A. *Operator Controlled Parameters*

1. Instrumentation
   - 1.1 Tuned
   - 1.2 Broad-band
   - 1.3 Special Modifications
   - 1.4 Production Model
   - 1.5 Manufacturer
2. Wave Mode
   - 2.1 Longitudinal
   - 2.2 Shear (angle)
   - 2.3 Surface
   - 2.4 Lamb (angle)
   - 2.5 Delta (angle)
3. Transducer
   Active Element
   - 3.1 Size
   - 3.2 Frequency
   - 3.3 Material
   - 3.4 Focal length if focused
   - 3.5 Dampening media
   - 3.6 Frequency spectrum
   - 3.7 Beam width (2 axes)
   - 3.8 Focal length/water path
4. Coupling Method
   - 4.1 Contact (shoe couplant)
   - 4.2 Immersion (liquid path length)
5. Data Presentation
   - 5.1 A-scan
   - 5.2 B-scan
   - 5.3 C-scan
   - 5.4 Imaging
6. Instrument Calibration
   - 6.1 Electronic (linearity)
   - 6.2 Artificial Defects (standards of known character)
   - 6.3 Natural Occurring Defects (estimated character)
   - 6.4 Control Settings
7. Motion Control/Equipment Capability
   - 7.1 Automatic Indexing
   - 7.2 Manual Indexing
   - 7.3 Digital Readout
8. Operator Qualification[c]
   - 8.1 ASNT Level I
   - 8.2 ASNT Level II
   - 8.3 ASNT Level III
9. Detectability Enhancement
   - 9.1 Proof Loading
   - 9.2 Thermal
   - 9.3 Prior Operator Knowledge of Defect
10. Preparation of Part

B. *Inspection Appliction Parameters*

1. Material Properties
   - 1.1 Material (alloy)
   - 1.2 Material Grade
   - 1.3 Base Material
   - 1.4 Weld
   - 1.5 Material Form
   - 1.6 Surface Condition
   - 1.7 Thermomechanical History - Grain Structure
2. Specimen Geometry
   - 2.1 Dimensions
   - 2.2 Shape
   - 2.3 Surface condition
3. Defect (Visually confirmed)
   - 3.1 Type
   - 3.2 Dimensions
   - 3.3 Shape
   - 3.4 Orientation
   - 3.5 Location
   - 3.6 Procedure for Producing Defects
   - 3.7 Method of Actual Crack Size Determination
4. Purpose
   - 4.1 Manufacturing (Product Qualification)
   - 4.2 Maintenance (In-service Inspection)
   - 4.3 Laboratory Inspection

II. Eddy Current Testing

A. *Operator Controlled Parameters*

1. Instrumentation
   - 1.1 Single-Frequency Sinusoidal
   - 1.2 Multiple-Frequency Sinusoidal
   - 1.3 Pulse-Generator
   - 1.4 Special Modifications
   - 1.5 Production Model
   - 1.6 Manufacturer
2. Eddy Current Probes
   - 2.1 Shape (probe coil or encircling)
   - 2.2 Type (absolute or differential)
   - 2.3 Size
   - 2.4 Number of Turns
   - 2.5 Operating Frequency
3. Signal Processing
   - 3.1 Response Filtering
   - 3.2 Phase Discrimination
   - 3.3 Multifrequency Variable Separation
   - 3.4 Custom Designed (combinations of above)
4. Coupling Method
   - 4.1 Contact
   - 4.2 Noncontact
5. Data Presentation
   - 5.1 Meters
   - 5.2 Cathode-ray Oscilloscopes
   - 5.3 Warning Lights
   - 5.4 Audible Indicators
   - 5.5 Strip Chart Recorders
6. Test Object Handling Equipment
   - 6.1 Hand Scanning
   - 6.2 Automated
   - 6.3 Special Probe Fixtures
7. Detectability Enhancement
   - 7.1 Proof Loading
   - 7.2 Thermal
   - 7.3 Prior Operator Knowledge of Defect
8. Operator Qualification[c]
   (See I.A.8)
9. Calibration Standards
   - 9.1 Electronic
   - 9.2 Artificial Defects
   - 9.3 Natural Occurring Defects
   - 9.4 Control Settings
10. Preparation of Part to be Tested

[c]From ASNT Recommended Practice No. SNT–TC–1A, "Personnel Qualification and Certification in Nondestructive Testing."

B. *Inspection Application Parameters*
   1. Material Properties
      1.1 Material
      1.2 Material Grade
      1.3 Alloy Composition
      1.4 Thermomechanical History-Grain Structure
      1.5 Depth of any Surface Treatments
      1.6 Surface Condition
      1.7 Electrical Conductivity
      1.8 Magnetic Permeability
      1.9 Weld Material
      1.10 Base Material
   2. Specimen Geometry
      (See I.B.2)
   3. Defect
      (See I.B.3)
   4. Purpose
      (See I.B.4)

III. Penetrants

A. *Operator Controlled Parameters*
   1. Classification of Penetrant Material System[d]
      1.1 Group I
      1.2 Group II
      1.3 Group III
      1.4 Group IV
      1.5 Group V
      1.6 Group VI
      1.7 Group VII
      1.8 Manufacturer
   2. Inspection Procedure
      2.1 Surface Preparation
      2.2 Method of Penetrant Application
      2.3 Dwell Time (immersed or draining)
      2.4 Method of Excess Penetrant Removal (water wash, post emulsified)
      2.5 Drying Temperature and Drying Time
      2.6 Developer Type and Application and Time
      2.7 Inspection Light Intensity at Surface of Workpiece
   3. Detectability Enhancement
      3.1 Wing Penetrant
      3.2 Spin Penetrant
      3.3 Hot-Penetrant
      3.4 Proof Loading
      3.5 Prior Operator Knowledge of Defect
   4. Procedure Qualification
      4.1 Artificial Defects
      4.2 Natural Occurring Defects
   5. Operator Qualification[c]
      (See I.A.8)

B. *Inspection Application Parameters*
   1. Material Properties
      1.1 Material (alloy)
      1.2 Surface Condition
      1.3 Base Material
      1.4 Weld
      1.5 Material Form
      1.6 Thermomechanical History
   2. Specimen Geometry
      (See I.B.2)
   3. Defect
      (See I.B.3)
   4. Purpose
      (See I.B.4)

IV. Magnetic Particle

A. *Operator Controlled Parameters*
   1. Instrumentation
      1.1 Direct Current
      1.2 Half-Wave Rectified
      1.3 Pulsating DC
      1.4 Alternating Current
   2. Method of Magnetization
      2.1 Yoke
      2.2 Prod
      2.3 Wrapped Coil
      2.4 Stationary Coil
      2.5 Contact Plates
   3. Direction of Magnetization
      3.1 Longitudinal
      3.2 Circular
      3.3 Specific Orientation of Specimen Relative to Head or Coil
   4. Selection of Current Amplitude
      4.1 Current Amplitude
      4.2 Magnetic Flux Density
   5. Magnetic Particle Materials
      5.1 Size
      5.2 Shape
      5.3 Density or Concentration
      5.4 Dye (Colored Pigment-fluorescent)
      5.5 Liquid Vehicle
   6. Particle Application
      6.1 Continuous, with Current On
      6.2 Residual, with Current Off
   7. Operator Qualification[c]
      (See I.A.8)
   8. Preparation of Part to be Tested
   9. Procedure Qualification
      9.1 Electronic
      9.2 Artificial Defect
      9.3 Natural Occurring Defect
   10. Detectability Enhancement
      10.1 Proof Loading
      10.2 Thermal
      10.3 Prior Operator Knowledge of Defect

B. *Inspection Application Parameters*
   1. Material Properties
      1.1 Material (alloy)
      1.2 Material Grade
      1.3 Base Material
      1.4 Weld
      1.5 Material Form
      1.6 Magnetic Permeability
   2. Geometry
      (See I.B.2)
   3. Defect
      (See I.B.3)
   4. Purpose
      (See I.B.4)
   5. Surface Condition
      5.1 Roughness
      5.2 Porosity
      5.3 Coatings

V. Radiography

A. *Operator Controlled Parameters*
   1. Instrumentation (Radiation Source)
      1.1 X-ray
      1.2 Gamma
      1.3 Neutron
   2. Radiographic Procedures
      2.1 Method of Radiation Generation
      2.2 Radiation Quality (x-ray voltage, effective gamma energy)
      2.3 Intensity (x-ray current - source strength)
      2.4 Source to Film Distance (SFD)
      2.5 Film Classification (Class I, II, III, IV)

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[c]From ASNT Recommended Practice No. SNT-TC-1A, "Personnel Qualification and Certifiction in Nondestructive Testing."

[d]From MIL-I-25135C (AS6) "Military Specification Inspection Materials, Penetrant."

2.6 Processing (chemicals and time, automatic or manual)
2.7 Radiographic Quality Level (penetrameters, density)
2.8 Masking Techniques
3. Exposure Setup and Part Orientation
3.1 Part Orientation
3.2 Number of Radiographs
3.3 Plane of Film
3.4 Single or Multiple Cassette Loading
4. Data Presentation
4.1 Film
4.2 Paper
4.3 Electrostatic Charged Screens
4.4 Imaging (TV-vidicons, Solid-state Amplifiers, Image Amplifiers, Fluorescent Screens)
5. Detectability Enhancement
5.1 Proof Loading
5.2 Contrast Enhancement Techniques: computer graphics, electronic, radio-opaque materials
5.3 Prior Operator Knowledge of Defect
6. Personnel Qualification[c] (See I.A.8)

B. *Inspection Application Parameters*
1. Material Properties
1.1 Material (alloy)
1.2 Material Grade
1.3 Basic Material
1.4 Weld
1.5 Metal Form
1.6 Surface Condition
1.7 Thermomechanical History-Grain Structure
2. Geometry (See I.B.2)
3. Defect (See I.B.3)
4. Purpose (See I.B.4)

APPENDIX B—STATISTICS

B.1 Preliminary Considerations

B.1.1 *Choice of Flaw Parameters*

The first task in a reliability study or certification will be to choose the flaw parameter against which reliability is to be determined. The choice of flaw parameter has to be, at this time, somewhat arbitrary. The almost complete lack of prior reliability studies, added to the rudimentary state of knowledge of the effect of flaws on the strength of practical structures, forces one to specify "plausible" parameters. For example, for surface cracks, the surface length (2c) of the crack; for cracks in bolt holes, either radial length or bore length or some combination of the two lengths.

In all cases, the flaws used in the reliability study should be characterized as well as possible, and these characterizations should be published with results of the reliability study. This will allow the basic data to be reevaluated at a later date using another flaw parameter if later experience indicates that another flaw parameter is more significant.

B.1.2 *Flaw Parameter Size Intervals*

There are two questions here which will have to be answered simultaneously when a reliability study is being planned. One needs to determine (1) the flaw size range that is to be considered and the division of this total range into size intervals, and (2) the total number of flawed specimens to be used in the study.

As an illustration of this relationship, consider the case of 90% reliability with 95% confidence limits. As will be explained below, a minimum of 29 flaw specimens per flaw size interval is needed to establish this reliability-confidence limit mix. If the total flaw size range of interest is to be divided into four intervals, a minimum of 116 flawed specimens is required. Increasing the number of intervals per force increases the minimum number of flawed specimens required.

Conversely, if only a set number of flawed specimens are available, the number of flaw size intervals is automatically limited.

Note that the discussion above concerns the minimum number of flawed specimens. Since generally the use of more than 29 flawed specimens per flaw size interval will be desirable (in the case of 90% reliability; 95% confidence limits) the number of required specimens will be correspondingly greater.

B.1.3 *One-Sided Confidence Limits*

The specific situation that this document addresses itself to is the determination that an inspection procedure is more than 90% reliable either with the 95% or 50% confidence. For this purpose, the use of one-sided confidence limits is appropriate since the data must support the conclusion that there is only a 5% (or 50%) chance that the "true" reliability of the inspection procedure is less than 90%.

The procedure for calculating the lower one-sided confidence limits follows in B.3.

B.2 Number of Data Points Needed to Support Reliability - Confidence Conclusions

The following inspection results are required to establish the appropriate reliability-confidence levels.

90% Reliability - 95% Confidence
29 successes in 29 trials
45 successes in 46 trials
59 successes in 61 trials
72 successes in 75 trials
85 successes in 89 trials
98 successes in 103 trials

90% Reliability - 50% Confidence
7 successes in 7 trials
16 successes in 17 trials
25 successes in 27 trials
34 successes in 37 trials
43 successes in 47 trials
52 successes in 57 trials
61 successes in 67 trials
70 successes in 77 trials
79 successes in 87 trials
88 successes in 97 trials

[c]From ASNT Recommended Practice No. SNT-TC-1A, "Personnel Qualification and Certifiction in Nondestructive Testing."

The above listing has been arbitrarily terminated at approximately 100 specimens. (Table B-1 provides an expansion of this approach for a success probability of 90%.) Since this number of flawed specimens is required in each flaw size interval and there will, in general, be several intervals in any reliability study, 100 specimens seem a maximum practical number. However, the above table can easily be extended using the following method.

TABLE B-1 Sample Sizes and Permitted Failures to Demonstrate a Minimum Success Rate at 90% with Indicated Confidence

No. Failures	Confidence Level 50	60	70	80	90	95	99	99.9
0	7	9	12	16	22	29	51	66
1	17	20	24	29	38	46	72	89
2	27	31	36	42	52	61	90	108
3	37	42	47	54	65	76	106	126
4	47	52	58	66	78	89	122	143
5	57	63	70	78	91	103	137	159
6	67	73	81	90	104	116	152	175
7	77	84	91	101	116	129	167	190
8	87	94	102	113	128	142	181	205
9	97	105	113	124	140	154	195	220
10	107	115	124	135	152	167	209	235
11	117	125	135	146	164	179	222	249
12	127	136	145	157	175	191	236	263
13	137	146	156	169	187	203	249	277
14	147	156	167	180	199	215	262	291
15	157	167	177	191	210	227	275	305
16	167	177	188	202	222	239	288	318
17	177	187	199	213	233	251	301	332
18	187	197	209	224	245	263	314	345
19	197	208	220	234	256	275	327	358
20	207	218	230	245	267	286	340	372

B.3 Determination of Upper and Lower Confidence Limits on a Proportion Given:

N Trials, *X* Successes; Experimental Proportion

$$P = X/N$$

B.3.1 *Problem*

1. The upper limit (P_u) such that there is only a $(1-\alpha)$ probability that the true proportion $P' > P_u$.
2. The lower limit (P_l) such that there is only a $(1-\alpha)$ probability that the true proportion $P' < P_L$.

B.3.2 *Solution*

Lower Limit

1. Calculate Degrees of Freedom

$f_1 = 2(N - X + 1)$
$f_2 = 2X$

Upper Limit

1. Calculate Degrees of Freedom

$f_1 = 2(X + 1)$
$f_2 = 2(N - X)$

2. Specify the α limit desired.
3. Obtain the appropriate percentile of the *F* distribution, $F_\alpha(f_1, f_2)$, from a statistical table (e.g.—"Introduction to Statistical Analysis"—W. J. Dixon; F. J. Massey, Jr.—Table A-7c, Page 472ff; McGraw-Hill Book Company—3rd Edition—1969).
4. Calculate

$$P_l = \frac{X}{X + (N - X + 1)F_\alpha(f_1, f_2)}$$

4. Calculate

$$P_u = \frac{(X+1)F_\alpha(f_1, f_2)}{(N-X) + (X+1)F_\alpha(f_1, f_2)}$$

Example: If we have 27 successes of 29 trials, what is the upper limit P_u such that there is only a 0.05 chance that $P' > P_u (P' = \text{true proportion})$?

1. $N = 29$ $\quad X = 27$
   $f_1 = 56$ $\quad f_2 = 4$
2. $1 - \alpha = 0.05$—therefore $\alpha = 0.95$
3. $F_{0.95}(56, 4) = 5.69$ (from Table)

$$P_u = \frac{(28)\,(5.69)}{2 + 28\,(5.69)} = \frac{159.32}{161.32}$$

$$P_u = 0.988$$

General Reference for Procedure: "Statistical Theory with Engineering Applications"—A. Hald—page 697ff—(John Wiley & Sons, Inc.—1952)

B.4 Maximum Probability Graph Construction

B.4.1 *Problem*

Given *X* successes in *N* trials, find a number that will represent the maximum probability of achieving a specified reliability-confidence level figure (e.g. 90–95) if more than *N* trials are attempted.

B.4.2 *Solution*

1. If we achieved *X* successes in *N* trials we can calculate, by the method outlined above, an upper limit proportion, P_u, such that there is only a 0.05 probability that $P' > P_u$ ($P' =$ true proportion).
2. Using P_u as the maximum proportion that one can reasonably expect on the basis of *X* of *N* successes, the probability of having X' successes in the next N' trials is

$$P(X', N') = \frac{(N')\,!}{(X')\,!\,(N' - X')\,!} P_u^{X'} (1 - P_u)^{N' - X'}$$

which is just a general term of the binomial distribution.

The interest in this case is in having a complete success in the next N' trials, thus $X' = N'$, and the expression reduces to

$$P(N', N') = P_u^{N'}$$

3. This term is then calculated for the P_u determined from past performance and the number of added trials N' needed to achieve the specified reliability-confidence figure.

Example: If 27 of 29 flawed specimens were identified what is the maximum probability of achieving the 90% reliability - 95% confidence level figure?

Since, in this case, we have to identify the next 32 flawed specimens successfully to get the 59 of 61 required for the 90–95 figure, $N' = 32$. The maximum probability of $P_u = 0.988$.

$$P_{max} = (0.988)^{32} = 0.68$$

APPENDIX C—METALLIC SPECIMEN PREPARATION

C.1 General

NDI demonstration reliability specimens should simulate hardware with respect to material form, i.e., sheet, plate, forging, etc., alloy and condition, geometry, surface finish and area of inspection concern. These parameters are unique to specific applications and must be satisfied by specific design qualification programs. The applicability of an NDI technique, process qualification and audit, and personnel qualification and audit, may be demonstrated by use of flat specimens as test hardware. The methods described herein are guides to producing flat specimens. The technique consists of:

a) Introducing a controlled starter notch (usually by EDM) into specimen;
b) Promoting a fatigue crack from the notch by cyclically fatigue loading the specimen with axial and/or bending loads;
c) Removal of the starter notch to retain only the sharp fatigue crack and to produce a desired specimen surface finish.

Several practice specimens must be made and fractured to establish starter notch and crack growth parameters. Parameters for crack shape and size are established to enable duplication of cracks in test specimens.

C.2 Flat Specimen Description

Experience has shown that small, tightly closed cracks are one of the most difficult types of flaws to detect and are one of the flaw types most detrimental to load carrying structure. Small tightly closed fatigue cracks of predictable size and shape may be generated in flat test specimens and are recommended for NDI demonstration.

C.3 Specimen Configuration

Flat test specimens shall be prepared from material stock having the same or similar alloy and heat treatment as the simulated hardware. Specimen layout shall be convenient to the test equipment available and shall be selected such that a finished specimen size of approximately 4 inches by 8 inches can be prepared. A typical layout is shown in Figure C-1.

Surface flaws are introduced in the specimen by first notching the surface and then by subjecting it to cyclic loading to initiate and extend a fatigue crack.

C.4 Flaw Initiation

The surface notch located in the specimen area is introduced by drilling a hole or cutting a slot by either conventional machining, or by electro-discharge machining (EDM). Notches shall be oriented with their long axis perpendicular to the edge of the specimen (and to the material grain direction). The size, depth and shape of the notch will determine the extended crack geometry and shall be controlled in a manner consistent with the final desired crack configuration.

The notch will be removed by machining the specimen surface after fatigue extension, thus, the starter notch depth should be as shallow as possible. The direction and type of machining relative to crack direction shall be recorded.

Figure C-2 shows typical notch shapes and final crack configurations.

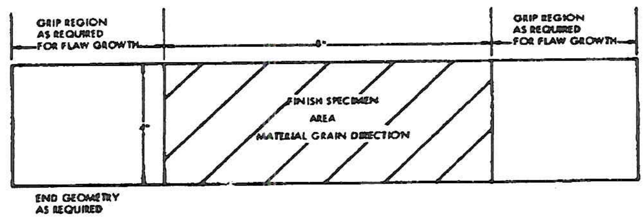

Figure C-1—Flat test specimen layout.

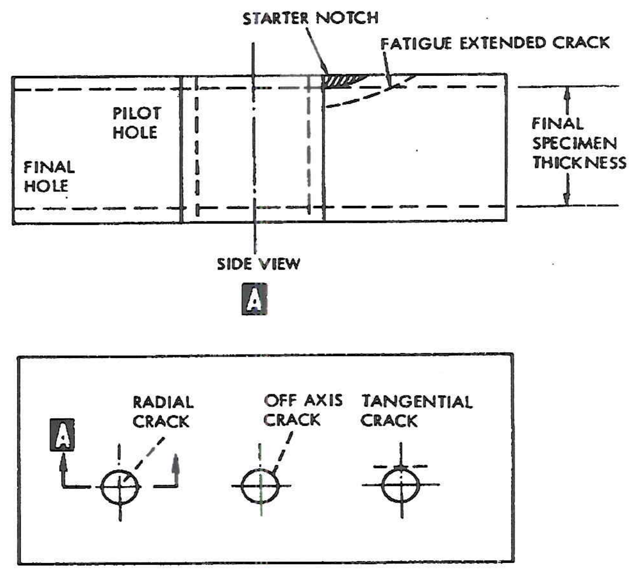

Figure C-2—Cracks around holes.

The ends of the specimen may be increased in width (dogboned) or reinforcement doublers may be adhesively bonded to the ends if the fatigue load requirement causes grip and failure to occur in simple constant width (function-gripped) specimens as depicted in Figure C-1.

C.5 Flaw Growth

Cracks are grown by cyclic loading to produce a fatigue extended flaw from the starter notch. Cyclic loading may be performed by three point bending, by tension loading, or by combination of each to produce the desired crack configuration.

Cyclic loading of a surface notch in three point bending results in initiation of a surface crack at the notch which tends to propagate in the length (i.e., the $2c$) dimension at a faster rate than in the depth dimension, especially as the crack depth approaches the neutral axis of the flat sheet sample.

Cyclic loading in tension may be used to increase crack propagation in the depth direction as compared to surface crack length propagation, i.e., dimension increases the $a/2c$ ratio.

The surface length of a crack may be monitored visually by locally polishing the surface in the area of the crack and by measuring the crack length with the aid of a microscope.

The precise location and measured surface crack length should be documented for reference. Identification must include notation of front and reverse side of the specimen surface. An estimate of crack depth should be recorded.

Residual stresses generated during fatigue crack growth should be partially overcome by final compressive cyclic loading. For cracks grown in bending, the cracked side of the specimen may be inverted in the fatigue machine and a cyclic load which produces a maximum bending stress of 0.8 F_{ty} may be applied ($R=0.08$) for a minimum of 50,000 cycles. A similar compression loading sequence may be applied for flaws grown in the axial tension mode.

C.6 Flaw Modification

Cracks around cut-outs, fastener holes, etc. may be simulated by drilling, machining, etc., to modify the grown flaws. For example, cracks around fastener holes may be simulated by drilling a pilot hole to remove a portion of a crack as shown in Figure C-2. Orientation of the crack with respect to the hole may be varied to simulate a desired configuration. Following final specimen machining, the hole will be drilled or reamed to final size.

C.7 Final Specimen Preparation

The specimen containing the flaw will be machined to final thickness such that a final and controlled surface finish is produced. Material removal on the flaw side shall be controlled to completely remove the starter notch and to retain the predetermined dimensions of the fatigue extended crack.

Material removal from the reverse side of the specimen shall be controlled to obtain desired surface finish and obtain the desired final thickness dimension. Machining may be accomplished by face milling using an end mill, a shell cutter, or a fly cutter to randomize the orientation of machining. A vacuum chuck hold down is useful for holding non-magnetic specimens and should be supplemented by edge clamping to ensure controlled surface removal.

Following surface machining, holes introduced around cracks are enlarged by drilling or reaming to final size.

End or grip areas required for flaw growth may be removed if desired, or may be retained for subsequent proof loading or other operations.

Specimens should be identified, cleaned by* vapor degreasing or solvent wiping and submitted for inspection in accordance with Paragraph 3.5.

*CAUTION! Vapor is harmful if inhaled. Avoid prolonged skin contact.