U.S. Department
of Transportation
**Federal Aviation
Administration**

Advisory Circular

Subject: Damage Tolerance for Material Anomalies in Titanium Life-Limited Turbine Engine Rotors

Date: 4/17/23

Initiated By: AIR-624

AC No: 33.70-3

This advisory circular (AC) describes an acceptable means for demonstrating compliance with the requirements of title 14, Code of Federal Regulations (14 CFR) 33.70, *Engine Life-Limited Parts*.

If you have suggestions for improving this AC, you may use the Advisory Circular Feedback Form at the end of this AC.

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CHAPTER 1. INTRODUCTION

1.1 Purpose.

This advisory circular (AC) describes an acceptable means for demonstrating compliance with the requirements of title 14, Code of Federal Regulations (14 CFR) 33.70, *Engine Life-Limited Parts*. Section 33.70 contains requirements applicable to engine life-limited parts of turbine aircraft engines, including rotating parts made of titanium.

1.2 Applicability.

1.2.1 The guidance in this AC is for engine manufacturers, modifiers, and Federal Aviation Administration (FAA) employees and designees.

1.2.2 The contents of this AC do not have the force and effect of law and are not meant to bind the public in any way, and this AC is intended only to provide information to the public regarding existing requirements under the law or agency policies. This AC is not mandatory and does not constitute a regulation. This AC describes an acceptable means, but not the only means, for showing compliance with § 33.70. When the method of compliance in this AC is used, terms such as "should," "may," and "must" are used only in the sense of ensuring applicability to this particular method of compliance. The FAA will consider other means of showing compliance that an applicant may elect to present. While these guidelines are not mandatory, they are derived from extensive FAA and industry experience in determining compliance with the relevant regulations. If, however, the FAA becomes aware of circumstances that convince the agency that following this AC would not result in compliance with the applicable regulations, the agency will not be bound by the terms of this AC, and may require additional substantiation as a basis for finding compliance.

1.2.3 The material in this AC does not change or create any additional regulatory requirements, nor does it authorize changes in, or permit deviations from, existing regulatory requirements.

1.3 Related Reading Materials.

The following materials are related to the guidance in this AC. Unless otherwise indicated, you should use the current edition if following the method of compliance set forth in this AC.

1.3.1 <u>Title 14, Code of Federal Regulations (CFRs).</u>

- Section 33.4, *Instructions for Continued Airworthiness*.
- Section 33.15, *Materials*.
- Section 33.19, *Durability.*

- Section 33.27, *Turbine, compressor, fan, and turbosupercharger rotor overspeed*.
- Section 33.63, *Vibration.*
- Section 33.70, *Engine life-limited parts.*
- Section 33.75, *Safety analysis.*

1.3.2 FAA Publications.

- AC 33.14-1, *Damage Tolerance for High Energy Turbine Engine Rotors*.
- AC 33.70-1, *Guidance Material for Aircraft Engine Life-Limited Parts Requirements*.
- AC 33.70-2, *Damage Tolerance of Hole Features in High-Energy Turbine Engine Rotors.*
- ANE-2002-33.15-R0, *14 CFR § 33.15, Materials.*
- DOT/FAA/AR-06/3, *Guidelines to Minimize Manufacturing Induced Anomalies in Critical Rotating Parts* (available here DOT/FAA/AR-06/3).
- DOT/FAA/AR-07/63, *Update of Default Probability of Detection Curves for the Ultrasonic Detection of Hard Alpha Inclusions in Titanium Alloy Billets* (available here DOT/FAA/AR-07/63).

1.3.3 Industry Publications.

- AIAA-97-1068, *The Development of Anomaly Distributions for Aircraft Engine Titanium Disk Alloys*. Technical paper, presented by the AIA Rotor Integrity Sub-Committee at the American Institute of Aeronautics and Astronautics (AIAA) Conference.
- ASME 2000-GT-0421, *A Probabilistically-Based Damage Tolerance Analysis Computer Program for Hard Alpha Anomalies in Titanium Rotors*. Proc. 45th ASME International Gas Turbine & Aero-Engine Technical Conference, Munich, Germany.
- ASME GT2006-90843, *The Development of Anomaly Distributions for Machined Holes in Aircraft Engine Rotors*. Technical paper, presented at ASME Turbo Expo in Barcelona, Spain.
- ASME GT2012-68987, *Review of Probabilistic Damage Tolerance Methodology for Hard Alpha Anomalies*. Technical paper, presented at ASME Turbo Expo in Copenhagen, Denmark.
- MCIC-HB-01R, *Damage Tolerant Design Handbook: A Compilation of Fracture and Crack-Growth Data for High-Strength Alloys*.
- SAE AIR1537, *Report on Aircraft Engine Containment*. Technical report, SAE International.
- SAE AIR4003, *Report on Aircraft Engine Containment*. Technical report, SAE International.

- SAE SP-1270, *Uncontained turbine engine rotor events: data period 1984 through 1989*. Technical report, SAE International.

1.3.4 Industry Standards.

- SNT-TC-1A, *Personnel Qualification and Certification in Nondestructive Testing*.
- ASTM E1417, *Standard Practice for Liquid Penetrant Testing.*
- ATA-105, *Guidelines for Training and Qualifying Personnel in Nondestructive Testing Methods*.
- NAS410, *Certification & Qualification of Nondestructive Test Personnel*.
- SAE AMS2628 Class A, *Ultrasonic Immersion Inspection Titanium and Titanium Alloy Billet Premium Grade.*
- SAE AMS2644, *Inspection Material, Penetrant.*
- SAE AMS2647, *Fluorescent Penetrant Inspection, Aircraft and Engine Component Maintenance.*

1.4 Definitions.

See appendix F for a list of definitions that apply to this AC.

1.5 Background.

1.5.1 Section 33.70 contains requirements applicable to the design and life management of propulsion system life-limited parts, including high-energy rotating parts. This AC presents a damage tolerance approach that can be used to address inherent material anomalies in rotating life-limited engine parts made of titanium. This approach can be integrated with the existing life management process (safe-life). Section 33.70 and AC 33.70-1 define the safe-life approach and the basic damage tolerance requirements, while this AC is specific to titanium life-limited rotating parts. This approach does not replace the existing safe-life methodology but supplements it by addressing risks not addressed by the safe-life approach. The use of damage tolerance procedures specified in this AC is not intended to allow operation beyond the component manual limit set using the existing safe-life approach. The existing safe-life approach limits the useful rotor life to the minimum number of flight cycles needed to initiate a crack. Rotor failure modes, for which full containment of high-energy debris can be demonstrated, are excluded from the procedures outlined in this AC.

1.5.2 Material and Manufacturing Anomalies.

Service experience with gas turbine engines has demonstrated that material and manufacturing anomalies do occur. These anomalies can potentially degrade the structural integrity of high-energy rotors. Conventional rotor, life management methodology (safe-life method) is founded on the assumption that abnormal material variations and manufacturing conditions can be eliminated. Therefore, the methodology does not explicitly address the occurrence of such anomalies, although some level of tolerance to anomalies is essentially built-in using design margins, as well as factory and field inspections.

1.5.3 Safe-Life Methodology.

Under nominal (anomaly-free) conditions, the safe-life methodology provides a structured process for the design and life management of high-energy rotors, assuring structural integrity throughout the life of the rotor. Undetectable material processing and manufacturing-induced anomalies represent a departure from the assumed nominal conditions. To measure the extent of such occurrences, the FAA requested that the Society of Automotive Engineers (SAE) convene several ad hoc committees to document the number of uncontained events. The statistics pertaining to uncontained rotor events are reported in SAE committee reports AIR1537, AIR4003, and SP-1270. While no adverse trends were identified during the 1984-1989 reporting period, the committee expressed concern that the projected 5 percent increase in airline passenger traffic each year would lead to an increase in the number of aircraft accidents from uncontained rotor events. Uncontained rotor events have the potential to cause catastrophic aircraft accidents.

1.5.4 Probabilistic Damage Tolerance Approach.

Following the Sioux City event in 1989[1], the gas turbine engine industry collaborated with the FAA to develop a probabilistic damage tolerance approach to address hard alpha melt anomalies in rotating life-limited parts made of titanium. The FAA later published a methodology in AC 33.14-1. With the release of AC 33.14-1, engine manufacturers can ensure future rotor parts will achieve a reduced event rate associated with the occurrence of hard alpha anomalies. This methodology was based on the best information available in 1996.

1.5.5 Titanium Melt Anomalies Knowledge Base.

Substantial progress has been made in expanding the industry knowledge base associated with melt anomalies in titanium. Through the collective efforts of engine manufacturers, melters, and forgers, there has been a significant improvement in the cleanliness of cast and wrought titanium rotor grade materials. In addition, FAA-funded research and development work performed through programs such as the Turbine Rotor Material Design at Southwest Research Institute has led to a deeper understanding of the fundamental material characteristics of hard alpha. This effort has led to the development and widespread availability of risk prediction design tools, enhanced inspection methods for billets and forgings, and an improved understanding and range of inspection capabilities.

[1] NTSB Aircraft Accident Report - United Airlines Flight 232

1.5.6 Anomaly Distribution Curves.

The knowledge gained between 1996 and 2012 has enabled the construction of new default hard alpha size and frequency distributions (anomaly distribution curves). The new curves provided in appendix C apply to billet materials that have been inspected using zoned ultrasonic inspection. The new curves benefit from the following:

1. Improved assumptions regarding the size and frequency of hard alpha anomalies present at the ingot stage.
2. An improved understanding of the capability of the titanium billet zoned ultrasonic inspection reflected in the revised probability of detection (POD) curves.

1.5.7 Default-Zoned Ultrasonic Inspection POD Curves.

The new default-zoned ultrasonic inspection POD curves and the method used to develop the POD curves are contained in FAA Report, DOT/FAA/AR-07/63. This report specifies that the new zoned POD accounts for a "dual reject criteria based on amplitude and signal-to-noise," consistent with AMS2628 Class A. The new anomaly distribution curves do not reflect the improvements in material cleanliness that have occurred since 1996. The hard alpha find rate, per million pounds, remains unchanged and consistent with the 1996 information provided in AC 33.14-1. The intent is to provide margin to address other major anomaly types found in titanium and accommodate fluctuations in the annual hard alpha find rate.

1.5.8 Default Hard Alpha Size and Frequency Curves.

Future updates to the default hard alpha size and frequency curves should be based on the updated ingot size distribution (see GT2012-68987). Future default hard alpha size and frequency curve updates should maintain a margin between the hard alpha find rate used in the development of the curves and the prevailing 5-year moving average. This margin will allow for fluctuations in the annual rate and other major anomaly types found in titanium.

1.5.9 Enhanced Life Management Process.

The Enhanced Life Management Process first introduced in AC 33.14-1 is retained. The probabilistic fracture mechanics assessment methodology and calibration test case described in AC 33.14-1 is also retained and unchanged. It is included in this document for convenience purposes.

1.5.10 Fracture Mechanics-Based Methodology.

The applicant should assess titanium rotor designs using the fracture mechanics-based methodology contained in this AC. Anomaly distribution curves should be selected from appendix C unless an FAA-approved company-specific curve is available. Anomaly distribution curve selection should be consistent with the production inspection process for the design in question. Designs satisfying the design target risk (DTR) values will be considered compliant with the damage tolerance requirements required by § 33.70 for titanium melt anomaly only. AC 33.70-1 and AC 33.70-2 define other damage tolerance requirements that apply when using this method.

1.5.11 Results of Gained Industry Experience.

Industry experience resulting from improvements in material cleanliness, billet and forging processes ultrasonic inspections, and the publication of AC 33.14-1 has been positive. Since 1990, there have not been any incidents of a cracked or fractured titanium rotor component related to hard alpha anomalies.

CHAPTER 2. CONVENTIONAL ("SAFE-LIFE") LIFE MANAGEMENT PROCESS

2.1 Safe-life Philosophy.

2.1.1 The traditional safe-life philosophy has served the turbine engine industry and flying public well. It provides a solid foundation, which can be enhanced to address the threat from anomalies that cannot be eliminated by the best available manufacturing and inspection processes.

2.1.2 AC 33.14-1 originally introduced the "Enhanced Life Management Process" to the conventional life management procedure. This process was designed to expand the safe-life philosophy, not replace it.

2.2 Addition of Damage Tolerance Assessment.

2.2.1 In 2007, the FAA added a new requirement, "Damage Tolerance," with the introduction of section 33.70.

2.2.2 The new element, Damage Tolerance Assessment, is designed to minimize the occurrence of uncontained rotor failures due to material and manufacturing induced anomalies, therefore, improving flight safety (see figure 3-1).

CHAPTER 3. ENHANCED LIFE MANAGEMENT PROCESS

3.1 Damage Tolerance Assessment for Critical Titanium Rotating Parts.

Section 33.70 requires applicants to perform appropriate damage tolerance assessments (see figure 3-1). Damage tolerance assessments are fracture-mechanics based probabilistic risk assessments that predict the relative probability of failure (POF) for each part. The predicted POF is compared to an allowable DTR. Designs that satisfy the allowable DTR will be considered compliant with the titanium melt anomaly damage tolerance requirements as set forth in § 33.70.

3.2 Options to Reduce the POF.

Engine manufacturers have several options available to reduce the POF to meet the allowable DTR. They include, but are not limited to, the following options:

- Component redesign.
- Material changes.
- Material process improvements.
- Manufacturing inspection improvements.
- In-service inspections.
- Life limit reductions.

Chapter 4 presents an overview of the methodology for conducting the fracture-mechanics based probabilistic analyses mentioned above.

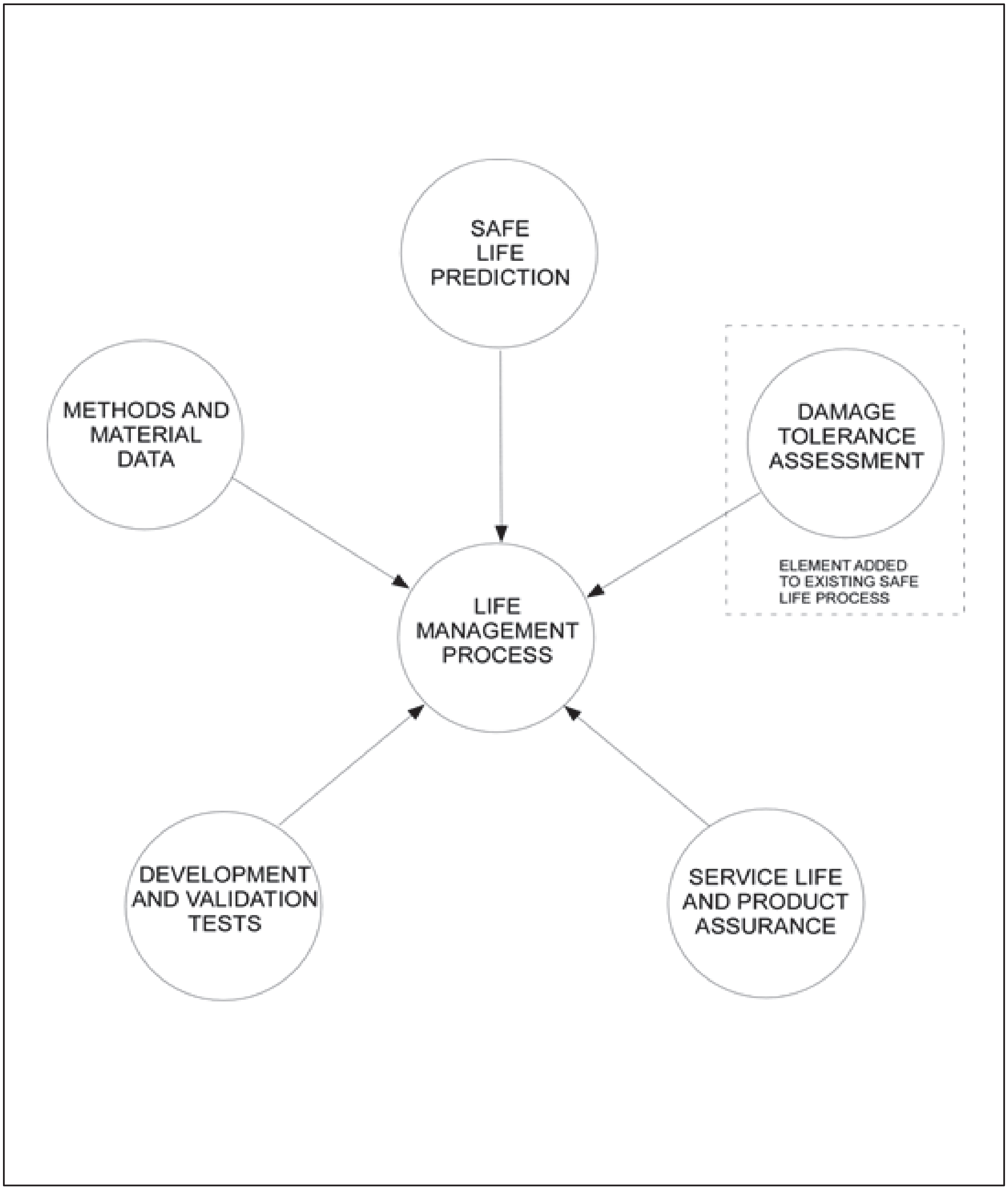

Figure 3-1. Life Management Process

CHAPTER 4. DAMAGE TOLERANCE ASSESSMENTS

4.1 Approach.

4.1.1 Probabilistic Damage Tolerance Risk Assessment (PDTRA).

4.1.2 As described in AC 33.70-1, a PDTRA is an acceptable method to assess a part's ability to tolerate anomalies. The assessment results provide the basis to evaluate the relative damage tolerance capabilities of candidate part designs. The results also allow the engine manufacturer to balance enhanced reliability and customer impact.

4.1.3 These results are compared to the allowable DTR to determine if the design meets the DTR criteria (see paragraph 4.6).

4.1.4 While the DTR was selected to limit the probability of hard alpha anomaly failures in titanium rotor parts, its selection was restricted to risk levels that were technologically achievable. The use of probabilistic risk assessment tools and compliance with the DTR is acceptable for undesirable part conditions that cannot be eliminated by the best manufacturing and inspection processes available. Satisfactory compliance with the DTR should not be used to reject or eliminate manufacturing and inspection techniques capable of limiting or reducing the number of anomalies.

4.2 Further Risk Reduction Actions.

4.2.1 The need to reduce a part's risk will be based on whether or not the design under consideration satisfies the desired DTR at both the individual component level and the engine level. If the targets are met, then the design is considered compliant with the damage tolerance requirements, as defined in § 33.70. The manufacturer has several options available to achieve the required DTRs and may conduct quantitative parametric studies to determine the influence of key variables, such as inspection methods and frequency, hardware geometry and processing, material selection, and life limit reduction.

4.2.2 The manufacturer may then make changes to the design or the part's field management procedures, or both, to achieve the allowable DTR (see figure 4-1). This approach gives the engine manufacturer the flexibility to develop an optimal engine design solution consistent with customer requirements, company policies and procedures, and available resources. An example assessment using this methodology is described in paragraph 4.3 and appendix A.

4.2.3 Probabilistic damage tolerance risk assessments are usually performed during the detail design phase of the engine component. Paragraph 4.3 defines an assessment methodology applicable to material melt-related induced anomalies. It contains a standardized list of inputs for conducting these assessments and a process for refining the design to meet the allowable DTR.

4.3 **Methodology.**

4.3.1 Manufacturers may conduct probabilistic risk assessments using a variety of methods such as the Monte Carlo simulation or numerical integration techniques.

4.3.2 Figure 4-1 conceptually depicts a melt-related anomaly probabilistic assessment process. Standardized inputs and default data are contained in the appendices of this AC. Applicants should use them to perform the PDTRA. The use of standardized inputs and default information is necessary to achieve consistent industry-wide assessment results, which can then be compared to the allowable DTRs.

4.3.3 A list of standardized inputs is provided below. Default input data is described in paragraphs 4.3.5 and 4.3.6. The use of default data in probabilistic assessments requires no further demonstration of applicability or accuracy. However, if this data is used, the manufacturer should follow the guidelines accompanying this data to ensure applicability. The use of input data, other than the default information, may require additional validation to verify applicability, adequacy, and accuracy.

4.3.4 Probabilistic risk assessments should incorporate the following inputs as part of a basic approach:

- Anomaly distribution.
- Inspection POD.
- Maintenance exposure rate.
- Component stress and volume.
- Material properties.
- Crack growth lives.
- Design service life.

4.3.5 Input.

4.3.5.1 **Anomaly Distribution.**
For melt-related (hard alpha) assessments, use one of the following:

- The default anomaly distributions outlined in paragraph 4.4; or
- FAA-approved company-specific data.

Manufacturers should develop company-specific data with the same process used to develop the default anomaly distributions. This process is described in GT2012 68987 and AIAA-97-1068. Manufacturers should also treat anomalies as sharp propagating cracks from the first stress cycle.

Inspection of titanium billets should comply with FAA Policy ANE 2002 33.15-R0. This policy states in part–

- "Require the billet UT inspection system output to be electronic c-scan data, which can be acquired, retained, stored, and retrieved electronically."
- "Perform the UT inspection in accordance with SAE Document AMS2628 [Class A], sections 3 and 4," using the following sensitivity standards or an equivalent FAA accepted procedure.

Table 4-1. Billet Inspection Standards

Billet Inspection Standards	Billet Dia. – Inches	FBH Size – Inches
Standard 1	>5 but <10	2/64
Standard 2	>10	3/64

To comply with the FAA inspection policy, manufacturers should use the default anomaly distributions listed in appendix C to conduct the PDTRA. Manufacturers using forging input material < 5 inches in diameter should provide data to substantiate the use of the default anomaly distribution selected.

4.3.5.2 **Probability of Detection.**

Manufacturers should ensure the subsurface assessments consider the effects of subsurface inspection techniques, such as ultrasonic inspection or X-ray inspection only. Additionally, they should verify the surface assessments also consider the effects of fluorescent penetrant inspection (FPI) and eddy current inspection (ECI), as applicable. Paragraph 4.5 of this section contains default PODs and instructions on the use of company-specific values.

4.3.5.3 **Maintenance Exposure Interval.**

When assessing inspection benefits, the exposure interval curves for the engine, module, or component in question, may be modeled in the analysis as appropriate.

4.3.5.4 **Stress.**

A part's operating stress is a variable that has a major influence on crack propagation life. Manufacturers should base this input on the most limiting operational principal stresses, as follows:

- Subsurface assessments should incorporate the appropriate subsurface and near-surface stress distributions.
- Surface assessments should incorporate the appropriate surface stress distributions, including the effects of stress concentrations.

Manufacturers should also:

- Use certification or actual usage flight cycles, if known, to establish stress variation during the flight profile.
- Consider the influence of major and minor flight cycles since the cyclic damage accumulation can differ dramatically between crack propagation and crack initiation.

Note: The method described in this AC has been calibrated against industry experience without considering the surface enhancement effects, such as shot peening on predicted crack propagation lives. Therefore, it is inappropriate to include the beneficial effects of such enhancements.

4.3.5.5 **Volume.**

This variable (volume) is required to predict the probability of having a defect in a part. The part is divided into multiple smaller sub-volumes; each sub-volume represents the volume of material at a specific stress level. Sub-volumes are required to assess the risk associated with subsurface anomalies.

Manufacturers should sub-divide the part's surface into thin surface volumes ("onion skin"). Where a non-axisymmetric feature, such as a series of holes in a disk web, has a localized stress concentration, manufacturers should decide whether it makes a significant contribution to the probability of failure. This decision should be based on a combination of:

- The mass of material at high stress; and
- The size of the anomaly that would cause the part's failure, prior to reaching its safe-life.

While the method described in this AC assumes axisymmetric features, a non-axisymmetric feature can also be included. To do this, reduce the cross-sectional area to ensure that the total volume, when integrated around the whole circumference, is equal to the volume at high stress.

4.3.5.6 **Material Data.**

Manufacturers should use the average, cyclic crack growth rate properties of the base material generated in an air environment as the default condition to calculate anomaly propagation life.

4.3.5.7 **Propagation Life.**

Propagation life is defined as the number of cycles for a given size anomaly to grow to a critical size. It is based on all of the following factors:

- Knowledge of part stress,
- Temperature,
- Geometry,

- Stress gradients,
- Anomaly orientation, and
- Material properties.

Manufacturers should use linear elastic fracture-mechanics for calculating propagation life. Default conditions should assume anomalies to be in the worst orientation to the stress field.

4.3.6 Calibration.

Engine manufacturers should conduct the industry test case detailed in appendix A of this AC to calibrate their analytical prediction tools. The test case consists of a probabilistic analysis of an ideal titanium ring disk, using specified inputs and scenarios.

Test case results considered acceptable are in the ranges below:

- 1.27E-09 to 1.93E-09 (for the “no inspection” case).
- 8.36E-10 to 1.53E-09 (for the “with in-service inspection” case).

Test case results outside these ranges may indicate problems with either the probabilistic assessment technique or the assumptions.

4.3.7 Output.

4.3.7.1 **Component Level Assessments.**

Manufacturers should calculate the probabilistic assessments and prediction of event potential over the entire anticipated service life of a part. This result should be expressed as the number of predicted events for each cycle and designated as the predicted “component event rate.” For multiple stage components, such as spools, manufacturers should conduct the assessment for each stage. The predicted component event rate should then be compared to the component-level allowable DTR to assess design acceptability.

4.3.7.2 **Engine Level Assessments.**

When all critical titanium rotors in a given engine configuration have satisfied the allowable component level DTR, the cumulative event rate for these components should then be calculated and compared to the allowable engine-level DTR for acceptability.

4.3.7.3 **Allowable Design Target Risks.**

Paragraph 4.6 specifies the allowable DTRs for titanium.

4.3.8 General Comments.

Standardized inputs and default data for melt related PDTRA assessments are available for titanium material, melt-related (hard alpha) anomalies. Industry and the FAA are collaborating to develop the following:

- Material anomaly information for other rotor grade materials (for example, nickel).
- Inputs and default data for manufacturing and maintenance-induced anomalies.

4.3.9 The FAA strongly encourages engine manufacturers to incorporate fracture-resistant design concepts, when possible. The FAA may give credit for fracture or burst-resistant engine design features that clearly demonstrate a reduction in rotor failure due to the presence of melt induced anomalies from unanticipated material. Manufacturers should demonstrate the reduction in rotor failure through analysis and test.

4.3.10 The design of an aircraft turbine-engine rotor is a lengthy process involving numerous iterations, each of which can substantially alter the initial calculated predicted risk. Therefore, it is important that the DTR values be satisfied at the time of engine certification.

4.3.11 Risk assessments may also be conducted several years after the engine enters service because of changes. These changes could come from design changes associated with in-service problems or changes in the analytical results from evolving predictive capability.

Note: The allowable DTRs should be satisfied at both the individual component and overall engine levels throughout the life of the part.

4.4 Anomaly Distributions.

4.4.1 <u>Ingot Distributions.</u>

Key inputs associated with PDTRA assessments are the size and rate of occurrence of the anomalies. This type of information is statistical and can be presented in a form that plots the number of inclusions that exceed a particular size in a specified amount of material. Anomaly distributions may be referred to as “exceedance curves.” At a high-level, a similar approach was used to develop the distributions in AC 33.14-1 and this AC. However, some of the detailed assumptions that went into defining the underlying ingot distribution were different for this AC based on updated information available since AC 33.14-1 was issued. Publications AIAA-97-1068 and ASME GT2012-68987 (see paragraph 1.3.3 of this AC for full citation) provide detailed information covering the development of the ingot distributions and downstream exceedance curves, including how the POD data were used and verification against fleet experience. Therefore, although both sets of curves are meaningful for assessing risk from hard alpha in titanium, manufacturers should not use them in direct comparison to draw conclusions about the billet or forging inspection techniques, technology, or capability.

4.4.2 <u>Titanium Melt-Related (Hard Alpha) Distributions.</u>

The hard alpha anomaly distributions contained in appendix C of this AC apply to fully machined components. The exceedance curves assume that:

- The material is triple vacuum arc remelt (3VAR), or cold hearth melt (CHM), plus vacuum arc remelt (VAR) melted material.

- The material has been inspected at the billet and forging stages according to the standards specified on the curve and are consistent with the POD curves as described in paragraph 1.5.8.

For example, figure C-1 represents the anomaly distribution for a component produced from >10-inch diameter billet and is:

- Inspected at the billet stage using a zoned ultrasonic inspection performed in accordance with AMS2628 Class A.
- Calibrated to a #3 flat bottom hole (FBH).
- Calibrated at the sonic shape using a conventional (non-zoned) ultrasonic probe calibrated to at least a #3 FBH.

Manufacturers may use the anomaly distributions contained in appendix C to determine compliance with the allowable DTR options listed in paragraph 3.2. The background associated with the development of these distributions is contained in GT2012 68987 and AIAA-97-1068. The distributions were developed by modeling a complex series of interrelated steps that simulated the entire component manufacturing and inspection process, from billet conversion to final part machining.

Individual engine manufacturers who desire to use an alternate anomaly distribution or an improved inspection should use the methodology contained in GT2012 68987 and AIAA-97-1068 to create the alternate distributions. Manufactures must substantiate alternate distributions with the appropriate background data. An alternate distribution should:

1. Include three dimensional inclusion data.
2. Include inspection POD data.
3. Account for potential undetected, uncracked, and unvoided inclusions.
4. Be based upon substantial field experience.

4.5 Default Input - POD by Nondestructive Evaluation.

4.5.1 Detection of Local Material Anomalies.

The capability of individual nondestructive evaluation (NDE) processes, such as eddy current, penetrant, or ultrasonic inspection, to detect local material anomalies (discontinuities or potential anomalies) is a function of numerous parameters, including the size, shape, orientation, location, and chemical or metallurgical character of the anomaly. In addition, manufacturers should consider the following parameters when assessing the capabilities of an NDE process.

1. The material being inspected, such as its composition, grain size, conductivity, surface texture, etc.

2. The inspection materials or instrumentation, such as specific penetrant and developer, inspection frequency, instrument bandwidth and linearity, etc.

3. The inspection parameters, such as scan index.

4. The inspector, such as visual acuity, attention span, training, etc.

4.5.2 Default POD Data.

The "default" POD data supplied in appendix E are characteristic of inspection capability that has been measured under typical, well-controlled conditions. The FAA is providing these default POD values to assist with the selection of nondestructive inspection techniques that are best suited to support the completion of damage tolerance inspections. Although properly applied inspections should result in capability similar to these default values, they are strictly applicable only under the conditions in which they were acquired (see appendix E). Default POD curves are listed below:

1. For a description of default POD curves, see appendix E.

2. For an example of a calibration test case using this data, see appendix A.

3. For NDE applicability of these POD curves, see appendix E.

4.6 Design Target Risk.

4.6.1 Allowable DTR.

The allowable DTR is a benchmark risk level selected to improve the overall safety of rotating titanium components that have been designed to the standards specified in this AC. The selected goal is expected to achieve a significant and distinct improvement over the 1990s rotor designs and represents a potential event rate reduction between 3x to 10x. The potential improvement for each OEM part will depend on each engine manufacture's component design characteristics.

4.6.2 Allowable "Component Level DTRs" and "Engine Level DTRs."

Allowable "component level DTRs" and an "engine level DTR" for titanium hard alpha anomalies were established to provide an event rate reduction relative to the baseline period presented in SAE report, SP-1270. The "component level DTR" corresponds to the maximum allowable predicted component event rate. The "engine level DTR" corresponds to the maximum allowable (cumulative) component event rate for all critical titanium rotating parts in a given engine. The allowable DTRs were developed based on assessments of representative component configurations using the methodology and inputs described in chapter 5 of this AC.

Note: The allowable DTRs apply only to the anomaly distributions contained within appendix C of this AC. This is primarily due to the selection method of allowable DTRs. Engine manufacturers desiring to use alternate company-specific anomaly distributions will be required to develop alternate allowable component and engine level

DTRs. Alternate DTRs can be shown to provide an event rate reduction consistent with paragraph 4.6.1 using the methodology in GT2012 68987 and AIAA-97-1068.

4.6.3 Rotor Titanium Life-Limited Parts.

Rotor titanium life-limited parts must satisfy the component level DTR and the engine level DTR to be considered acceptable.

4.6.3.1 **Application.**

Default DTR values have been established for melt related (hard alpha) anomalies. Calculated event rates should be assessed against appropriate allowable DTR values. For multiple stage components, such as spools, each individual stage must satisfy the component level DTR value.

4.6.3.2 **Allowable DTR Values for Titanium Melt Related (Hard Alpha) Anomalies.**

The allowable DTR values for titanium melt related (hard alpha) anomalies are as follows:

- Component level DTR: 1 x 10-9 events/flight cycle.
- Engine level DTR: 5 x 10-9 events/flight cycle.

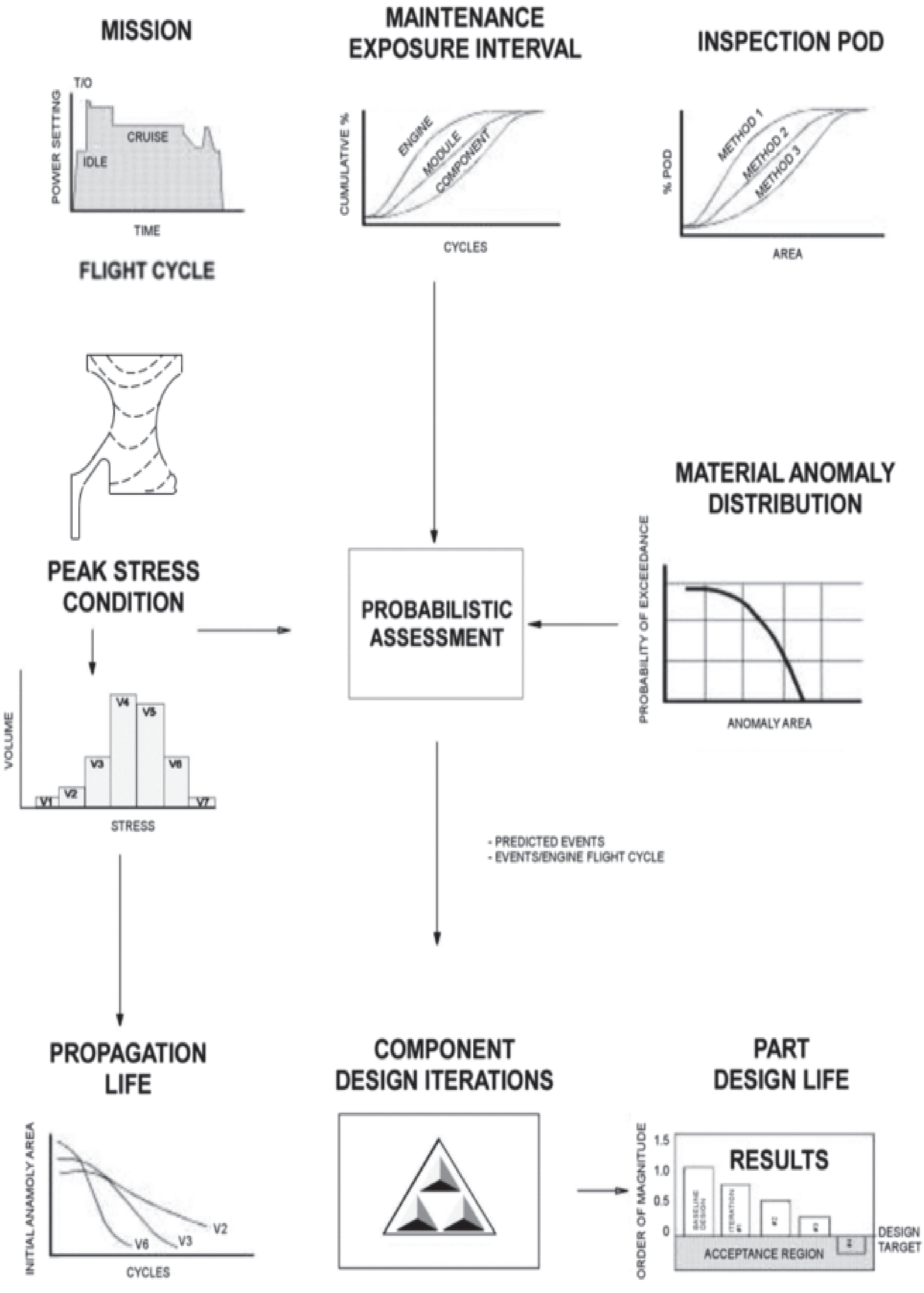

Figure 4-1. Typical Elements of a Titanium Melt-Related Anomaly Risk Assessment

CHAPTER 5. “SOFT TIME INSPECTION” ROTOR LIFE MANAGEMENT

5.1 Approach.

5.1.1 Overview of the Life Management Process.

The life management process encompasses a wide spectrum of design, manufacture, and product support issues. This section addresses only one facet of that overall process: the assurance of structural integrity using inspection techniques and intervals derived from a damage tolerance (fracture-mechanic based) assessment. The inspection philosophy is solely intended to protect against anomalous conditions. It is not intended to allow operation beyond the safe-life limit specified in the airworthiness limitations section (ALS) of the instructions for continued airworthiness (ICA).

5.1.2 When Risk Levels are Greater than the Desired Target.

In instances where probabilistic assessment indicates risk levels are greater than the desired target, manufacturers can use many strategies to reduce the predicted risk to the allowable level. This discussion only addresses the in-service inspection option.

5.1.3 Industry Data on Uncontained Fracture Experience.

Industry data on uncontained fracture experience was used to guide the development of the inspection philosophy as summarized in SAE reports AIR1537, AIR4003, and SP-1270.

These reports indicate that the maintenance-induced, uncontained failure rates were comparable to the failure rates for anomalous conditions (material and manufacture). This data suggests that additional inspection requirements would reduce the uncontained failure rates if properly integrated into the normal maintenance scheduled for the engine.

5.1.4 General Inspection Philosophy.

The inspection philosophy presented evolved from the desire to have inspections easily integrated into the operation of the engine, yet achieve a measurable reduction in uncontained failure rates.

Additionally, it advocates for the use of opportunity inspections rather than forced inspections at “not to exceed” intervals. Opportunity inspections occur due to the “on condition” maintenance practices currently used by operators. Although opportunity inspections occur at random intervals, they can be treated statistically and used effectively to lower the calculated risk of an uncontained event.

5.1.5 Opportunity Inspections.

Opportunity inspection refers to instances when the hardware in question is available such that technicians can perform the specified inspection. This condition is generally viewed as being reduced to the piece part. However, technicians can perform opportunity inspections on assembled modules. For example, a disk bore ECI may be specified on an assembled module when the module is available. This inspection is an opportunity inspection based on module availability rather than piece part availability.

5.1.6 Forced Inspection Opportunities (by Disassembly).

The designs should use opportunity inspections to meet the DTR levels whenever possible. In some instances, the probabilistic analysis may indicate unacceptable risk levels when using only opportunity inspections; therefore, additional action may be required to meet the DTR. One of the many options to mitigate this risk is to force inspection opportunities by specifying disassembly of modules or engines when a cyclic life interval has been exceeded. There are many options on how to implement forced disassembly. The options range between the following:

- Mandatory engine removal and subsequent teardown at "not to exceed" cyclic limits ("hard-time" limits).
- Mandatory module teardown when the naturally occurring module availability exceeds the specified cyclic life inspection interval of one of the parts contained within that module ("soft-time" limits).

This AC only recommends the soft-time inspection option when forced disassembly of a module is needed to meet the DTR levels.

5.1.7 "On-Condition" Maintenance Practice Philosophy.

The soft-time inspection philosophy retains the "on-condition" maintenance practice and minimizes the impact of additional module disassembly. The inspection philosophy applies only after the engine has been removed from the aircraft for a reason other than the inspection itself, and the engine is sufficiently disassembled to afford access to the module containing the component in question. A module containing a part with cycles since last inspection (CSLI) in excess of the soft-time interval should be sufficiently disassembled to allow inspection according to the procedure specified by the engine manufacturer. The engine manufacturer should evaluate the risk associated with parts that become available for inspection before the soft-time interval to determine if the CSLI can be reset.

5.1.8 Consideration of Maintenance Impact of Soft-Time Intervals.

The maintenance impact of the soft-time intervals should be considered during the design phase. To develop designs that achieve the design target, but also result in acceptable soft-time intervals and procedures (should such action be required), manufacturers should use the following inputs:

- Probabilistic analysis.
- Anticipated engine removal rate.
- Module availability.
- Piece part availability.

5.1.9 Interval Limits as Invoked by Soft-Time Inspection.

When invoked, the soft-time inspection approach establishes interval limits beyond which rotor components must be inspected when the rotors are available in modular form. The soft-time inspection interval is not intended to affect or modify current forced inspection programs, which address the safety of flight concerns that arise in the course of engine operation and maturation. Manufacturers should continue to address safety of flight concerns through aggressive inspection programs mandated through airworthiness directives.

5.1.10 Communication and Implementation of Inspection Assumptions.

The inspection assumptions made in the probabilistic risk assessment must be accurately implemented and communicated to the field using the AL section of the ICA. The assumptions must also be validated by engine removal rate reviews, as well as module and piece part availability data.

For example:

- The AL section must call out an immersion ultrasonic inspection if that was an assumption used to set the original soft-time interval.
- The amount of inspected material should correspond to the analysis assumptions. •
- If field experience suggests that the opportunity inspection intervals are in excess of the assumed rates in the probabilistic risk assessment, then appropriate corrective action is required (for example, modifying the inspection plan).

Manufacturers will:

- Specify the soft-time inspection interval and reference the corresponding inspection procedures in the AL section of the ICA. This information is to be provided for all rotor parts with specified retirement life-limits that require inspection plans beyond opportunity inspections to meet DTR levels.
- Include required inspection information in the AL section of the ICA with the other rotor inspection requirements.
- Provide necessary information to focus the prescribed inspections to the highest relative risk areas.

5.2 Inspection Scenarios.

The scenarios in the following subparagraphs clarify the action to take at a maintenance inspection opportunity. Note that the inspection plans may vary for each part, depending on the probabilistic assessment outcomes.

5.2.1 Maintenance Opportunity - Hardware Available for Opportunity Inspection.

For hardware available in the condition to perform the specified opportunity inspection, you must inspect using the procedures specified in the AL section of the ICA. This condition would be a mandatory inspection.

5.2.2 Maintenance Opportunity - Module Below Soft-Time Interval.

For hardware accessible in the assembled or partially disassembled module, you may nondestructively inspect using the procedures specified in the AL section of the ICA. You may reset the CSLI to zero provided the engine manufacturer has assessed the risk impact associated with this action. This condition would be a discretionary inspection.

5.2.3 Maintenance Opportunity - Module Above Soft-Time Interval.

For hardware listed in the AL section of the ICA, you must make it available for nondestructive inspection using the specified procedures. You must perform this inspection whenever the module is available, and the CSLI for any contained hardware exceeds the inspection cycle limit. This condition would be a mandatory inspection.

APPENDIX A. CALIBRATION TEST CASE

A.1 Overview of Self-contained Package.

This appendix provides a self-contained package for the calibration of a probabilistic risk assessment methodology. The package includes all required input data for the test case, analysis guidelines, and a test case analysis section. The test case analysis section permits manufacturers to estimate the level of acceptability of their risk calculations and gain insights on intermediate results.

A.2 Test Case Input Data.

A.2.1 Anomaly Distribution Curve.

The FAA is providing the anomaly distributions in figure A-11 for this test case. Billet and forging manufacturing inspections are fully accounted for in this curve; no additional modifications are necessary.

1. It is assumed that anomalies are spherically shaped and uniformly distributed throughout the part.
2. The anomaly distribution should be linearly extrapolated when anomaly sizes are required outside the range of data provided.

A.2.2 Probability of Detection.

The POD curve used to determine the effect of an in-service inspection is contained in appendix E of this AC. The default curve to use is the mean POD for ultrasonic inspection of field components with reject indications equal to or greater than those from a 3/64 inch (1.19 mm) diameter FBH. For the test case, it is assumed that this curve applies to the whole volume, including the near-surface volume of the component.

A.2.3 Maintenance Exposure Interval.

Assume that 100 percent of the fleet is ultrasonically inspected at 10,000 cycles, which represents 50 percent of the certified part life (20,000 cycles).

A.2.4 Incubation.

No anomaly incubation life should be assumed.

A.2.5 Stress.

The hoop stress is the limiting operational principal stress.

A.2.6 Material Data.

Two sets of material data are provided:

1. Physical properties. Data required:

   Density: 4,450 kg/m^3 or 0.161 lb/in^3

   Young modulus: 120,000 MPa or 17.4E3 ksi

Poisson's ratio: 0.361

2. Crack Growth. Assume the following data represents both air and vacuum crack propagation. Crack propagation rate:

da/dN = 9.25 E-13 $(\Delta K)^{3.87}$ (da/dN in m/cycle and ΔK in MPa√m)

— or —

da/dN = 5.248 E-11 $(\Delta K)^{3.87}$ (da/dN in in/cycle and ΔK in ksi√in-)

K threshold = 0.0 MPa√m or 0 ksi√in

Fracture toughness = 64.5 MPa√m or 58.7 ksi√in

Yield = 834 MPa or 121.0 ksi

UTS = 910 MPa or 132.0 ksi

Note 1: The above data applies at the test case component temperature.

Note 2: Crack propagation data are for a stress ratio of zero; therefore, no stress ratio correction is required.

Note 3: The FAA obtained this data from MCIC-HB-01R, *Damage Tolerant Design Handbook - A Compilation of Fracture and Crack-Growth Data for High-Strength Alloys*, vol. 1, dated December 1983, (page 411.257, figure 4.113.104). It represents generic Ti 6-4 Paris fit data. The FAA is providing this data for example purposes only. It does not constitute a recommendation for analyzing actual components.

A.3 Test Case Analysis Guidelines.

The FAA is providing the analytical guidelines for the probabilistic assessments with the intent to minimize the variations of the applicant’s results due to analytical assumptions.

The practice presented is based on a typical, embedded anomaly probabilistic fracture-mechanics approach. The component is subdivided into zones, the relative risk or probability of failure (POF) is calculated for each zone, and results for each zone are summed statistically to arrive at the total component POF or relative risk.

This analytical approach can be divided into the following five basic steps:

1. Stress analysis.
2. Zone definition and volume calculation.
3. Crack growth model definition.
4. Crack growth calculation.
5. Zone and total part POF calculation.

Note: Paragraph A.4 provides a systematic example for the calibration test case.

A.3.1 General Analytical Guidelines.

A.3.1.1 **Stress Analysis.**

The applicant determines the level of mesh refinement of the part model. However, applicants should take steps to ensure that the final answer does not change by a significant amount (5 percent on relative risk or POF) if a finer mesh is chosen.

A.3.1.2 **Zone Definition.**

Zones are defined as regions of the component (typically made up of a number of finite elements) where life is approximately constant for a given initial crack size. Grouping elements into zones based on stress intervals of 5 ksi (34.5 MPa) is a suggested practice for initial zone definition. Figure A-1 provides a general description of the typical types of zones.

A.3.1.3 **Crack Growth Calculation.**

Applicants should base the crack growth-life assumed for each zone on the minimum life location in the zone. This conservative assumption may require that regions of the component that make a significant contribution to the total part POF be broken down into multiple zones. Carry out this subdivision process until you reach convergence of the risk calculation.

Note: The method described in this AC has been calibrated against industry experience without considering the surface enhancement effects, such as shot peening, on predicted crack propagation lives. Therefore, it is inappropriate to include the beneficial effects of such enhancements.

A.3.1.4 **Probability of Failure (POF) and/or Risk Calculation.**

The POF of the part is calculated by statistically combining the POF of each zone (surface and subsurface). The POF of each zone can be calculated in either of the following two ways:

1. An integrated probabilistic method.
2. The “Monte Carlo” method. The number of simulations required is related to the computed risk. The general rule is that the number of simulations should be at least two orders of magnitude higher than the computed risk. For example, if risk is one failure in 104 parts, the number of samples required is 106. This ensures that about 100 “failed” parts are involved in the assessment.

A.3.2 Specific Guidelines for Fracture-Mechanics Modeling, Zone Definition, and Volume Calculations.

A.3.2.1 **Subsurface Zones.**

Applicants should:

1. Not model surface enhancements for the test case. The method described in this AC has been calibrated against industry experience without considering the surface enhancement effects, such as shot peening, on predicted crack propagation lives. Therefore, it is inappropriate to include the beneficial effects of such enhancements.
2. Use the maximum principal stress in each zone in the crack growth calculations.
3. Consider the impact of stress gradients. To reach a converged solution, high stress, near-surface regions of the part may require additional refinement beyond the 5 ksi bands suggested in the general guidelines (for example, disk bores and bore sides). Subdividing the regions into sub-surface layers will likely capture the rapid change in life from surface to subsurface and reduce conservatism in the prediction. Engineering judgment and experimentation will be required to determine the optimum near-surface zone geometry (for example, width and thickness).
4. Consider a surface crack growth correction factor in the stress intensity (K) solution for cracks transitioning to surface cracks.
5. Position the crack at the life-limiting location in each zone.
6. Assume a circular crack geometry ($a = c$).
7. Consider the defect area equal to the circular crack area.
8. Assume the zone volume to be equal to the volume of the finite elements (or fractions of elements) used to construct the zone.
9. Take crack depth (a) as the diameter of the subsurface crack (2a) when transitioning to a surface crack, just as it touches the surface (see figure A-2).
10. Use average air crack growth data.

A.3.2.2 **Surface Zones.**

Applicants should:

1. Not model surface enhancement for the test case. The method described in this AC has been calibrated against industry experience without considering the surface enhancement effects, such as shot peening, on predicted crack propagation lives. Therefore, it is inappropriate to include the beneficial effects of such enhancements.
2. Use the maximum principal stress in each zone in the crack growth calculations.

3. Consider the impact of stress gradients.
4. Consider a surface crack growth correction factor in the stress intensity (K) solution.
5. Position the crack at the life-limiting location in each zone.
6. Assume a 2:1 crack aspect ratio with surface length (2c) equal to twice the depth (a).
7. Assume the defect area equal to 1/2 the area of a circle with a radius of crack depth (a).
8. Base the volume on the zone surface face length and on an onion skin thickness of 0.020 in (0.5 mm).
9. Use average air crack growth data.

A.3.2.3 **Surface Corner Zones.**

Applicants should:

1. Not model surface enhancements for the test case. The method described in this AC has been calibrated against industry experience without considering the surface enhancement effects, such as shot peening, on predicted crack propagation lives. Therefore, it is inappropriate to include the beneficial effects of such enhancements.
2. Use the maximum principal stress in each zone in the crack growth calculations.
3. Consider the impact of stress gradients.
4. Consider a surface crack growth correction factor in the stress intensity (K) solution.
5. Position the crack at the life-limiting location in each zone.
6. Assume a 1:1 crack aspect ratio with surface length (c) equal to depth (a).
7. Assume the defect area equal to 1/4 the area of a circle with the radius of crack depth (a).
8. Base the volume on the zone surface face lengths and on an onion skin thickness of 0.020 in (0.5 mm).
9. Use average air crack growth data.

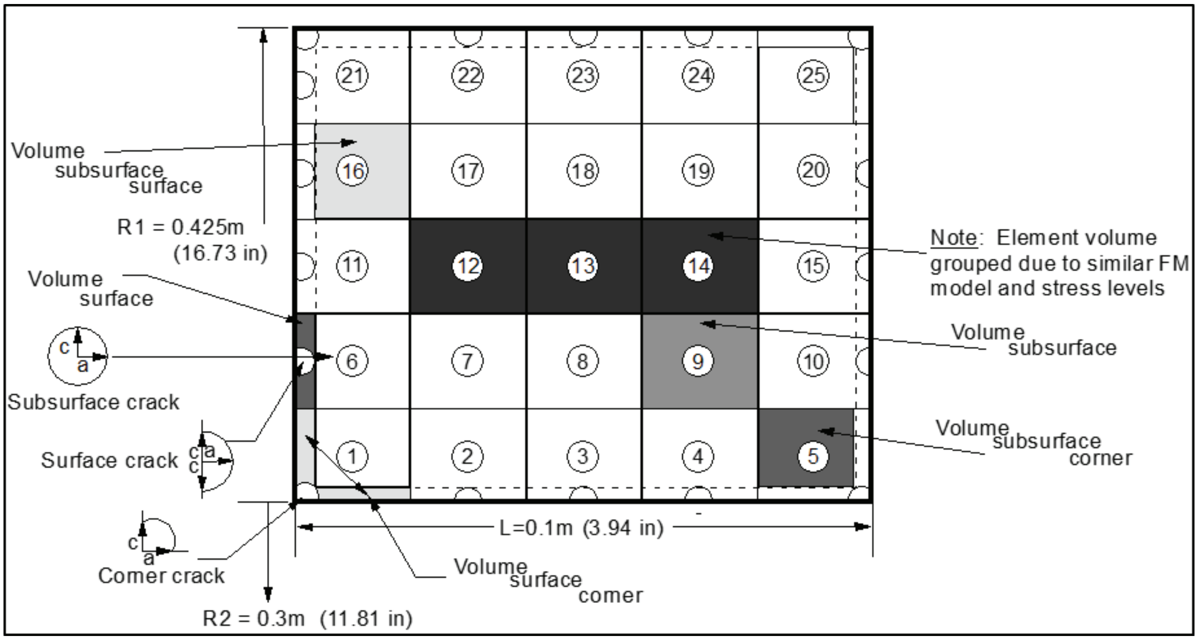

Figure A-1. Typical Zone Types

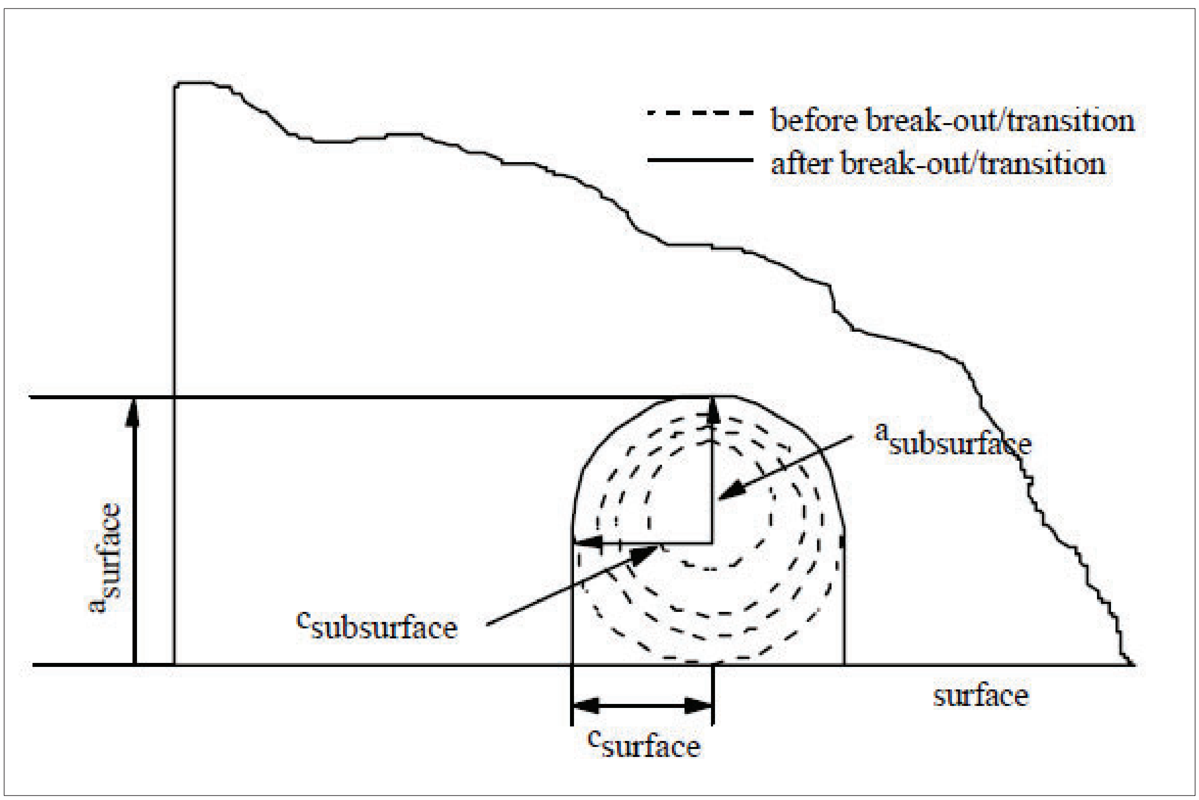

Figure A-2. Guidelines for Crack Growth Analysis

A.4 **Test Case Analysis Example.**

A.4.1 Problem Description.

The test case geometry consists of a titanium ring disk under simple cyclic loading for 20,000 cycles. The maximum speed is 6,800 RPM, and an external pressure load of 50 MPa (7.25 ksi) is applied on the outer diameter to simulate blade loading. The disk probability of failure will be calculated, assuming no in-service inspection and with a single in-service inspection at 10,000 cycles (see figures A-3 and A-4).

A.4.2 Step 1 - Component Stress Analysis.

Component stresses are determined to perform crack growth analysis, define zones, and calculate zone volumes. The stress analysis results are shown below as a component stress contour plot for the maximum principal stress in each band. Since crack growth calculations are to be performed, maximum principal (hoop) stresses are used (see figure A-5).

Assumptions:

1. Disk is at a constant temperature.
2. No thermal stresses.

A.4.3 Step 2 - Stress Volume Calculation.

Incremental volumes are used to determine the probability of having an anomaly in a particular region of the part. The disk is partitioned into zones where within a zone, the residual life is nearly constant. Next, the volume of each zone is calculated. The disk shown in figure A-6 has been partitioned into 36 zones. The FAA provides guidelines for defining the volume of each zone in paragraph A.3. Stress volume results are shown in Table A-2.

Assumptions:

1. Stress volumes partitioned at 5 ksi (34.5 MPa) increments are good starting points to perform the risk integration.
2. A 0.020 in (0.5 mm) thick onion skin provides adequate definition of the surface volume.

A.4.4 Step 3 - Crack Growth Model Definition.

Crack growth models are constructed for each of the zones defined in paragraph A.4.3. Examples for zones 17, 22, and 10 are shown in figure A-7 of this AC. The FAA provides guidelines for crack growth analysis in figure A-2 of this AC.

Assumptions:

1. The crack is positioned in the most life-limiting location within the zone.
2. Surface anomalies are modeled as semicircular cracks.
3. Surface corner anomalies are modeled as quarter circles.
4. Subsurface anomalies are modeled as circular cracks.

A.4.5 Step 4 - Crack Growth Calculations.

Crack growth calculations are performed using the predicted stresses and crack growth rate data to determine the residual life associated with each zone (figure A-8). The calculations are conducted for a range of initial crack sizes to ensure that the component service life is covered.

Assumptions:

1. All anomalies act as sharp propagating cracks and are orientated normal to the maximum principal stress: hoop stress.
2. The crack growth rate curve is the same for both surface and subsurface calculations.
3. Average air crack growth data.
4. No surface enhancement effects.

A.4.6 Step 5 - Relative Risk Calculation - No In-Service Inspection.

The probability of failure for each stress volume is calculated, integrating the volume, anomaly distribution, and residual life information from the previous steps (figure A-9). The results for each zone are statistically summed to determine the total component probability of failure. The calculated probability of failure without an in-service inspection is 1.9E-09 events/cycle.

A.4.7 Step 6 - Relative Risk Calculations - With a Single In-Service Inspection.

The "with inspection" probability of failure calculations are performed in the same manner as in paragraph A.4.6, except the ultrasonic inspection POD data and cycles to inspection are included in the risk integration (figure A-10). The calculated probability of failure with a mid-life inspection is 1.4E-09 events/cycle.

Assumptions:

1. The ultrasonic inspection POD curve is applicable for 100 percent of the component volume (surface connected and subsurface).
2. Inspection is performed at 10,000 cycles.
3. The anomaly area in the inspection plane is equivalent to the anomaly area in the stress plane.

A.4.8 Step 7 – Results.

Numerous manufacturers have performed this test case. A statistical analysis of the results, given in failure risk for each cycle, demonstrated the following statistical values.

Table A-1. Failure Risk Data

Failure risk for each cycle	Mean value: m	m – 1.65s	m + 1.65s
Without in-service inspection	1.57E-09	1.27E-09	1.93E-09
With in-service inspection	1.13E-09	8.36E-10	1.53E-09

Note 1: All results in the "m-1.65s and m+1.65s" range are considered acceptable for both conditions. A graphical representation is shown in figure A-12.

Note 2: This range defines the interval, centered on the mean value, covering 90 percent of the result population, assuming a log-normal distribution.

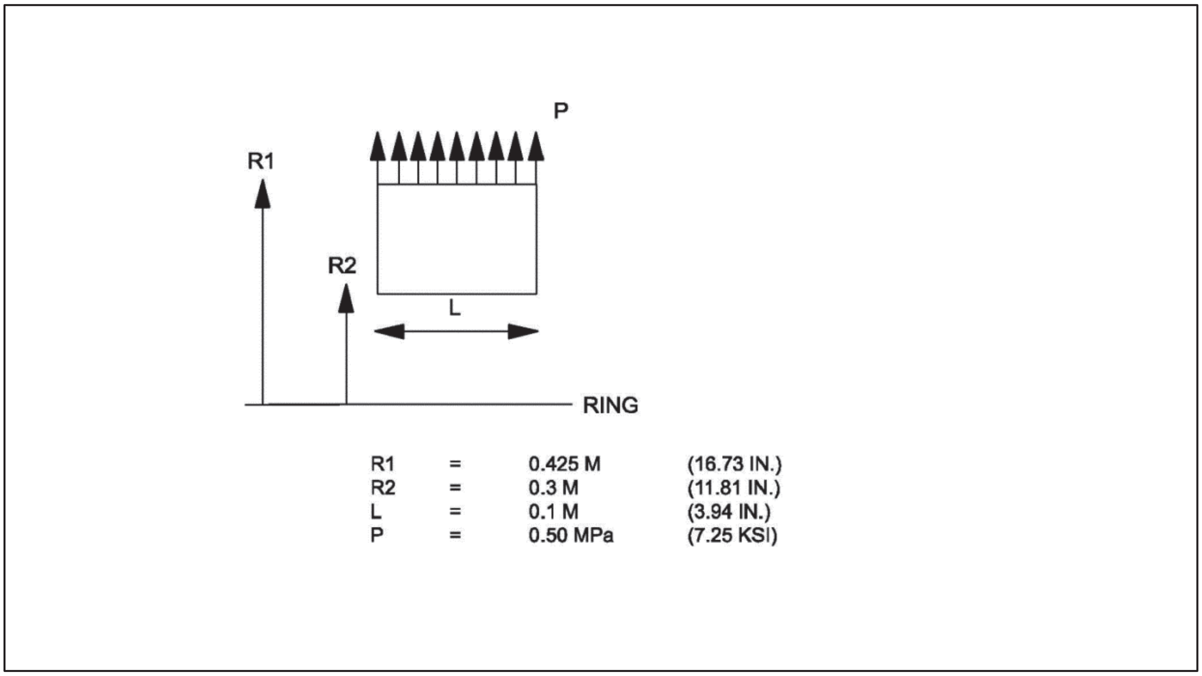

Figure A-3. Geometry

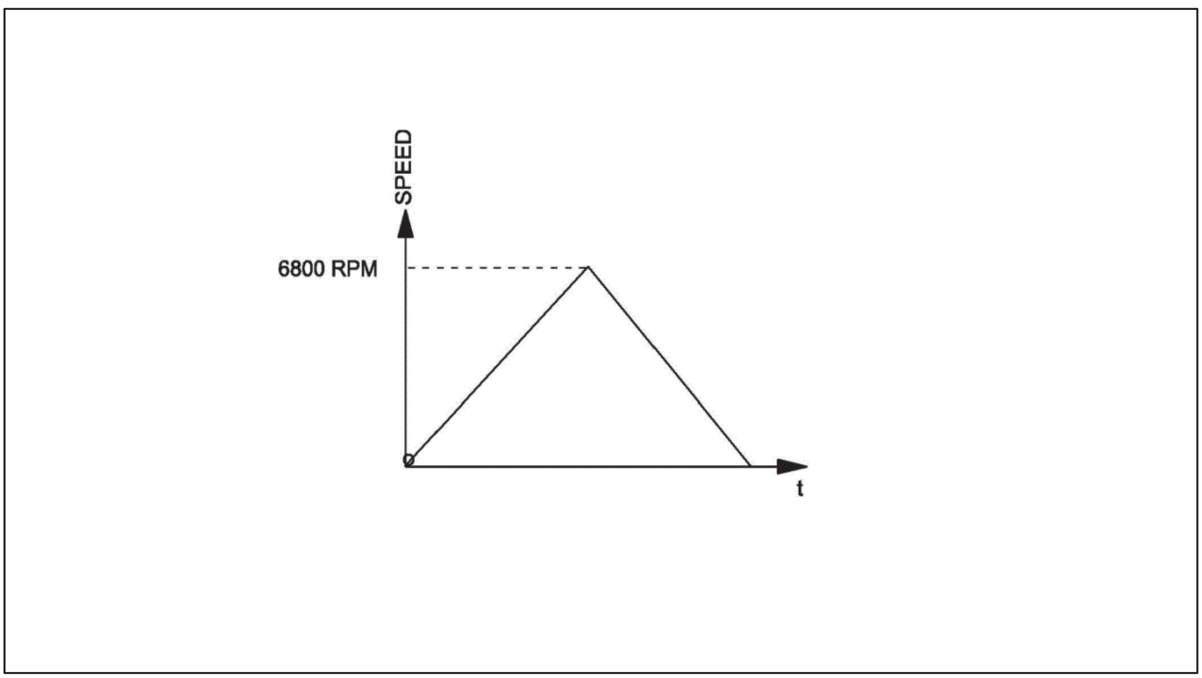

Figure A-4. Room Temperature Test Cycle

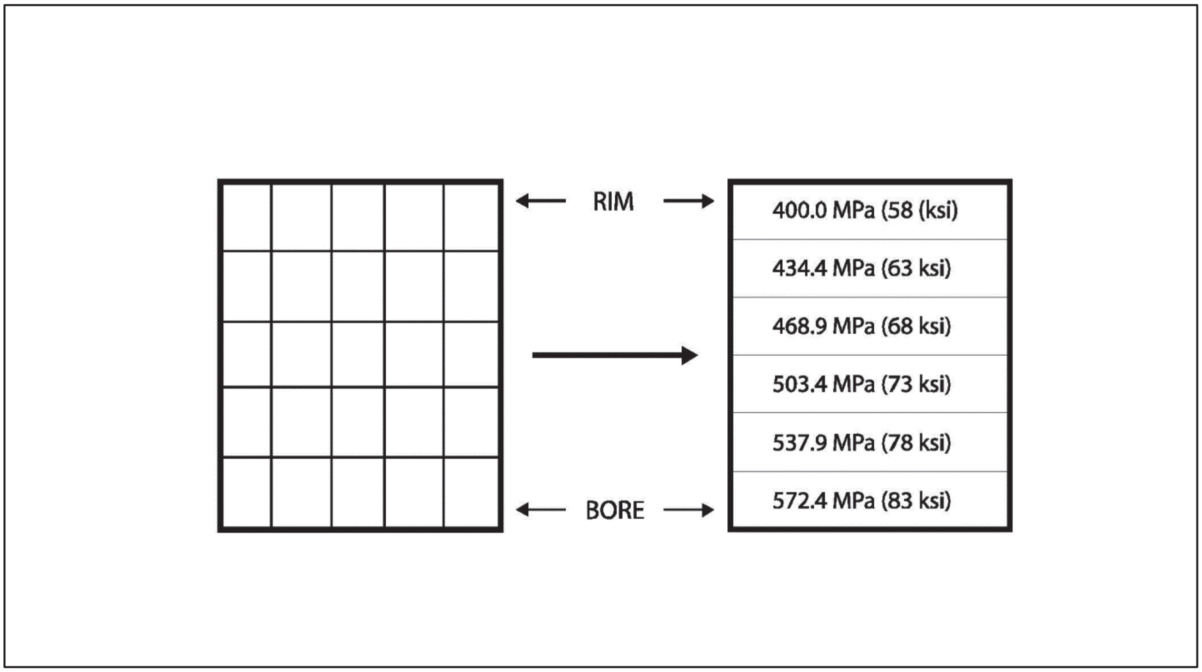

Figure A-5. Component Stress Model and Component Principal Stress Contour Plot

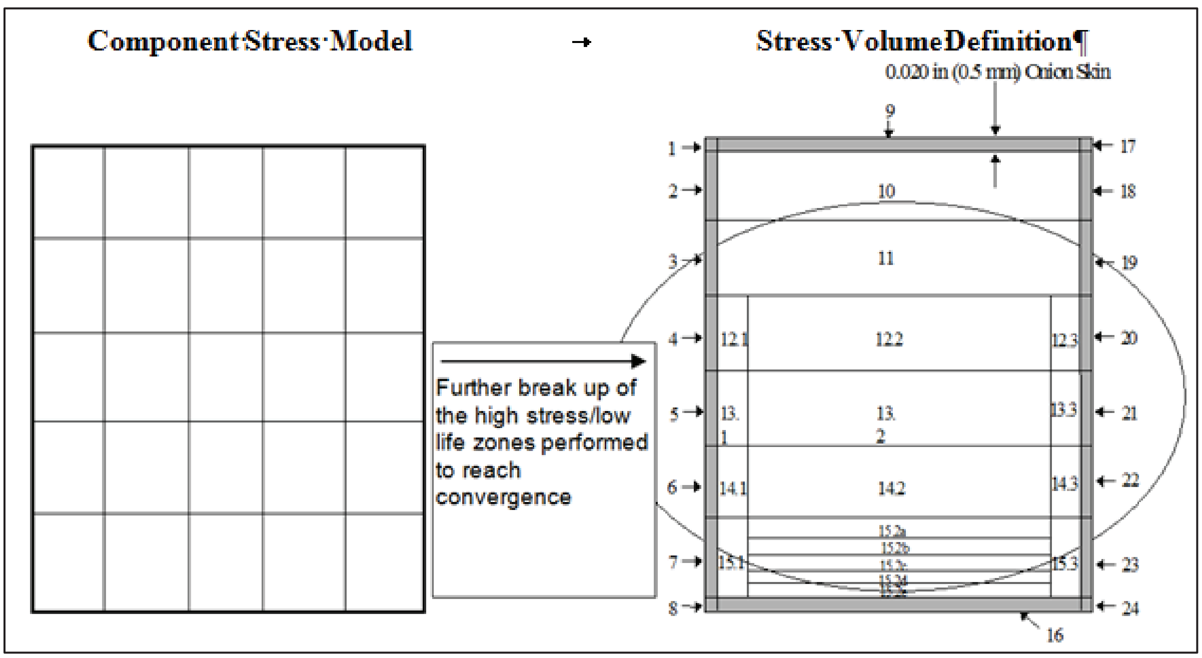

Figure A-6. Component Stress Model/Stress Volume Definition

Table A-2. Zone Volume Data

Zone Number	Volume, cm^3	Volume, in^3
1	0.69	0.042
2	18.8	1.15
3	34.9	2.13
4	29.2	1.78
5	24.2	1.48
6	20.1	1.23
7	16.1	0.98
8	0.49	0.030
9	134.37	8.20
10	3675.5	224.29
11	6809.8	415.56
12.1	144.48	8.81
12.2	5403.46	329.68
12.3	144.48	8.81
13.1	119.95	7.32
13.2	4488.2	273.84
13.3	119.95	7.32
14.1	99.58	6.08
14.2	3724.1	227.22
14.3	99.58	6.08
15.1	79.82	4.87
15.2a	1958.8	119.51
15.2b	324.02	19.77
15.2c	459.58	28.04
15.2d	182.75	11.15
15.2e	91.13	5.56
15.3	79.82	4.87
16	94.90	5.79
17	0.69	0.042
18	18.8	1.15
19	34.9	2.13
20	29.2	1.78
21	24.2	1.48
22	20.1	1.23
23	16.1	0.98
24	0.49	0.030

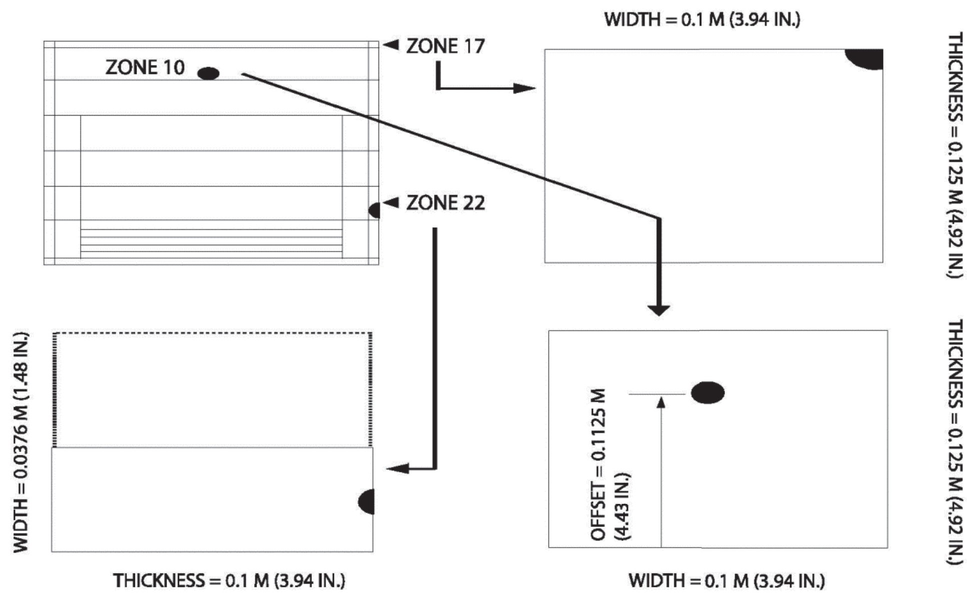

Figure A-7. Zone Crack Location

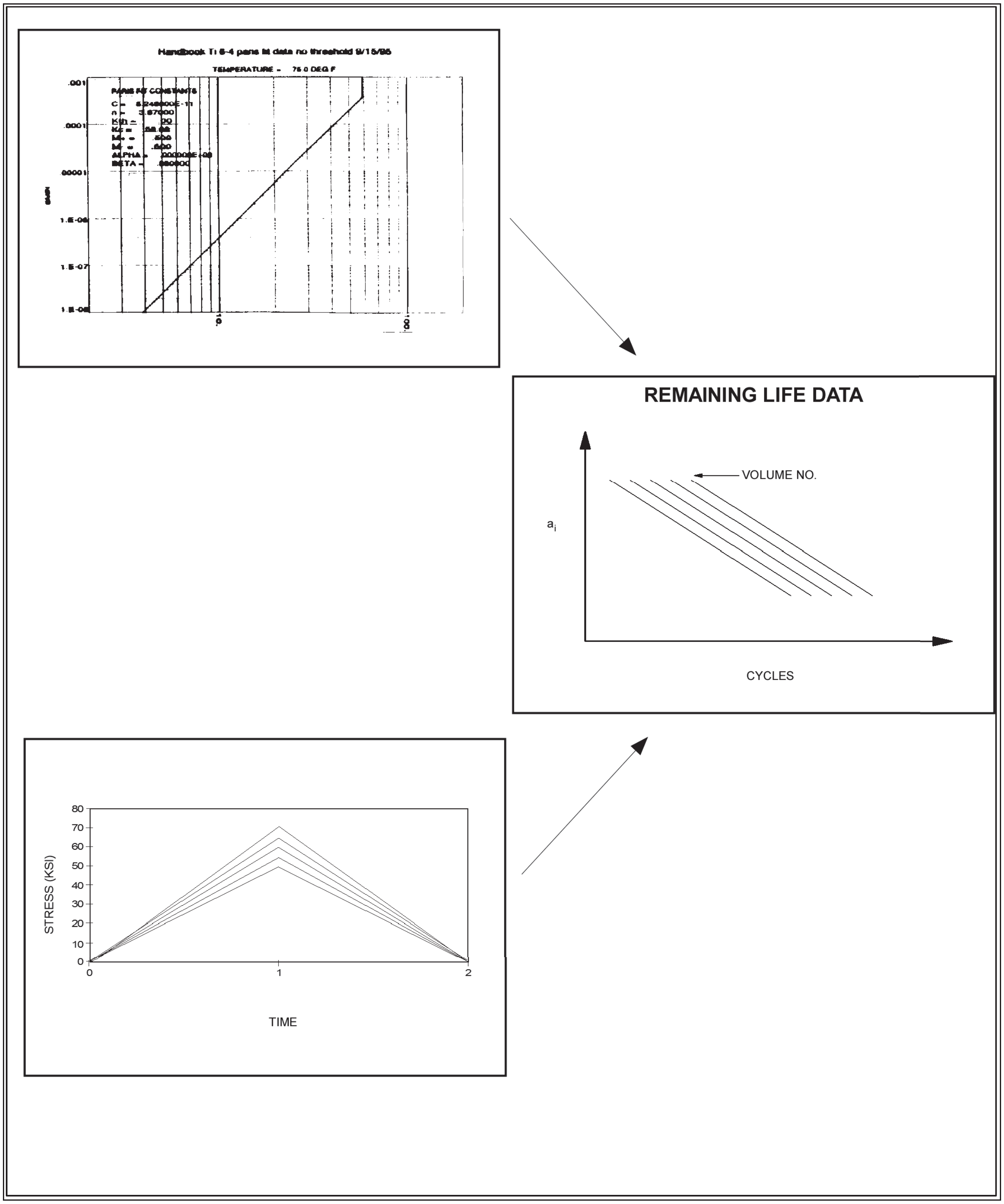

Figure A-8. Crack Growth Calculation

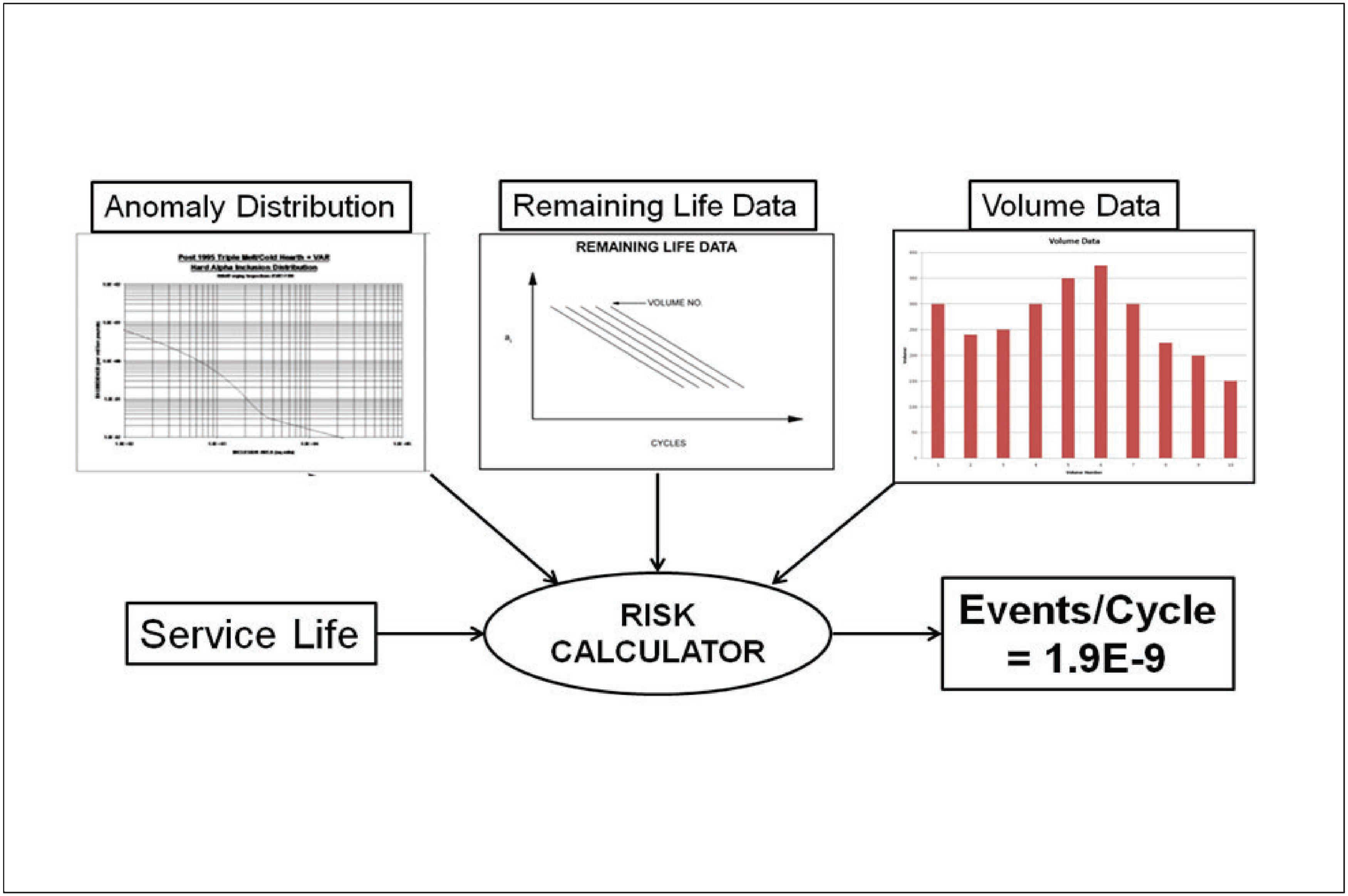

Figure A-9. Overall Probabilistic Assessment Process – No In-Service Inspection

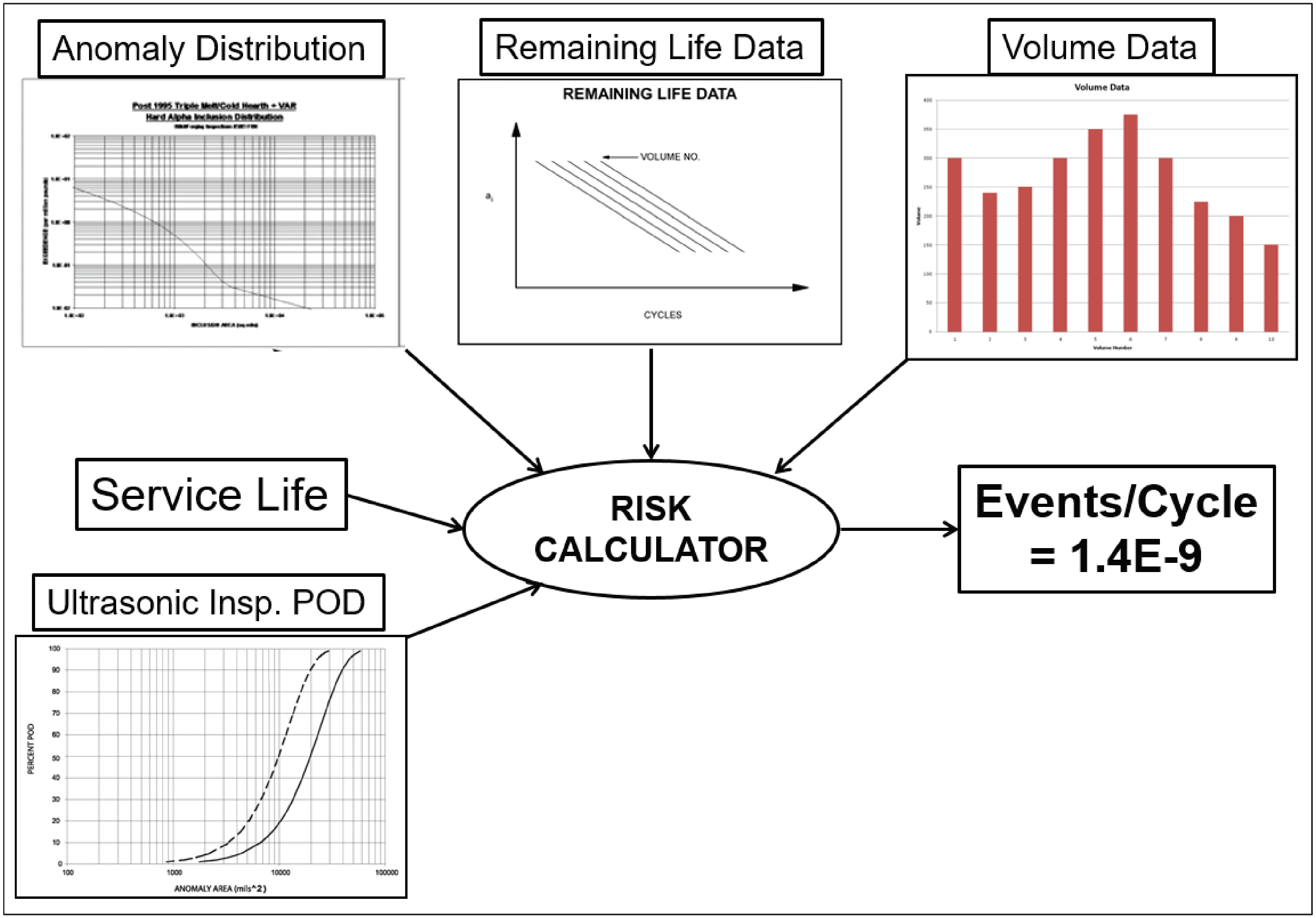

Figure A-10. Overall Probabilistic Assessment Process – With In-Service Inspection

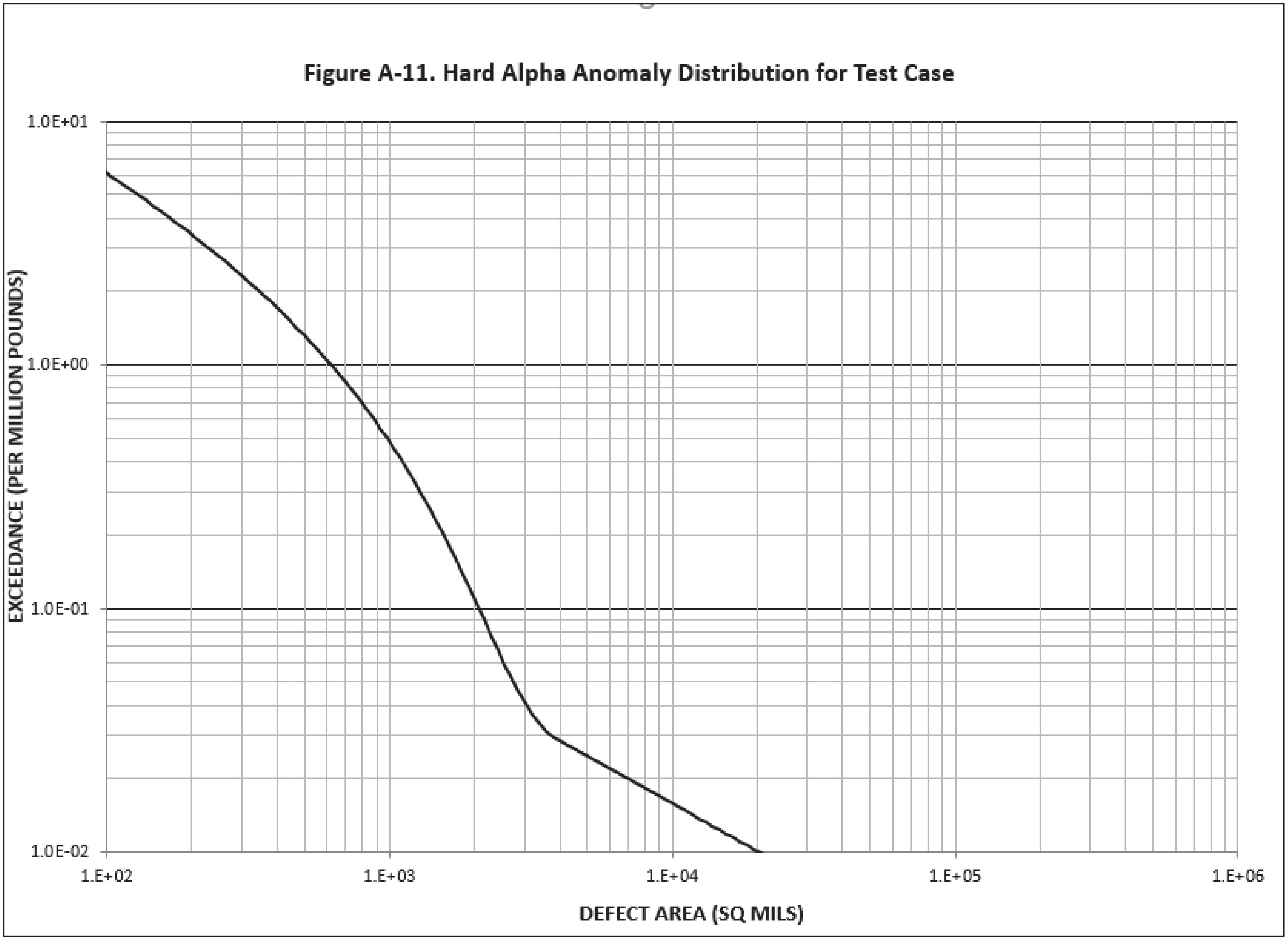

Figure A-11. Hard Alpha Anomaly Distribution for Test Case

Table A-3. Tabular Data – Anomaly Distribution Curves for Test Case (Figure A-11)

Area Sq. mils	Anomaly Distribution For Test Case Exceedance /Million lbs.	Area Sq. mils	Anomaly Distribution For Test Case Exceedance /Million lbs.	Area Sq. mils	Anomaly Distribution For Test Case Exceedance /Million lbs.
3.9	5.91E+01	26.7	1.63E+01	181	3.72E+00
4.2	5.70E+01	28.3	1.56E+01	192	3.54E+00
4.4	5.49E+01	29.9	1.50E+01	203	3.37E+00
4.7	5.29E+01	31.7	1.44E+01	215	3.20E+00
4.9	5.10E+01	33.5	1.39E+01	227	3.04E+00
5.2	4.91E+01	35.4	1.33E+01	240	2.88E+00
5.5	4.73E+01	37.5	1.28E+01	254	2.73E+00
5.8	4.56E+01	39.7	1.23E+01	269	2.58E+00
6.2	4.39E+01	42.0	1.18E+01	284	2.44E+00
6.5	4.23E+01	44.4	1.13E+01	301	2.31E+00
6.9	4.07E+01	46.9	1.09E+01	318	2.18E+00
7.3	3.92E+01	49.7	1.04E+01	337	2.06E+00
7.7	3.78E+01	52.5	1.00E+01	356	1.94E+00
8.2	3.64E+01	55.6	9.60E+00	377	1.83E+00
8.7	3.51E+01	58.8	9.21E+00	399	1.72E+00
9.2	3.38E+01	62.2	8.83E+00	422	1.61E+00
9.7	3.25E+01	65.8	8.46E+00	446	1.51E+00
10.3	3.13E+01	69.6	8.11E+00	472	1.41E+00
10.9	3.01E+01	73.7	7.77E+00	499	1.32E+00
11.5	2.90E+01	77.9	7.44E+00	528	1.23E+00
12.2	2.79E+01	82.4	7.13E+00	559	1.15E+00
12.9	2.69E+01	87.2	6.82E+00	591	1.07E+00
13.6	2.59E+01	92.3	6.53E+00	626	9.91E-01
14.4	2.49E+01	97.6	6.24E+00	662	9.18E-01
15.2	2.40E+01	103	5.97E+00	700	8.48E-01
16.1	2.31E+01	109	5.71E+00	741	7.82E-01
17.0	2.22E+01	116	5.45E+00	784	7.19E-01
18.0	2.14E+01	122	5.21E+00	829	6.60E-01
19.1	2.06E+01	129	4.97E+00	877	6.03E-01
20.2	1.98E+01	137	4.74E+00	928	5.50E-01
21.3	1.90E+01	145	4.52E+00	981	5.00E-01
22.6	1.83E+01	153	4.31E+00	1038	4.54E-01
23.9	1.76E+01	162	4.11E+00	1098	4.10E-01
25.3	1.69E+01	171	3.91E+00	1162	3.69E-01

Area Sq. mils	Anomaly Distribution For Test Case Exceedance /Million lbs.	Area Sq. mils	Anomaly Distribution For Test Case Exceedance /Million lbs.	Area Sq. mils	Anomaly Distribution For Test Case Exceedance /Million lbs.
1229	3.31E-01	5621	2.29E-02	25698	8.57E-03
1300	2.95E-01	5946	2.21E-02	27186	8.27E-03
1376	2.63E-01	6290	2.13E-02	28760	7.97E-03
1455	2.33E-01	6655	2.06E-02	30426	7.68E-03
1540	2.05E-01	7040	1.98E-02	32188	7.40E-03
1629	1.80E-01	7448	1.91E-02	34052	7.14E-03
1723	1.58E-01	7879	1.84E-02	36024	6.88E-03
1823	1.38E-01	8335	1.78E-02	38110	6.63E-03
1929	1.20E-01	8818	1.72E-02	40317	6.39E-03
2040	1.04E-01	9329	1.65E-02	42652	6.16E-03
2158	9.00E-02	9869	1.60E-02	45121	5.94E-03
2283	7.80E-02	10440	1.54E-02	47734	5.72E-03
2416	6.77E-02	11045	1.48E-02	50499	5.51E-03
2556	5.89E-02	11685	1.43E-02	53423	5.31E-03
2704	5.16E-02	12361	1.38E-02	56517	5.12E-03
2860	4.56E-02	13077	1.33E-02	59790	4.93E-03
3026	4.07E-02	13834	1.28E-02	63252	4.75E-03
3201	3.68E-02	14636	1.24E-02	66915	4.58E-03
3386	3.38E-02	15483	1.19E-02	70790	4.41E-03
3583	3.15E-02	16380	1.15E-02	74890	4.25E-03
3790	2.98E-02	17328	1.11E-02	79227	4.10E-03
4009	2.85E-02	18332	1.07E-02	83815	3.95E-03
4242	2.75E-02	19393	1.03E-02	88668	3.80E-03
4487	2.65E-02	20516	9.93E-03	93803	3.66E-03
4747	2.56E-02	21704	9.57E-03	99235	3.53E-03
5022	2.47E-02	22961	9.23E-03	----	----
5313	2.38E-02	24291	8.89E-03	----	----

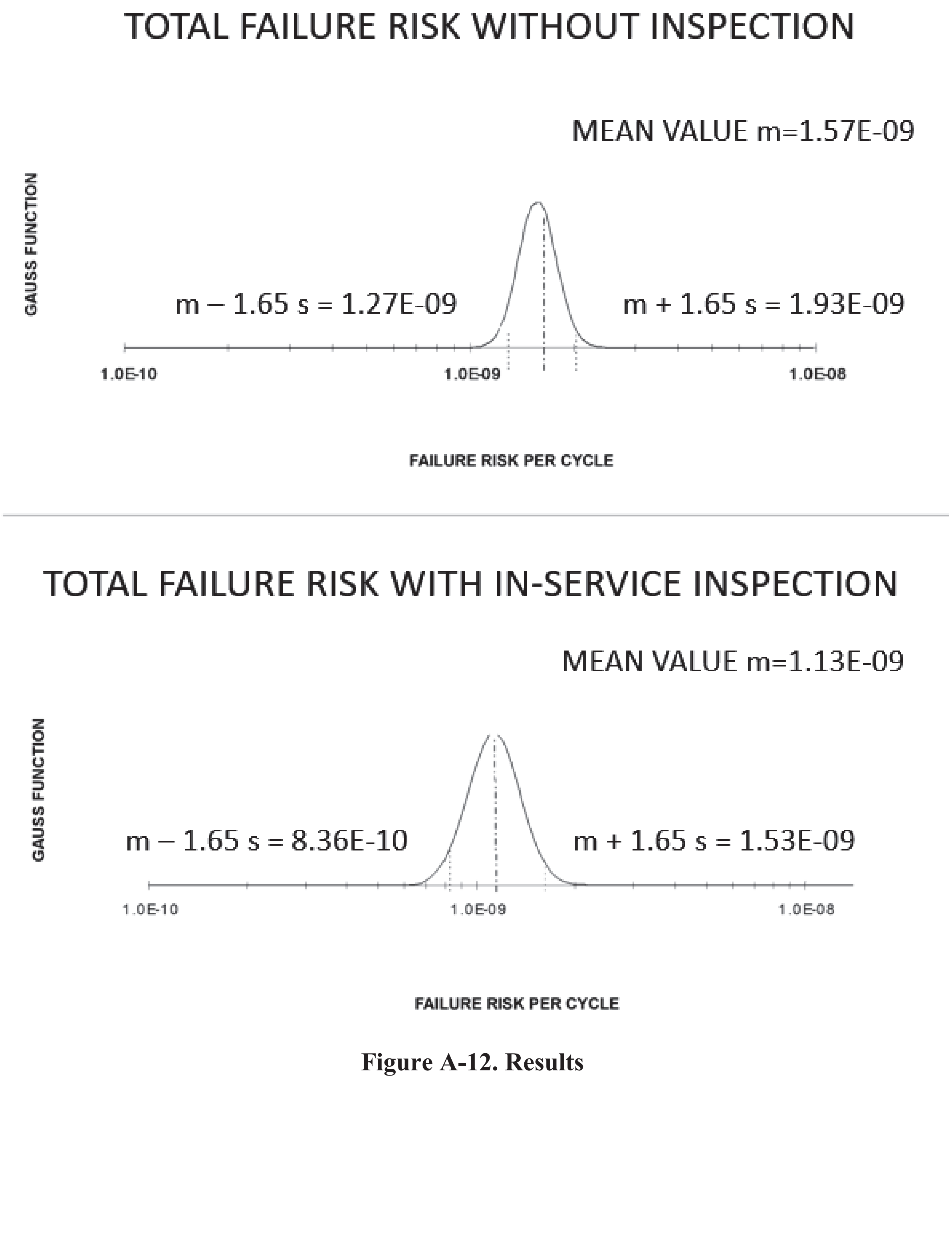

Figure A-12. Results

APPENDIX B. SOFT-TIME INSPECTION EXAMPLE

B.1 Overview of Soft-time Inspection Example.

This appendix provides an example of an acceptable process to set the opportunity inspection requirements that will be specified in the airworthiness limitations (AL) section of the instructions for continued airworthiness (ICA). As discussed in chapter 5, the application of the opportunity inspection is one of several options available to reduce the predicted probability of failure (POF) in the event that a component design does not meet the DTR criteria.

Chapter 5 introduced the following three scenarios for opportunity inspections to clarify the actions that technicians could take at a maintenance opportunity. The scenarios are as follows:

1. Hardware available for opportunity inspection.
2. Module below soft-time interval.
3. Module above soft-time interval.

Note: The FAA presents examples of the first and third scenarios in this appendix. The second scenario could be analyzed in a similar manner to the third scenario.

The key elements to determine opportunity inspection requirements, given any scenario, are as follows:

- Type of inspection method and associated level of sensitivity.
- Maintenance interval at which time the hardware will be exposed for inspection.
- Cyclic threshold or soft-time interval for module exposure at which time the inspections will be invoked.

Given each scenario, details of an inspection plan can take many forms. Figure B-1 shows the decision process to select the appropriate inspection requirements. The FAA will reference this flowchart throughout this section to guide the discussion.

B.2 Examples of Scenario 1: Hardware Available for Opportunity Inspection.

1. Figure B-1 shows that the predicted POF for the simple ring disk, without the benefit of in-service inspection, is 1.9 E-09 events/cycle. Therefore, the ring disk design does not meet the 1.0 E-09 event/cycle DTR (a “No” answer at block 3). If the ring disk POF were less than the DTR, the design would be considered acceptable (block 4), and no in-service inspection would be required.
2. Assuming a design change is not possible (for example, stress reduction, material change, or manufacturing inspection enhancement), then the decision is made (block 5) to explore the opportunity inspection option to reduce the component risk below the DTR.
3. With the decision made to pursue the inspection route, the level of maintenance opportunity is selected for the study. The options available are piece part, module,

engine, or some combination of these opportunities. The desire is to select an exposure level or combination of levels that minimize the impact on the operator, yet has a high potential to reduce the component risk level. It is anticipated that the applicant will use trial and error to arrive at the best solution. Working with these damage tolerance criteria will give the applicant experience to make good initial selections, which will reduce the amount of analytical effort in future analyses. For the initial pass, a one-time ultrasonic inspection at first piece part exposure (block 6) and an inspection threshold of zero cycles (block 7) will be evaluated. Figure B-2 shows the piece part, maintenance exposure distribution for the ring disk.

4. An ultrasonic inspection that rejects indications equal to or greater than a #3 FBH is selected. The solid line in figure E-4 is the POD for this inspection (block 8).
5. The POF calculations (block 9) are performed in the same manner as in paragraph A.4.7; except, instead of a fixed inspection at 10,000 cycles, inspections are assumed to occur as the piece parts are exposed. The piece part, exposure distribution is treated as a random variable in the probabilistic analysis.
6. The calculated probability of failure is 1.3E-9 events/cycle, which is still greater than the DTR (a “No” answer at block 10). On a second pass, a more sensitive ultrasonic inspection is assumed, which rejects indications equal to or greater than one-half the response from a #3 FBH. The dotted line in figure E-5 represents the associated POD for this inspection. The resulting POF is 9.9E-10 events/cycle, meeting the DTR (a “Yes” answer at block 10).
7. The design would be considered acceptable (relative to the damage tolerance criteria), and the following inspection requirements would be placed in step 12 of the AL section of the ICA.
   - Inspect at first piece part exposure.
   - Ultrasonic inspection calibrated to a #3 FBH.
   - Reject indications equal to or greater than one-half the response from a #3 FBH calibration.
   - Include reference to detailed ultrasonic inspection procedures.

B.3 Example of Scenario 3: Module above Soft-Time Interval.

1. For this example, piece part exposure of the ring disk is expected to occur at a lower rate than in the previous scenario. Figure B-3 depicts this change.
2. The predicted POF is 1.2E-09 events/cycle, assuming this new exposure distribution and the same UT inspection and sensitivity as in scenario 1. Since the predicted POF exceeds the DTR, additional action is necessary.
3. Assuming that it is not reasonable to use a more sensitive field ultrasonic inspection (for example, calibration to a smaller flat bottom hole), then the module exposure distribution is evaluated (figure B-4).

4. The resulting predicted POF is 8.3E-10 events/cycle, clearing the DTR with margin. However, specifying an ultrasonic inspection of the ring disk upon module exposure requires removal of the disk from the module, increasing the burden on the operator. Since there is margin between the predicted POF and the DTR, consider another inspection plan to alleviate some of the burdens of forcing modules to piece part level. This approach implements the soft- time, inspection interval scenario. Instead of going to the module exposure, the inspections would be performed at piece part exposure, at a specified cyclic interval, and then change to inspections at module exposure. The cyclic interval, before imposing an inspection based on module exposure, is the soft-time inspection interval.

5. This strategy essentially accelerates the piece part exposure rate, as shown in figure B-5. By iterating on the length of the soft-time interval, a 12,300 cycle value is found to yield a POF of 1.0E-09 events for each cycle, satisfying the DTR criteria. The design would be considered acceptable, relative to the damage tolerance criteria, and the following inspection requirements would be placed in step 12 of the AL section of the ICA.

    - Inspect at first piece part exposure.
    - For parts not previously inspected before 12,300 cycles, inspect at first module exposure above 12,300 cycles, soft-time inspection interval.
    - Ultrasonic inspection calibrated to a #3 FBH.
    - Reject indications equal to or greater than one-half the response from a #3 FBH calibration.
    - Include reference to detailed ultrasonic inspection procedures.

6. The information contained in this section is provided for example purposes only. Each individual component design and engine maintenance practice may require different solutions than those presented here. The AL section of the ICA requirements should reflect actions consistent with the analytical assumptions made to meet the DTR criteria.

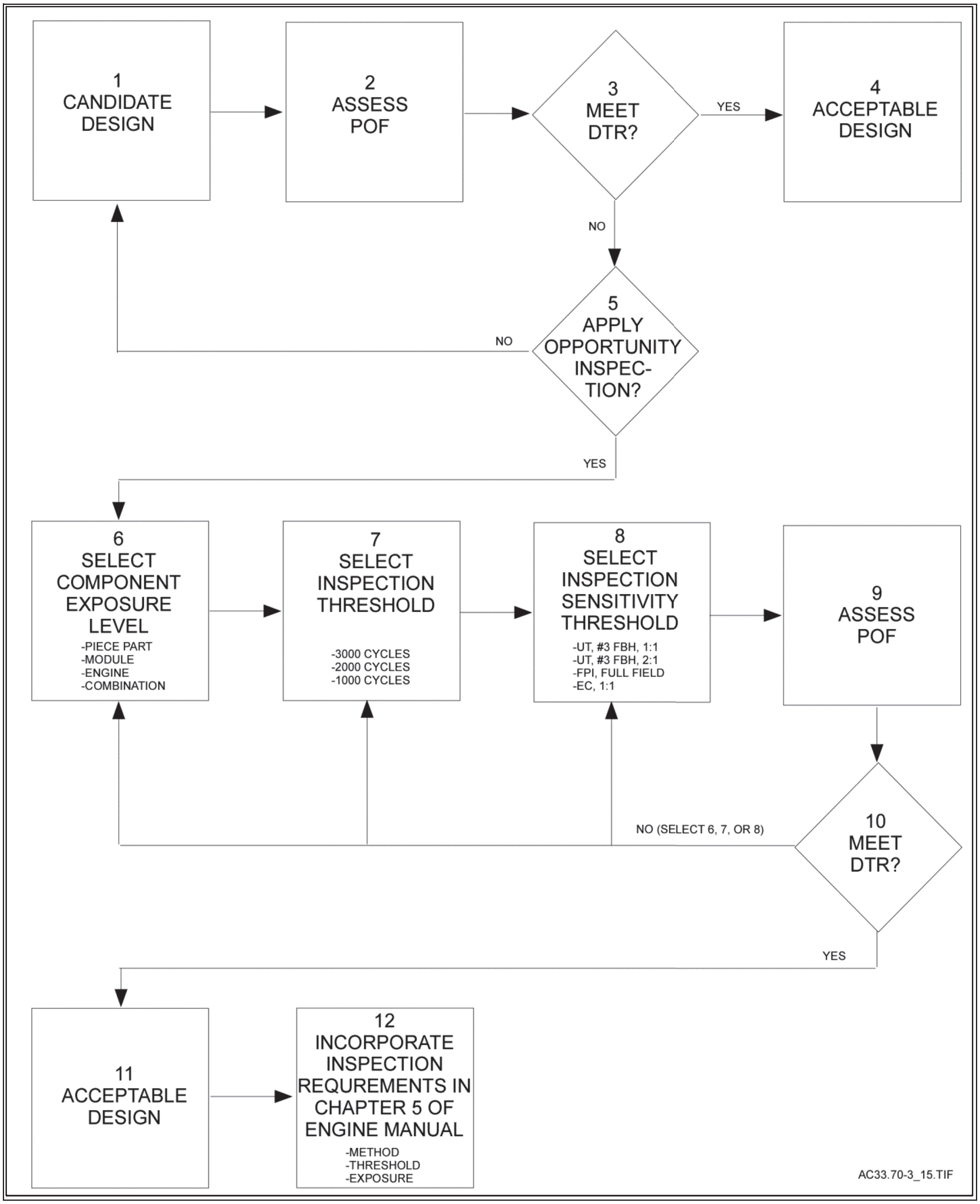

Figure B-1. In-Service Inspection Decision Process

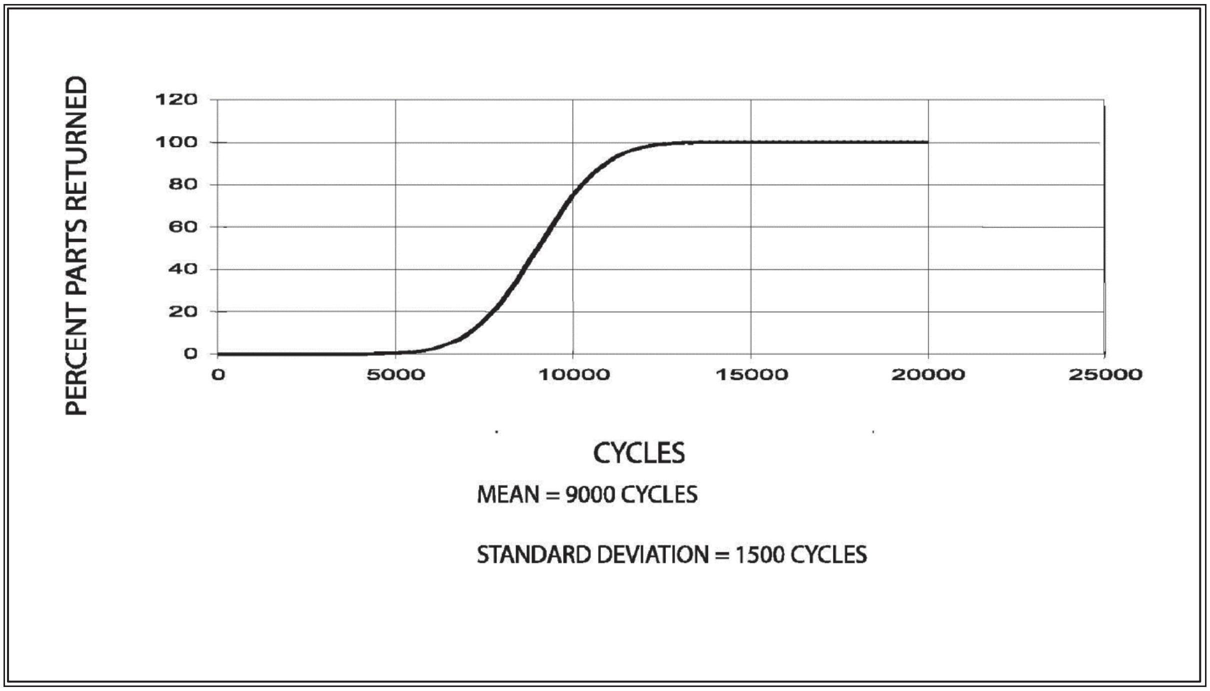

Figure B-2. Ring Disk Overhaul First Piece Part Exposure Distribution

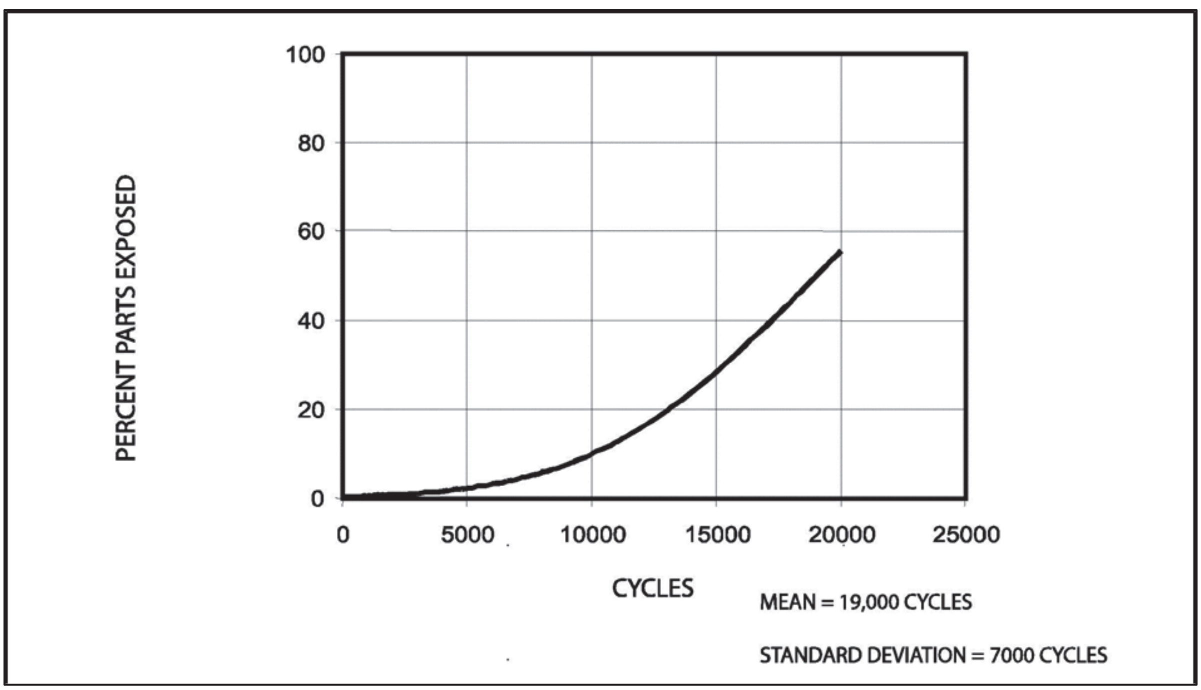

Figure B-3. New Ring Disk First Exposure Distribution

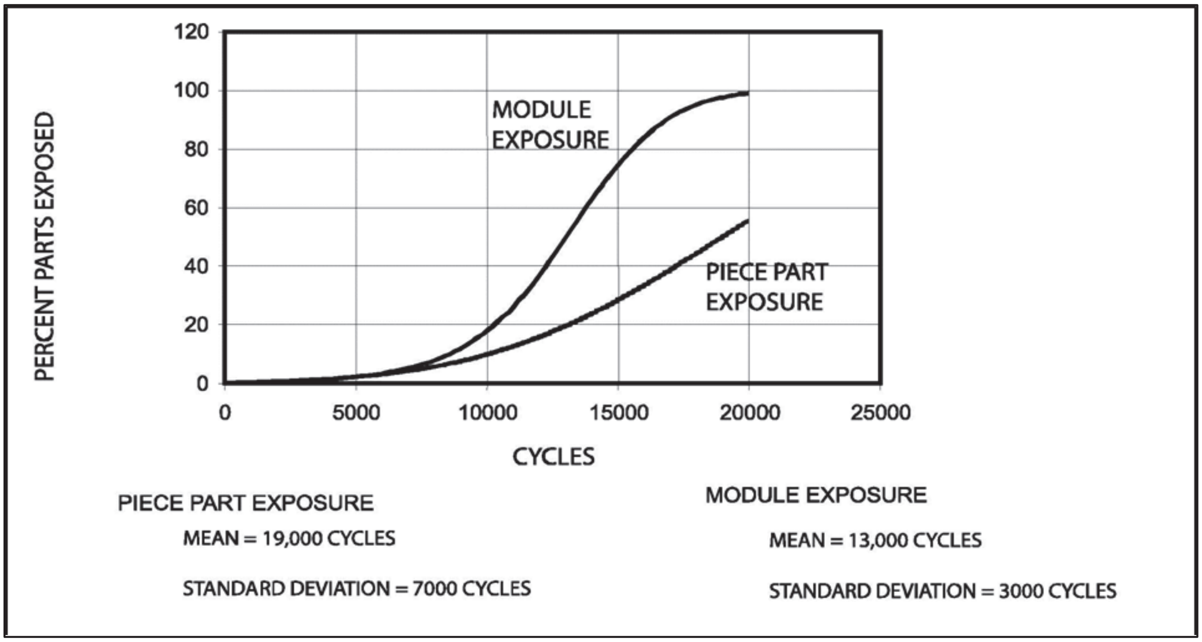

Figure B-4. New Ring Disk First Exposure Distributions

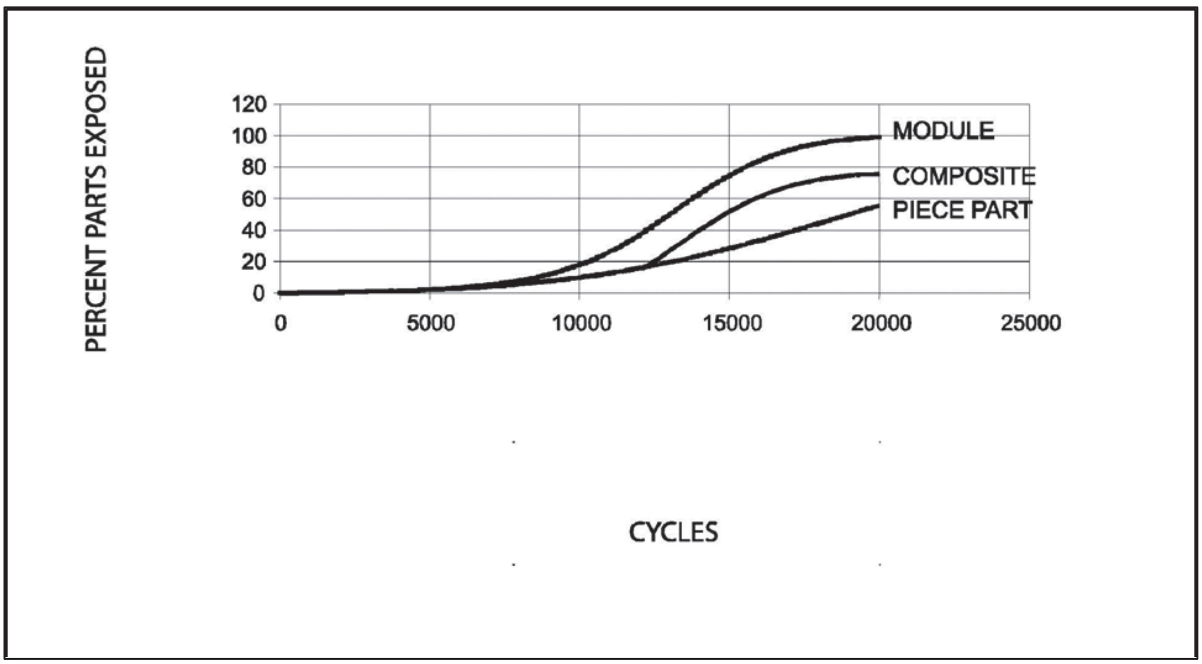

Figure B-5. Combination of First Piece Part and Module Exposure Distributions

APPENDIX C. DEFAULT ANOMALY DISTRIBUTION CURVES

C.1 Use of Anomaly Distribution Curves.

The anomaly distribution curves associated with hard alpha inclusions in titanium engine rotors are shown in figures C-1 through C-6. The following text provides additional information associated with using these distributions.

1. The distributions apply only to hard alpha inclusions in rotor grade (premium) titanium, melted using triple VAR or CHM plus VAR processes.
2. It is crucial to use the appropriate distribution curve that accurately reflects the inspection sensitivities performed at the billet and forging stages of the manufacturing process. The distributions in this appendix are applicable to components that were inspected at the billet stage using a zoned, ultrasonic inspection performed in accordance with the ultrasonic titanium billet inspection policy found in the FAA's Policy Memo ANE 2002-33.15-R0.
3. For example, the material must be inspected using ultrasonic inspection to at least a #3 FBH with the reject level set at one-half that of the calibration level (for additional instructions, see appendix E). Technicians must perform inspections at both the billet and sonic shape stages.
4. The distribution accounts for all steps required to manufacture a finished part, including the in-process billet and sonic shape, forging ultrasonic inspections. Therefore, the distribution used should reflect the inspection sensitivities used in the billet and forging inspections and should not be altered.

C.2 Critical Elements of Anomaly Distribution Curves.

Applicants and technicians should consider the following elements when referring to figures C-1 through C-6:

1. The vertical axis represents the expected number of hard alpha inclusions for each million-pounds of titanium. This information should be treated as the probability of having an inclusion of a given size or larger (exceedance probability).
2. The horizontal axis is the inclusion cross-sectional area, including the hard alpha core and the surrounding diffusion zone. Technicians should assume a circular inclusion cross-section with the corresponding diameter used as the initial size in the crack growth analysis.
3. Default curves, listed in Table C-1, are available to demonstrate compliance with § 33.70.

Table C-1. Default Curves

Billet Inspection	Forging Inspection	Figure
AMS2628 Class A Zoned >10 in. Billet Diameter (#3 FBH)	#3 FBH Conventional	Figure C-1
AMS2628 Class A Zoned >10 in. Billet Diameter (#3 FBH)	#2 FBH Conventional	Figure C-2
AMS2628 Class A Zoned >10 in. Billet Diameter (#3 FBH)	#1 FBH Conventional	Figure C-3
AMS2628 Class A Zoned 5-10 in. Billet Diameter (#2 FBH)	#3 FBH Conventional	Figure C-4
AMS2628 Class A Zoned 5-10 in. Billet Diameter (#2 FBH)	#2 FBH Conventional	Figure C-5
AMS2628 Class A Zoned 5-10 in. Billet Diameter (#2 FBH)	#1 FBH Conventional	Figure C-6

Note: For convenience, tabular data defining each curve is shown after the plots. Manufacturers using forging input material < 5 inches in diameter should provide data to substantiate use of the default anomaly distribution selected.

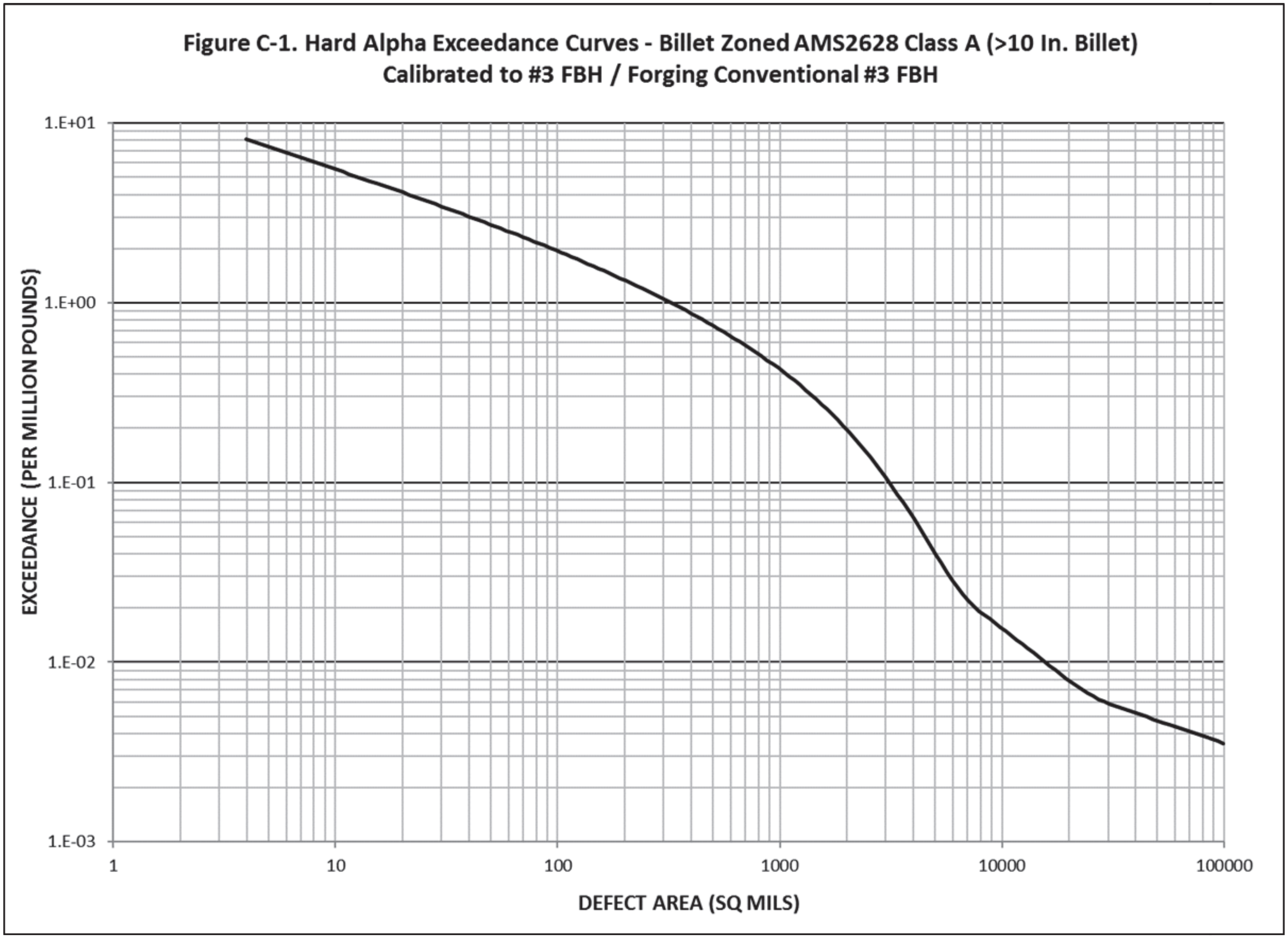

Figure C-1. Hard Alpha Exceedance Curves - Billet Zoned AMS2628 Class A (>10 In. Billet) Calibrated to #3 FBH / Forging Conventional #3 FBH

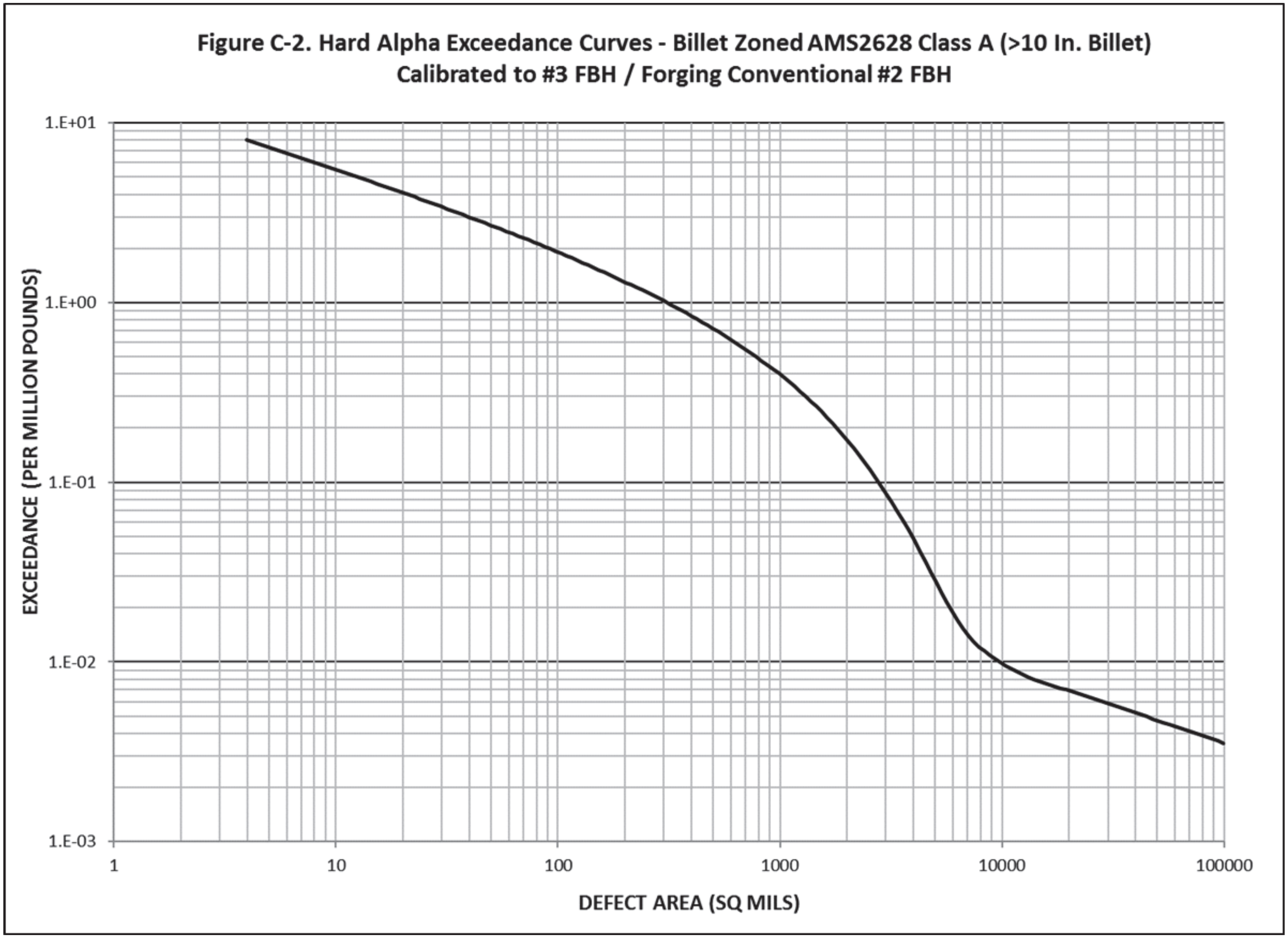

Figure C-2. Hard Alpha Exceedance Curves – Billet Zoned AMS2628 Class A (>10 In. Billet) Calibrated to #3 FBH / Forging Conventional #2 FBH

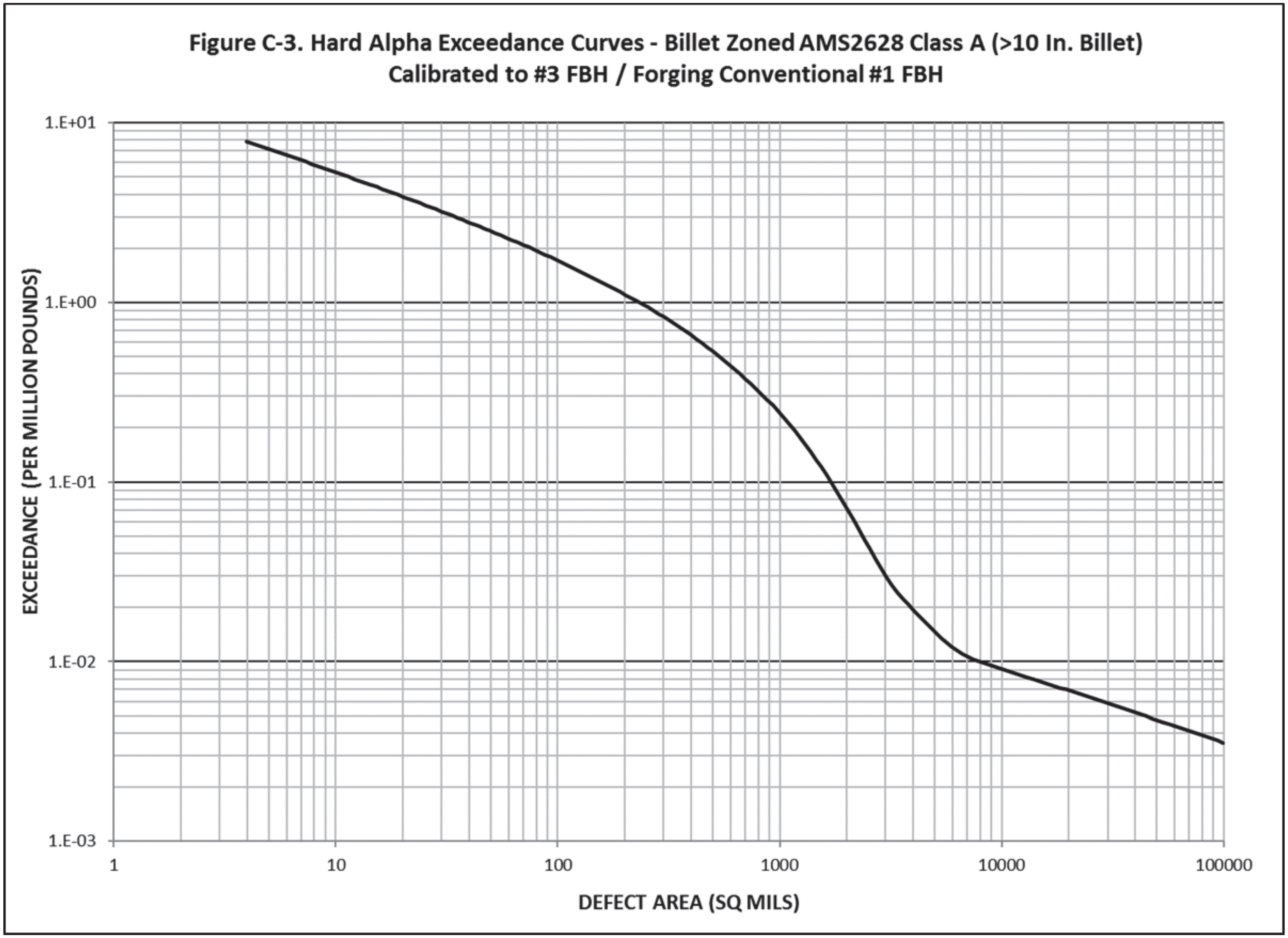

Figure C-3. Hard Alpha Exceedance Curves – Billet Zoned AMS2628 Class A (>10 In. Billet) Calibrated to #3 FBH / Forging Conventional #1 FBH

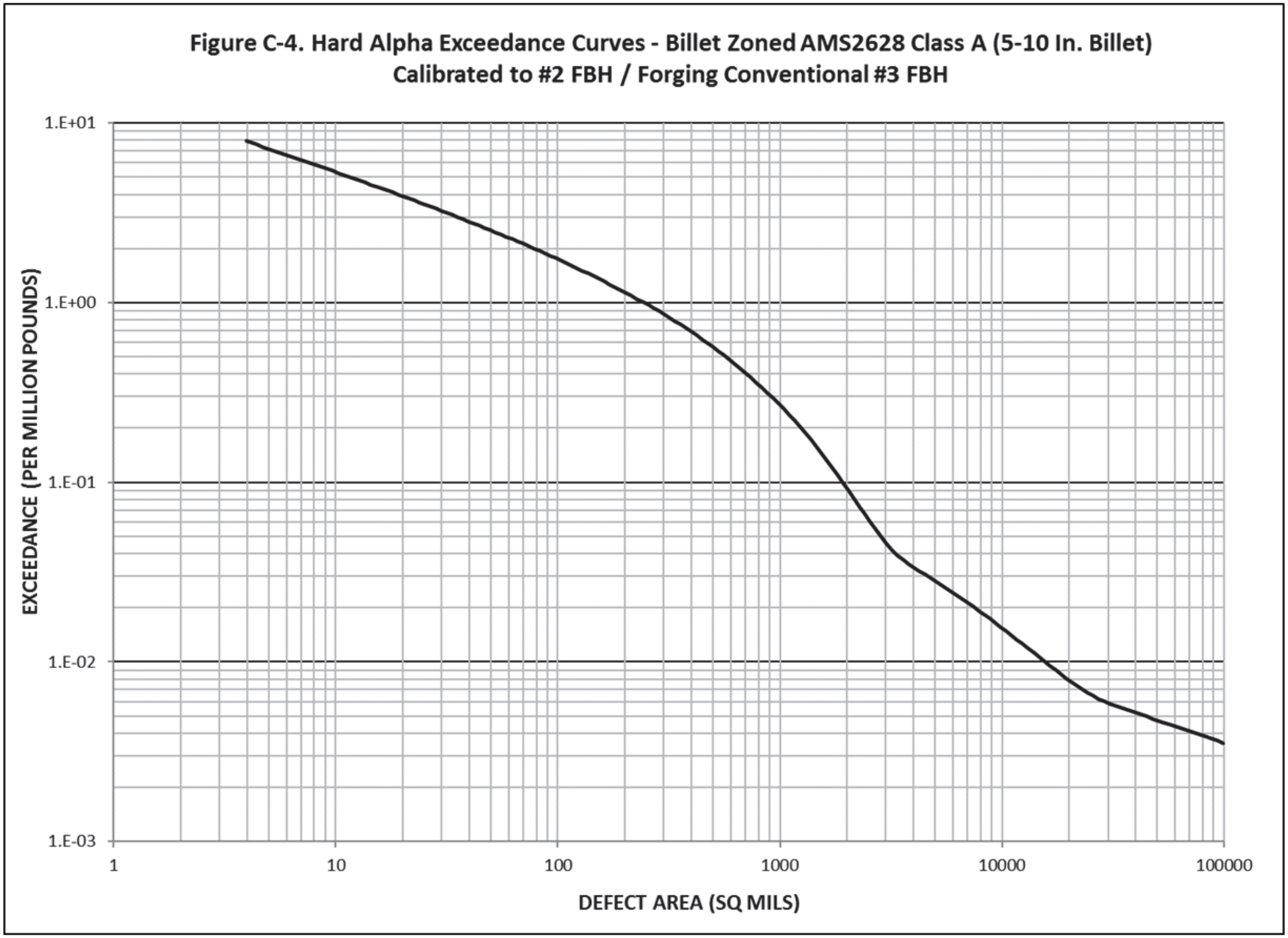

Figure C-4. Hard Alpha Exceedance Curves - Billet Zoned AMS2628 Class A (5-10 In. Billet) Calibrated to #2 FBH / Forging Conventional #3 FBH

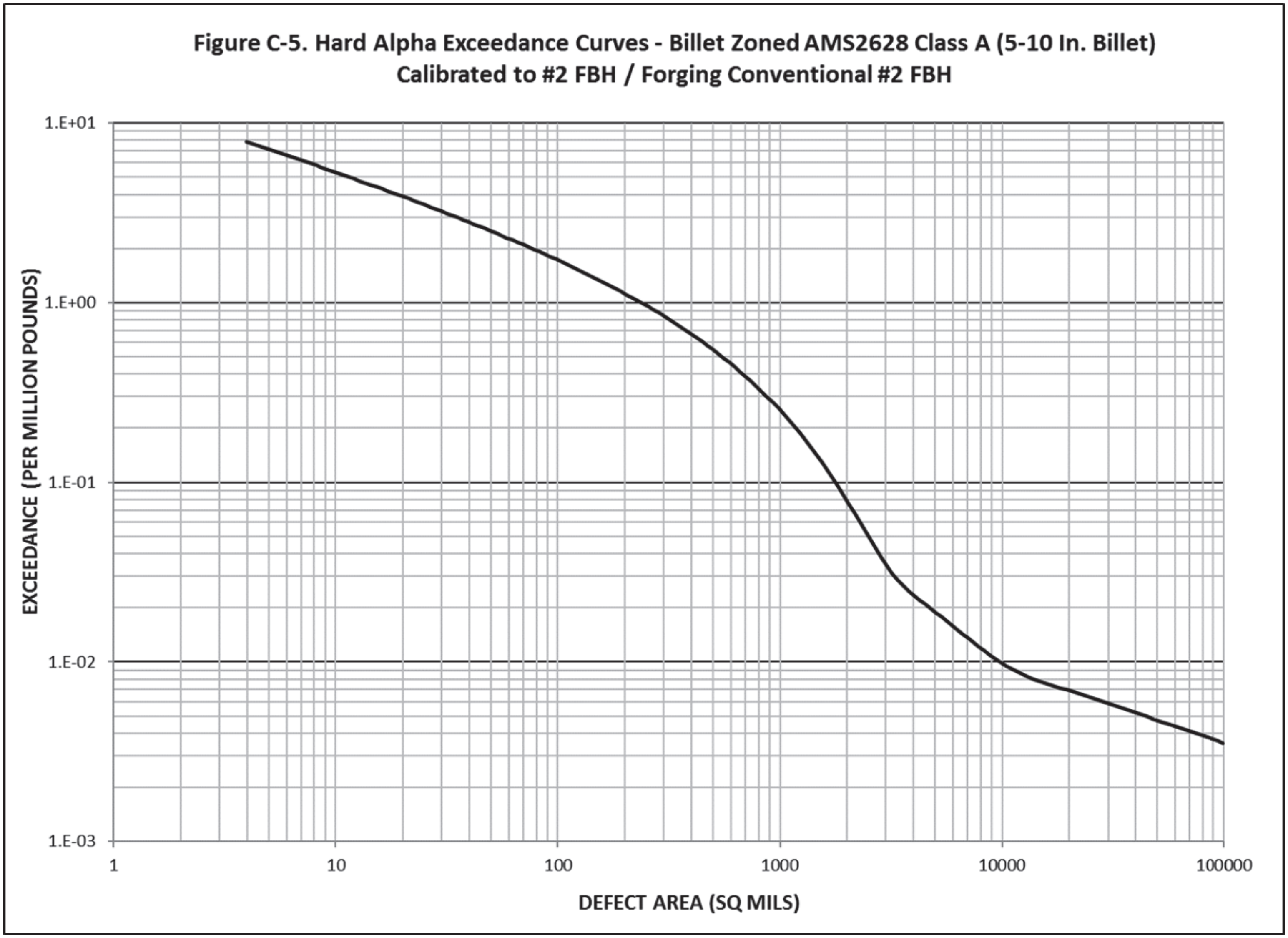

Figure C-5. Hard Alpha Exceedance Curves - Billet Zoned AMS2628 Class A (5-10 In. Billet) Calibrated to #2 FBH / Forging Conventional #2 FBH

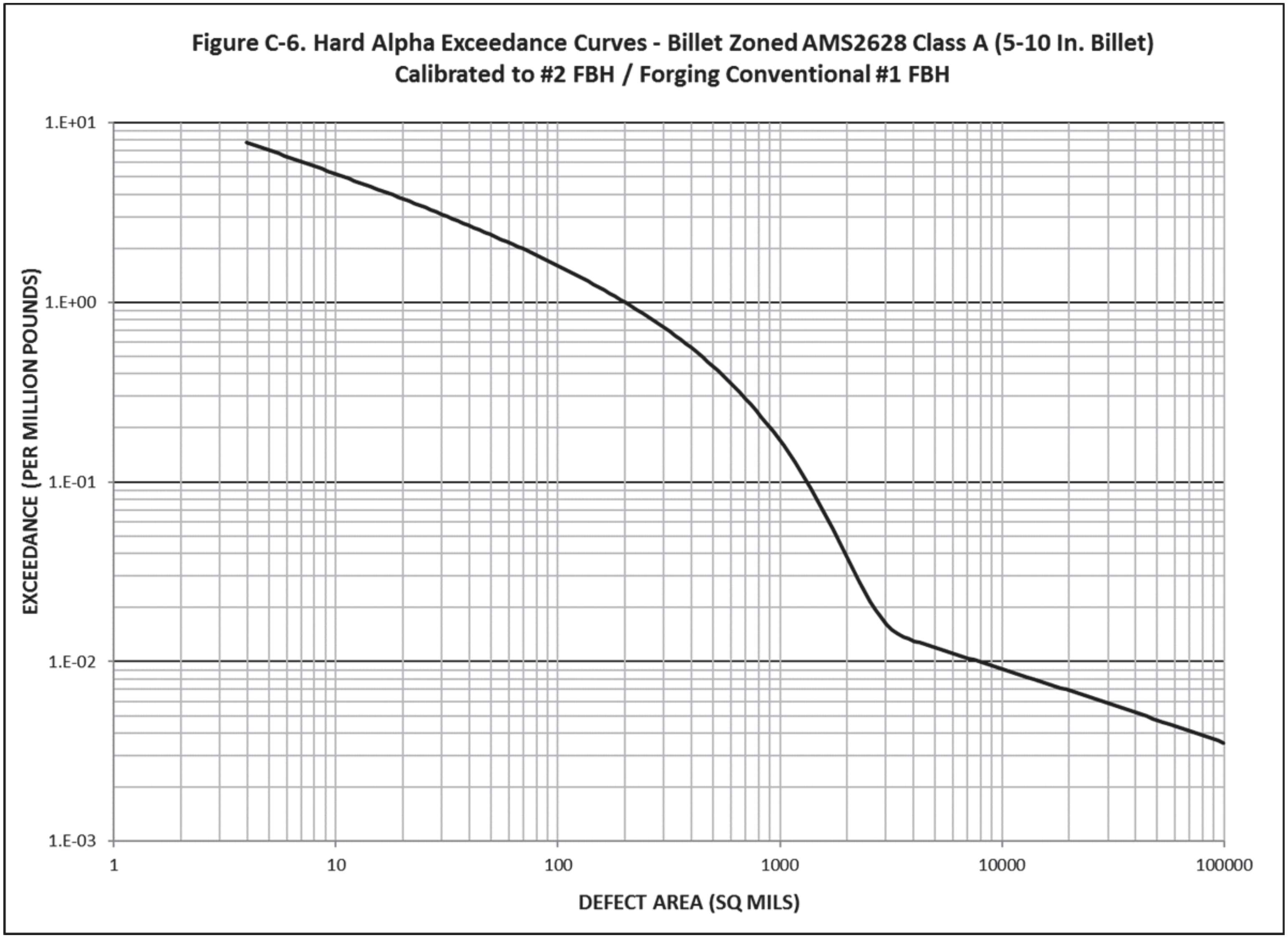

Figure C-6. Hard Alpha Exceedance Curves - Billet Zoned AMS2628 Class A (5-10 In. Billet) Calibrated to #2 FBH / Forging Conventional #1 FBH

Table C-2. Tabular Data – Anomaly Distribution Curves (Figure C-1 through Figure C-6)

Area Sq. mils	Billet zoned inspection to:					
	AMS2628 Class A (>10 In. Billet) Calibrated to #3 FBH / Forging Conventional Inspection Calibrated to #3 FBH Exceedance / Million lbs.	AMS2628 Class A (>10 In. Billet) Calibrated to #3 FBH / Forging Conventional Inspection Calibrated to #2 FBH Exceedance / Million lbs.	AMS2628 Class A (>10 In. Billet) Calibrated to #3 FBH / Forging Conventional Inspection Calibrated to #1 FBH Exceedance / Million lbs.	AMS2628 Class A (5-10 In. Billet) Calibrated to #2 FBH / Forging Conventional Inspection Calibrated to #3 FBH Exceedance / Million lbs.	AMS2628 Class A (5-10 In. Billet) Calibrated to #2 FBH / Forging Conventional Inspection Calibrated to #2 FBH Exceedance / Million lbs.	AMS2628 Class A (5-10 In. Billet) Calibrated to #2 FBH / Forging Conventional Inspection Calibrated to #1 FBH Exceedance / Million lbs.
3.9	8.11E+00	8.08E+00	7.88E+00	7.91E+00	7.89E+00	7.77E+00
4.2	7.93E+00	7.89E+00	7.69E+00	7.73E+00	7.71E+00	7.58E+00
4.4	7.75E+00	7.71E+00	7.51E+00	7.55E+00	7.53E+00	7.41E+00
4.7	7.57E+00	7.54E+00	7.34E+00	7.37E+00	7.35E+00	7.23E+00
4.9	7.40E+00	7.37E+00	7.17E+00	7.20E+00	7.18E+00	7.06E+00
5.2	7.23E+00	7.20E+00	7.00E+00	7.04E+00	7.01E+00	6.89E+00
5.5	7.07E+00	7.04E+00	6.84E+00	6.87E+00	6.85E+00	6.73E+00
5.8	6.91E+00	6.88E+00	6.68E+00	6.71E+00	6.69E+00	6.57E+00
6.2	6.75E+00	6.72E+00	6.52E+00	6.55E+00	6.53E+00	6.41E+00
6.5	6.60E+00	6.56E+00	6.36E+00	6.40E+00	6.38E+00	6.25E+00
6.9	6.45E+00	6.41E+00	6.21E+00	6.25E+00	6.23E+00	6.10E+00
7.3	6.30E+00	6.26E+00	6.07E+00	6.10E+00	6.08E+00	5.96E+00
7.7	6.15E+00	6.12E+00	5.92E+00	5.95E+00	5.93E+00	5.81E+00
8.2	6.01E+00	5.98E+00	5.78E+00	5.81E+00	5.79E+00	5.67E+00
8.7	5.87E+00	5.84E+00	5.64E+00	5.67E+00	5.65E+00	5.53E+00
9.2	5.74E+00	5.70E+00	5.50E+00	5.54E+00	5.52E+00	5.39E+00
9.7	5.60E+00	5.57E+00	5.37E+00	5.40E+00	5.38E+00	5.26E+00
10.3	5.47E+00	5.44E+00	5.24E+00	5.27E+00	5.25E+00	5.13E+00
10.9	5.34E+00	5.31E+00	5.11E+00	5.15E+00	5.12E+00	5.00E+00
11.5	5.22E+00	5.19E+00	4.99E+00	5.02E+00	5.00E+00	4.88E+00
12.2	5.10E+00	5.06E+00	4.86E+00	4.90E+00	4.88E+00	4.75E+00
12.9	4.98E+00	4.94E+00	4.74E+00	4.78E+00	4.76E+00	4.63E+00
13.6	4.86E+00	4.83E+00	4.63E+00	4.66E+00	4.64E+00	4.52E+00
14.4	4.74E+00	4.71E+00	4.51E+00	4.54E+00	4.52E+00	4.40E+00
15.2	4.63E+00	4.60E+00	4.40E+00	4.43E+00	4.41E+00	4.29E+00
16.1	4.52E+00	4.49E+00	4.29E+00	4.32E+00	4.30E+00	4.18E+00
17.0	4.41E+00	4.38E+00	4.18E+00	4.21E+00	4.19E+00	4.07E+00
18.0	4.30E+00	4.27E+00	4.07E+00	4.11E+00	4.09E+00	3.96E+00
19.1	4.20E+00	4.17E+00	3.97E+00	4.00E+00	3.98E+00	3.86E+00
20.2	4.10E+00	4.07E+00	3.87E+00	3.90E+00	3.88E+00	3.76E+00

Area Sq. mils	Billet zoned inspection to:					
	AMS2628 Class A (>10 In. Billet) Calibrated to #3 FBH / Forging Conventional Inspection Calibrated to #3 FBH Exceedance / Million lbs.	AMS2628 Class A (>10 In. Billet) Calibrated to #3 FBH / Forging Conventional Inspection Calibrated to #2 FBH Exceedance / Million lbs.	AMS2628 Class A (>10 In. Billet) Calibrated to #3 FBH / Forging Conventional Inspection Calibrated to #1 FBH Exceedance / Million lbs.	AMS2628 Class A (5-10 In. Billet) Calibrated to #2 FBH / Forging Conventional Inspection Calibrated to #3 FBH Exceedance / Million lbs.	AMS2628 Class A (5-10 In. Billet) Calibrated to #2 FBH / Forging Conventional Inspection Calibrated to #2 FBH Exceedance / Million lbs.	AMS2628 Class A (5-10 In. Billet) Calibrated to #2 FBH / Forging Conventional Inspection Calibrated to #1 FBH Exceedance / Million lbs.
21.3	4.00E+00	3.97E+00	3.77E+00	3.80E+00	3.78E+00	3.66E+00
22.6	3.90E+00	3.87E+00	3.67E+00	3.70E+00	3.68E+00	3.56E+00
23.9	3.81E+00	3.77E+00	3.57E+00	3.61E+00	3.59E+00	3.46E+00
25.3	3.71E+00	3.68E+00	3.48E+00	3.51E+00	3.49E+00	3.37E+00
26.7	3.62E+00	3.59E+00	3.39E+00	3.42E+00	3.40E+00	3.28E+00
28.3	3.53E+00	3.50E+00	3.30E+00	3.33E+00	3.31E+00	3.19E+00
29.9	3.44E+00	3.41E+00	3.21E+00	3.25E+00	3.23E+00	3.10E+00
31.7	3.36E+00	3.32E+00	3.13E+00	3.16E+00	3.14E+00	3.02E+00
33.5	3.27E+00	3.24E+00	3.04E+00	3.08E+00	3.05E+00	2.93E+00
35.4	3.19E+00	3.16E+00	2.96E+00	2.99E+00	2.97E+00	2.85E+00
37.5	3.11E+00	3.08E+00	2.88E+00	2.91E+00	2.89E+00	2.77E+00
39.7	3.03E+00	3.00E+00	2.80E+00	2.83E+00	2.81E+00	2.69E+00
42.0	2.95E+00	2.92E+00	2.72E+00	2.76E+00	2.73E+00	2.61E+00
44.4	2.88E+00	2.84E+00	2.65E+00	2.68E+00	2.66E+00	2.54E+00
46.9	2.80E+00	2.77E+00	2.57E+00	2.60E+00	2.58E+00	2.46E+00
49.7	2.73E+00	2.70E+00	2.50E+00	2.53E+00	2.51E+00	2.39E+00
52.5	2.66E+00	2.63E+00	2.43E+00	2.46E+00	2.44E+00	2.32E+00
55.6	2.59E+00	2.56E+00	2.36E+00	2.39E+00	2.37E+00	2.25E+00
58.8	2.52E+00	2.49E+00	2.29E+00	2.32E+00	2.30E+00	2.18E+00
62.2	2.45E+00	2.42E+00	2.22E+00	2.26E+00	2.24E+00	2.11E+00
65.8	2.39E+00	2.35E+00	2.16E+00	2.19E+00	2.17E+00	2.05E+00
69.6	2.32E+00	2.29E+00	2.09E+00	2.13E+00	2.11E+00	1.98E+00
73.7	2.26E+00	2.23E+00	2.03E+00	2.06E+00	2.04E+00	1.92E+00
77.9	2.20E+00	2.17E+00	1.97E+00	2.00E+00	1.98E+00	1.86E+00
82.4	2.14E+00	2.11E+00	1.91E+00	1.94E+00	1.92E+00	1.80E+00
87.2	2.08E+00	2.05E+00	1.85E+00	1.88E+00	1.86E+00	1.74E+00
92.3	2.02E+00	1.99E+00	1.79E+00	1.82E+00	1.80E+00	1.68E+00
97.6	1.96E+00	1.93E+00	1.73E+00	1.77E+00	1.75E+00	1.63E+00
103	1.91E+00	1.88E+00	1.68E+00	1.71E+00	1.69E+00	1.57E+00
109	1.85E+00	1.82E+00	1.62E+00	1.66E+00	1.64E+00	1.52E+00
116	1.80E+00	1.77E+00	1.57E+00	1.61E+00	1.58E+00	1.46E+00
122	1.75E+00	1.72E+00	1.52E+00	1.55E+00	1.53E+00	1.41E+00

Area Sq. mils	Billet zoned inspection to:					
	AMS2628 Class A (>10 In. Billet) Calibrated to #3 FBH / Forging Conventional Inspection Calibrated to #3 FBH Exceedance / Million lbs.	AMS2628 Class A (>10 In. Billet) Calibrated to #3 FBH / Forging Conventional Inspection Calibrated to #2 FBH Exceedance / Million lbs.	AMS2628 Class A (>10 In. Billet) Calibrated to #3 FBH / Forging Conventional Inspection Calibrated to #1 FBH Exceedance / Million lbs.	AMS2628 Class A (5-10 In. Billet) Calibrated to #2 FBH / Forging Conventional Inspection Calibrated to #3 FBH Exceedance / Million lbs.	AMS2628 Class A (5-10 In. Billet) Calibrated to #2 FBH / Forging Conventional Inspection Calibrated to #2 FBH Exceedance / Million lbs.	AMS2628 Class A (5-10 In. Billet) Calibrated to #2 FBH / Forging Conventional Inspection Calibrated to #1 FBH Exceedance / Million lbs.
129	1.70E+00	1.67E+00	1.47E+00	1.50E+00	1.48E+00	1.36E+00
137	1.65E+00	1.62E+00	1.42E+00	1.45E+00	1.43E+00	1.31E+00
145	1.60E+00	1.57E+00	1.37E+00	1.40E+00	1.38E+00	1.26E+00
153	1.55E+00	1.52E+00	1.32E+00	1.36E+00	1.34E+00	1.22E+00
162	1.50E+00	1.47E+00	1.28E+00	1.31E+00	1.29E+00	1.17E+00
171	1.46E+00	1.43E+00	1.23E+00	1.26E+00	1.24E+00	1.12E+00
181	1.41E+00	1.38E+00	1.19E+00	1.22E+00	1.20E+00	1.08E+00
192	1.37E+00	1.34E+00	1.14E+00	1.18E+00	1.16E+00	1.04E+00
203	1.33E+00	1.29E+00	1.10E+00	1.13E+00	1.11E+00	9.94E-01
215	1.28E+00	1.25E+00	1.06E+00	1.09E+00	1.07E+00	9.53E-01
227	1.24E+00	1.21E+00	1.02E+00	1.05E+00	1.03E+00	9.12E-01
240	1.20E+00	1.17E+00	9.76E-01	1.01E+00	9.90E-01	8.73E-01
254	1.16E+00	1.13E+00	9.37E-01	9.70E-01	9.51E-01	8.34E-01
269	1.12E+00	1.09E+00	8.99E-01	9.32E-01	9.12E-01	7.97E-01
284	1.09E+00	1.05E+00	8.62E-01	8.95E-01	8.75E-01	7.60E-01
301	1.05E+00	1.02E+00	8.26E-01	8.58E-01	8.39E-01	7.24E-01
318	1.01E+00	9.80E-01	7.90E-01	8.23E-01	8.03E-01	6.89E-01
337	9.76E-01	9.45E-01	7.55E-01	7.88E-01	7.68E-01	6.55E-01
356	9.41E-01	9.10E-01	7.21E-01	7.54E-01	7.34E-01	6.22E-01
377	9.07E-01	8.76E-01	6.88E-01	7.20E-01	7.01E-01	5.90E-01
399	8.74E-01	8.43E-01	6.56E-01	6.88E-01	6.69E-01	5.58E-01
422	8.41E-01	8.10E-01	6.24E-01	6.56E-01	6.37E-01	5.28E-01
446	8.09E-01	7.78E-01	5.94E-01	6.26E-01	6.06E-01	4.98E-01
472	7.78E-01	7.47E-01	5.64E-01	5.96E-01	5.76E-01	4.69E-01
499	7.48E-01	7.17E-01	5.35E-01	5.66E-01	5.47E-01	4.41E-01
528	7.18E-01	6.87E-01	5.07E-01	5.38E-01	5.19E-01	4.14E-01
559	6.89E-01	6.58E-01	4.79E-01	5.10E-01	4.91E-01	3.88E-01
591	6.60E-01	6.30E-01	4.52E-01	4.83E-01	4.64E-01	3.63E-01
626	6.33E-01	6.02E-01	4.26E-01	4.57E-01	4.38E-01	3.38E-01
662	6.05E-01	5.75E-01	4.01E-01	4.32E-01	4.13E-01	3.15E-01
700	5.79E-01	5.49E-01	3.77E-01	4.07E-01	3.89E-01	2.92E-01
741	5.53E-01	5.23E-01	3.53E-01	3.83E-01	3.65E-01	2.70E-01

Area Sq. mils	Billet zoned inspection to:					
	AMS2628 Class A (>10 In. Billet) Calibrated to #3 FBH / Forging Conventional Inspection Calibrated to #3 FBH Exceedance / Million lbs.	AMS2628 Class A (>10 In. Billet) Calibrated to #3 FBH / Forging Conventional Inspection Calibrated to #2 FBH Exceedance / Million lbs.	AMS2628 Class A (>10 In. Billet) Calibrated to #3 FBH / Forging Conventional Inspection Calibrated to #1 FBH Exceedance / Million lbs.	AMS2628 Class A (5-10 In. Billet) Calibrated to #2 FBH / Forging Conventional Inspection Calibrated to #3 FBH Exceedance / Million lbs.	AMS2628 Class A (5-10 In. Billet) Calibrated to #2 FBH / Forging Conventional Inspection Calibrated to #2 FBH Exceedance / Million lbs.	AMS2628 Class A (5-10 In. Billet) Calibrated to #2 FBH / Forging Conventional Inspection Calibrated to #1 FBH Exceedance / Million lbs.
784	5.28E-01	4.98E-01	3.31E-01	3.60E-01	3.42E-01	2.49E-01
829	5.03E-01	4.74E-01	3.09E-01	3.38E-01	3.20E-01	2.29E-01
877	4.79E-01	4.50E-01	2.87E-01	3.16E-01	2.98E-01	2.10E-01
928	4.56E-01	4.27E-01	2.67E-01	2.95E-01	2.78E-01	1.92E-01
981	4.33E-01	4.04E-01	2.47E-01	2.75E-01	2.58E-01	1.75E-01
1038	4.11E-01	3.82E-01	2.29E-01	2.56E-01	2.39E-01	1.59E-01
1098	3.89E-01	3.61E-01	2.11E-01	2.38E-01	2.21E-01	1.44E-01
1162	3.68E-01	3.40E-01	1.94E-01	2.20E-01	2.03E-01	1.29E-01
1229	3.48E-01	3.20E-01	1.77E-01	2.03E-01	1.87E-01	1.16E-01
1300	3.28E-01	3.01E-01	1.62E-01	1.87E-01	1.71E-01	1.03E-01
1376	3.09E-01	2.82E-01	1.47E-01	1.72E-01	1.56E-01	9.19E-02
1455	2.90E-01	2.64E-01	1.34E-01	1.58E-01	1.42E-01	8.13E-02
1540	2.73E-01	2.46E-01	1.21E-01	1.44E-01	1.29E-01	7.16E-02
1629	2.55E-01	2.29E-01	1.09E-01	1.32E-01	1.17E-01	6.29E-02
1723	2.38E-01	2.13E-01	9.75E-02	1.20E-01	1.05E-01	5.50E-02
1823	2.22E-01	1.97E-01	8.72E-02	1.09E-01	9.47E-02	4.80E-02
1929	2.07E-01	1.82E-01	7.77E-02	9.87E-02	8.49E-02	4.18E-02
2040	1.92E-01	1.68E-01	6.90E-02	8.94E-02	7.59E-02	3.64E-02
2158	1.77E-01	1.54E-01	6.12E-02	8.09E-02	6.77E-02	3.17E-02
2283	1.64E-01	1.41E-01	5.41E-02	7.31E-02	6.04E-02	2.77E-02
2416	1.51E-01	1.29E-01	4.79E-02	6.62E-02	5.38E-02	2.44E-02
2556	1.38E-01	1.17E-01	4.23E-02	6.00E-02	4.79E-02	2.16E-02
2704	1.27E-01	1.06E-01	3.75E-02	5.46E-02	4.28E-02	1.94E-02
2860	1.16E-01	9.56E-02	3.33E-02	4.98E-02	3.83E-02	1.76E-02
3026	1.05E-01	8.59E-02	2.98E-02	4.57E-02	3.45E-02	1.62E-02
3201	9.52E-02	7.69E-02	2.68E-02	4.22E-02	3.13E-02	1.51E-02
3386	8.61E-02	6.85E-02	2.44E-02	3.92E-02	2.86E-02	1.43E-02
3583	7.76E-02	6.08E-02	2.24E-02	3.68E-02	2.64E-02	1.38E-02
3790	6.97E-02	5.38E-02	2.07E-02	3.48E-02	2.46E-02	1.33E-02
4009	6.25E-02	4.74E-02	1.92E-02	3.32E-02	2.32E-02	1.30E-02
4242	5.59E-02	4.16E-02	1.79E-02	3.19E-02	2.20E-02	1.27E-02
4487	4.99E-02	3.65E-02	1.66E-02	3.06E-02	2.09E-02	1.25E-02

Area Sq. mils	Billet zoned inspection to: AMS2628 Class A (>10 In. Billet) Calibrated to #3 FBH / Forging Conventional Inspection Calibrated to #3 FBH Exceedance / Million lbs.	AMS2628 Class A (>10 In. Billet) Calibrated to #3 FBH / Forging Conventional Inspection Calibrated to #2 FBH Exceedance / Million lbs.	AMS2628 Class A (>10 In. Billet) Calibrated to #3 FBH / Forging Conventional Inspection Calibrated to #1 FBH Exceedance / Million lbs.	AMS2628 Class A (5-10 In. Billet) Calibrated to #2 FBH / Forging Conventional Inspection Calibrated to #3 FBH Exceedance / Million lbs.	AMS2628 Class A (5-10 In. Billet) Calibrated to #2 FBH / Forging Conventional Inspection Calibrated to #2 FBH Exceedance / Million lbs.	AMS2628 Class A (5-10 In. Billet) Calibrated to #2 FBH / Forging Conventional Inspection Calibrated to #1 FBH Exceedance / Million lbs.
4747	4.46E-02	3.19E-02	1.55E-02	2.93E-02	1.98E-02	1.22E-02
5022	3.98E-02	2.79E-02	1.45E-02	2.81E-02	1.88E-02	1.19E-02
5313	3.56E-02	2.45E-02	1.36E-02	2.68E-02	1.78E-02	1.17E-02
5621	3.19E-02	2.16E-02	1.28E-02	2.57E-02	1.68E-02	1.14E-02
5946	2.88E-02	1.91E-02	1.21E-02	2.45E-02	1.59E-02	1.12E-02
6290	2.61E-02	1.70E-02	1.15E-02	2.34E-02	1.51E-02	1.09E-02
6655	2.38E-02	1.53E-02	1.10E-02	2.23E-02	1.43E-02	1.07E-02
7040	2.20E-02	1.40E-02	1.06E-02	2.13E-02	1.35E-02	1.05E-02
7448	2.05E-02	1.29E-02	1.03E-02	2.02E-02	1.28E-02	1.02E-02
7879	1.93E-02	1.21E-02	1.00E-02	1.93E-02	1.21E-02	1.00E-02
8335	1.83E-02	1.15E-02	9.78E-03	1.83E-02	1.15E-02	9.78E-03
8818	1.74E-02	1.09E-02	9.57E-03	1.74E-02	1.09E-02	9.57E-03
9329	1.65E-02	1.04E-02	9.36E-03	1.65E-02	1.04E-02	9.36E-03
9869	1.57E-02	9.96E-03	9.15E-03	1.57E-02	9.96E-03	9.15E-03
10440	1.48E-02	9.53E-03	8.95E-03	1.48E-02	9.53E-03	8.95E-03
11045	1.40E-02	9.14E-03	8.75E-03	1.40E-02	9.14E-03	8.75E-03
11685	1.33E-02	8.80E-03	8.56E-03	1.33E-02	8.80E-03	8.56E-03
12361	1.26E-02	8.50E-03	8.37E-03	1.26E-02	8.50E-03	8.37E-03
13077	1.19E-02	8.24E-03	8.18E-03	1.19E-02	8.24E-03	8.18E-03
13834	1.13E-02	8.01E-03	8.00E-03	1.13E-02	8.01E-03	8.00E-03
14636	1.06E-02	7.82E-03	7.82E-03	1.06E-02	7.82E-03	7.82E-03
15483	1.01E-02	7.65E-03	7.65E-03	1.01E-02	7.65E-03	7.65E-03
16380	9.52E-03	7.48E-03	7.48E-03	9.52E-03	7.48E-03	7.48E-03
17328	9.02E-03	7.31E-03	7.31E-03	9.02E-03	7.31E-03	7.31E-03
18332	8.55E-03	7.15E-03	7.15E-03	8.55E-03	7.15E-03	7.15E-03
19393	8.11E-03	6.99E-03	6.99E-03	8.11E-03	6.99E-03	6.99E-03
20516	7.71E-03	6.83E-03	6.83E-03	7.71E-03	6.83E-03	6.83E-03
21704	7.35E-03	6.68E-03	6.68E-03	7.35E-03	6.68E-03	6.68E-03
22961	7.02E-03	6.53E-03	6.53E-03	7.02E-03	6.53E-03	6.53E-03
24291	6.72E-03	6.38E-03	6.38E-03	6.72E-03	6.38E-03	6.38E-03
25698	6.46E-03	6.24E-03	6.24E-03	6.46E-03	6.24E-03	6.24E-03
27186	6.22E-03	6.09E-03	6.09E-03	6.22E-03	6.09E-03	6.09E-03

Area Sq. mils	Billet zoned inspection to:					
	AMS2628 Class A (>10 In. Billet) Calibrated to #3 FBH / Forging Conventional Inspection Calibrated to #3 FBH Exceedance / Million lbs.	AMS2628 Class A (>10 In. Billet) Calibrated to #3 FBH / Forging Conventional Inspection Calibrated to #2 FBH Exceedance / Million lbs.	AMS2628 Class A (>10 In. Billet) Calibrated to #3 FBH / Forging Conventional Inspection Calibrated to #1 FBH Exceedance / Million lbs.	AMS2628 Class A (5-10 In. Billet) Calibrated to #2 FBH / Forging Conventional Inspection Calibrated to #3 FBH Exceedance / Million lbs.	AMS2628 Class A (5-10 In. Billet) Calibrated to #2 FBH / Forging Conventional Inspection Calibrated to #2 FBH Exceedance / Million lbs.	AMS2628 Class A (5-10 In. Billet) Calibrated to #2 FBH / Forging Conventional Inspection Calibrated to #1 FBH Exceedance / Million lbs.
28760	6.02E-03	5.96E-03	5.96E-03	6.02E-03	5.96E-03	5.96E-03
30426	5.84E-03	5.82E-03	5.82E-03	5.84E-03	5.82E-03	5.82E-03
32188	5.69E-03	5.69E-03	5.69E-03	5.69E-03	5.69E-03	5.69E-03
34052	5.56E-03	5.56E-03	5.56E-03	5.56E-03	5.56E-03	5.56E-03
36024	5.43E-03	5.43E-03	5.43E-03	5.43E-03	5.43E-03	5.43E-03
38110	5.30E-03	5.30E-03	5.30E-03	5.30E-03	5.30E-03	5.30E-03
40317	5.18E-03	5.18E-03	5.18E-03	5.18E-03	5.18E-03	5.18E-03
42652	5.06E-03	5.06E-03	5.06E-03	5.06E-03	5.06E-03	5.06E-03
45121	4.95E-03	4.95E-03	4.95E-03	4.95E-03	4.95E-03	4.95E-03
47734	4.83E-03	4.83E-03	4.83E-03	4.83E-03	4.83E-03	4.83E-03
50499	4.72E-03	4.72E-03	4.72E-03	4.72E-03	4.72E-03	4.72E-03
53423	4.61E-03	4.61E-03	4.61E-03	4.61E-03	4.61E-03	4.61E-03
56517	4.50E-03	4.50E-03	4.50E-03	4.50E-03	4.50E-03	4.50E-03
59790	4.39E-03	4.39E-03	4.39E-03	4.39E-03	4.39E-03	4.39E-03
63252	4.29E-03	4.29E-03	4.29E-03	4.29E-03	4.29E-03	4.29E-03
66915	4.19E-03	4.19E-03	4.19E-03	4.19E-03	4.19E-03	4.19E-03
70790	4.09E-03	4.09E-03	4.09E-03	4.09E-03	4.09E-03	4.09E-03
74890	3.99E-03	3.99E-03	3.99E-03	3.99E-03	3.99E-03	3.99E-03
79227	3.90E-03	3.90E-03	3.90E-03	3.90E-03	3.90E-03	3.90E-03
83815	3.80E-03	3.80E-03	3.80E-03	3.80E-03	3.80E-03	3.80E-03
88668	3.71E-03	3.71E-03	3.71E-03	3.71E-03	3.71E-03	3.71E-03
93803	3.62E-03	3.62E-03	3.62E-03	3.62E-03	3.62E-03	3.62E-03
99235	3.54E-03	3.54E-03	3.54E-03	3.54E-03	3.54E-03	3.54E-03

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APPENDIX D. DEFAULT PROBABILITY OF DETECTION APPLICABILITY

D.1 Use of Accepted Estimates of the Probability of Detection.

D.1.1 This appendix defines conditions relevant to the use of accepted estimates of the POD. These estimates are for specific types of anomalies and specific nondestructive evaluations or inspection techniques. Applicants may consider these estimates as default values when applied under appropriately similar conditions. The conditions defined in this appendix do not necessarily guarantee the validity of these POD values. For example, if inspection parameters such as penetrant concentration or temperature are inadequately controlled, the penetrant capability shown in the accompanying graph will not be reached even if the correct penetrant is selected. The FAA recommends using a written plan for controlling and monitoring inspection processes, as described in paragraph D.3.

D.1.2 If the conditions described for each inspection are not satisfied, the resulting inspection capability and reliability will be reduced. Accordingly, the use of default POD values would then be inappropriate and would result in an overly optimistic damage tolerance assessment.

D.2 Demonstrations of Inspection Capability.

For eddy current inspections (ECIs) and ultrasonic inspections, alternative default POD curves are given. Choose the appropriate POD curve based on demonstration that the stated calibration and reject signal levels are attainable on the component being inspected. Ensure that noise and geometrical features do not prevent appropriate POD selection. The demonstration conditions should be appropriate to the properties of the part inspected that may affect the inspection ability, such as surface conditions, depth to be inspected, proximity to edges, etc. No other demonstration of these default capabilities is necessary, as long as the requirements for the specific inspection technique are satisfied (see paragraphs D.3, D.4, D.5, and D.6).

D.3 Restrictions and Applicability.

D.3.1 <u>Inspection Process Control and Performance.</u>

The inspection process must be thoroughly controlled and performed in accordance with acceptable procedures, as defined by the engine standard practices manual. The inspection process must also be consistent with good industrial inspection practices, like those defined by military or industry standards.

D.3.2 <u>Inspection Process Parameters, Plans, and Fixtures.</u>

Written procedures should govern pertinent inspection process parameters, such as coverage, probe indexing, and scanning speeds. Inspection plans and applicable inspection fixtures should be designed to minimize human and other sources of variability.

D.3.3 Inspector Qualifications.

Inspectors must be qualified and trained according to ASNT-TC-1A, ATA-105, or equivalent, and have adequate training in the specific inspection method.

D.3.4 Data Limitations.

The default POD data presented in this AC apply only to titanium alloys used for engine disks and inspected material. Geometrical conditions, such as radii and edges, can create areas where inspections cannot be accomplished. Limitations relative to the depth of penetration and near-surface resolution also exist. Conditions under which the default POD data were acquired are outlined in paragraphs D.4, D.5, and D.6.

Note: Manufacturers should seek advice about the equivalence of alternative conditions from those with expertise in nondestructive evaluation (NDE). Areas of high compressive, residual stress can have negative effects on the capability of various NDE techniques, most notably penetrant inspection.

D.3.5 Applicability of Default POD Data.

Applicability of the default POD data is limited to components exhibiting no abnormal surface conditions, and have been properly cleaned per each shop manual's requirements. No other special pre-inspection cleaning or polishing is required.

D.4 Restrictions and Applicability: Eddy Current Inspection (ECI).

D.4.1 Overview of ECI.

ECI is an inspection technique suitable for detecting surface or near-surface anomalies. For purposes of this AC, it is primarily intended for application to engine-run components. The default POD data were acquired under the following conditions:

1. Probes containing absolute coils with inspection frequency in the 2-6 MHz range.
2. Probe fixtures capable of following surface contours on the component being inspected with adequate control of attitude, lift-off, and scan indexing. The scan direction was parallel with any uniform feature changes.
3. Provision was made for automatic recording of inspection process signals or automated alarm, or both, when the inspection threshold was exceeded.

D.4.2 Selection of Appropriate POD Curve.

The default POD data apply to surface-connected, low-cycle, fatigue cracks. Note the following criteria:

1. Cracks are assumed to have a 2:1 aspect ratio (length:depth).
2. Crack sizes are expressed in terms of the length at the surface.
3. Cracks must not be obscured by oxide, contaminants, etc.
4. Inspected surfaces should be flat or only moderately curved.

Choosing the appropriate POD curve from those provided must be based on component demonstration of the attainable inspection sensitivity (see paragraph D.2).

D.5 Restrictions and Applicability: Penetrant Inspection.

D.5.1 Overview of Penetrant Inspection.

Penetrant inspection is an inspection technique suitable for detecting anomalies that are open to the inspected surface. For the purposes of this AC, it is primarily intended for application to engine-run components. The default POD data were acquired under the following conditions:

1. Fluorescent penetrants qualified as level 4 by SAE AMS2644, or equivalent, and used with dry powder developer, as a minimum.
2. Application of penetrant and developer was automated for each standard practice (see ASTM E 1417 and SAE AMS2647).
3. Manipulation of the part was possible to present to the inspector an unrestricted view of the surface to be inspected.

D.5.2 Selection of Appropriate POD Curve.

The default POD data apply to surface-connected, low-cycle, fatigue cracks. Note the following:

1. Cracks are assumed to have a 2:1 aspect ratio (length:depth).
2. Crack sizes are expressed in terms of the length at the surface.
3. Cracks must not be hidden by oxide, contaminants, etc.
4. Inspected surfaces should be readily visible.

Choosing the appropriate POD curve from those provided must be based on whether focused or full-field inspection conditions apply, see figure E-1 and appendix F.

D.6 Restrictions and Applicability: Ultrasonic Inspection.

D.6.1 Overview of Ultrasonic Inspection.

Ultrasonic inspection is an inspection technique suitable for detecting subsurface anomalies. For purposes of this AC, it is intended for application to billet and engine-run components. The default POD data were acquired under the following conditions:

1. 5 MHz inspection frequency.
2. Water immersion, inspection conditions.
3. Normal incidence, longitudinal, wave mode for inspection of billet using single 0.5-inch x 1.0-inch cylindrically focused transducer.
4. Shear wave mode for inspection of finish-machined components using 0.75-inch diameter, spherically focused transducer.

5. Transducer (search unit) fixture was capable of following surface contours of the component being inspected with adequate control of attitude and scan indexing.
6. Provision was made for automatic recording of the inspection process signals or automated alarm, or both, when the inspection threshold was exceeded.

D.6.2 Selection of Appropriate POD Curve.

For ultrasonic inspection, the default POD data apply to mixtures of anomalies typical of those that may be found in billet or engine-run material, as appropriate. These anomalies include, for example:

- Hard alpha associated voids or cracks.
- Strain induced porosity.

Note the following observations:

1. Other anomaly types may occur, such as high-density inclusions, but these are not included in the current analysis.
2. Anomaly sizes are expressed in terms of maximum cross-sectional area perpendicular to the sound beam, including associated diffusion zones where appropriate.
3. Inspected finish-machined surfaces should be flat or only moderately curved.
4. Billets should be circular-cylindrical and in customary pre-inspection conditions (turned, ground, or peeled).

Choosing the appropriate POD curve from those provided must be based on component demonstration of the attainable inspection sensitivity (see paragraph D.2). Making provisions to maintain this sensitivity at all depths and effective distance amplitude compensation is required.

APPENDIX E. DEFAULT POD CURVES

E.1 Default POD Curves.

The following default POD curves apply to this AC.

- Figure E-1. POD for Fluorescent Penetrant Inspection of Finish-Machined Surface.
- Figure E-2. Mean (50 Percent Confidence) POD for Ultrasonic Inspection of Field Components, #1 FBH (1/64 In. Diameter) Calibration.
- Figure E-3. Mean (50 Percent Confidence) POD for Ultrasonic Inspection of Field Components, #2 FBH (2/64 In. Diameter) Calibration.
- Figure E-4. Mean (50 Percent Confidence) POD for Ultrasonic Inspection of Field Components, #3 FBH (3/64 In. Diameter) Calibration.
- Figure E-5. Mean (50 Percent Confidence) POD for Eddy Current Inspection of Finish Machined Components.

E.2 Reserved.

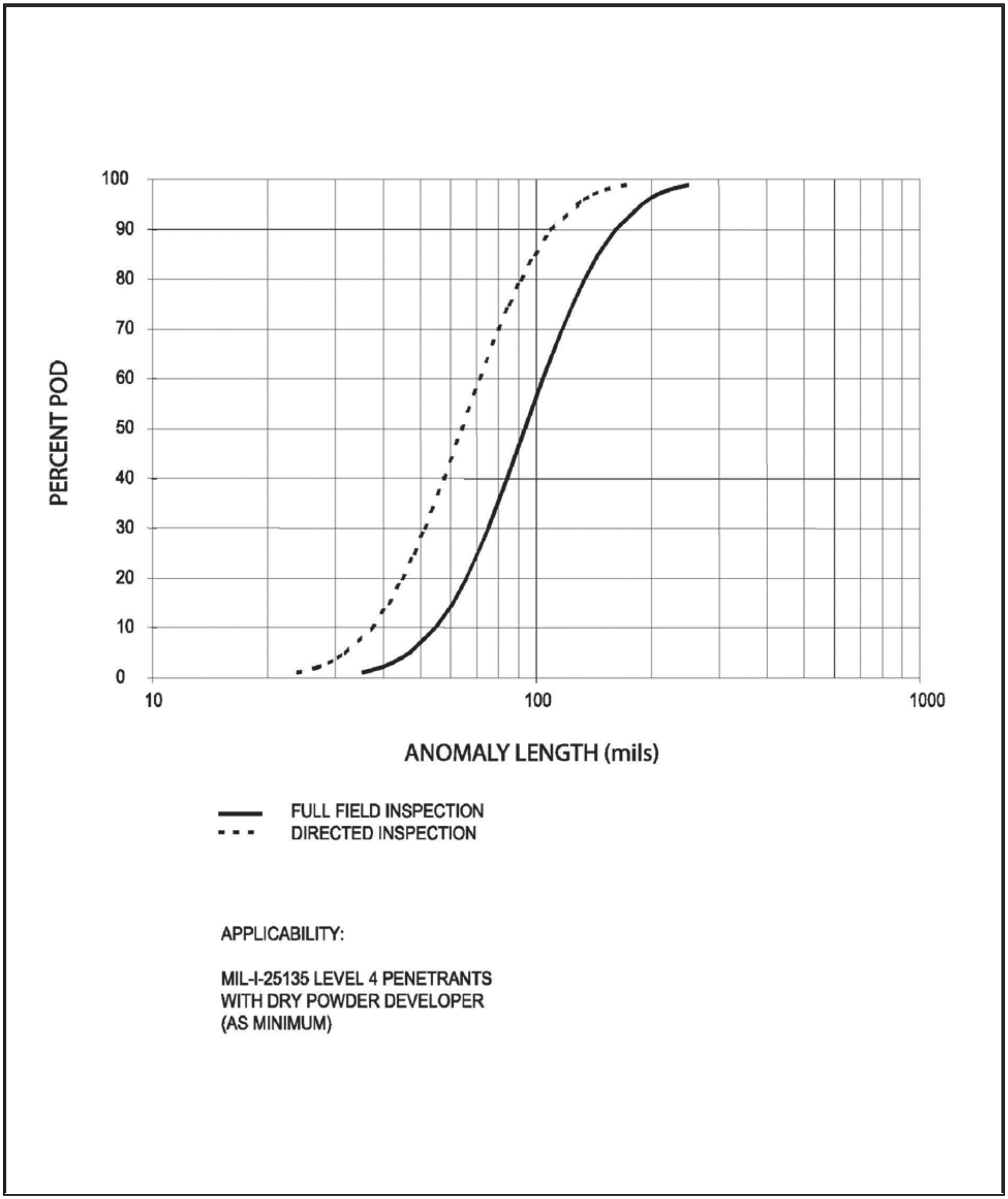
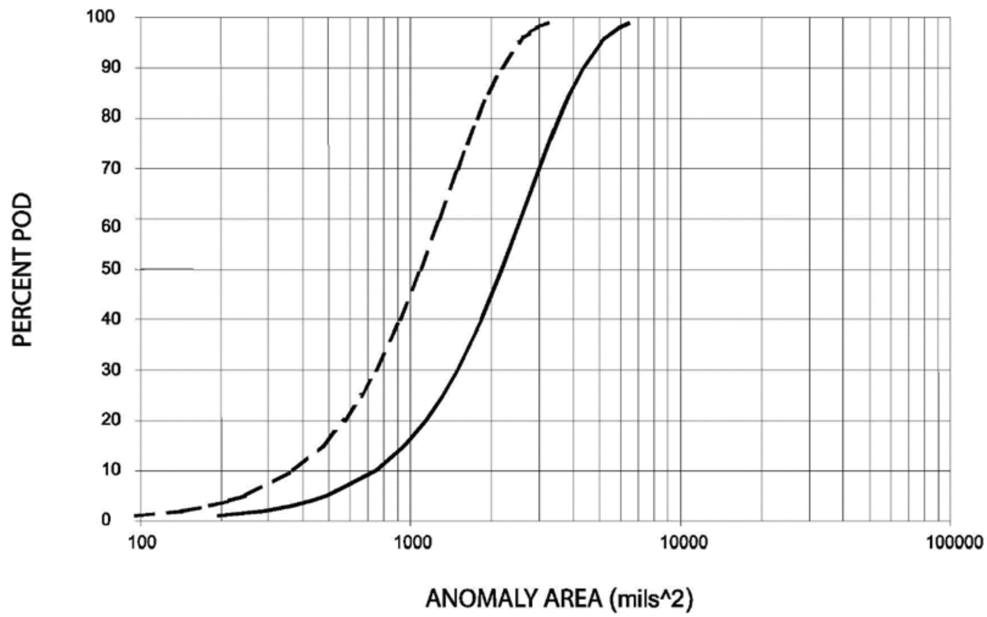


Figure E-1. POD for Fluorescent Penetrant Inspection of Finish-Machined Surfaces



BILLET: DATA TAKEN WITH 0.5 x 1 IN. CYLINDRICALLY FOCUSED TRANSDUCER

FINISH-MACHINED PART: DATA TAKEN WITH 0.75 IN. DIAMETER SPHERICALLY FOCUSED TRANSDUCER

——— REJECT INDICATIONS EQUAL TO OR GREATER THAN THOSE FROM A 1/64 IN. DIA FBH

— — REJECT INDICATIONS EQUAL TO OR GREATER THAN ONE HALF THOSE FROM A 1/64 IN. DIA FBH

APPLICABILITY:

HARD-ALPHA ASSOCIATED INCLUSIONS / CRACKS / VOIDS (INCLUDES DIFFUSION ZONES).

BILLET: 5 Mhz LONGITUDINAL (COMPRESSIONAL) WAVE INSPECTION CIRCULAR-CYLINDRICAL BILLET.

FINISH-MACHINED: 5 Mhz SHEAR (TRANSVERSE) WAVE INSPECTION APPLICABLE ONLY IF THE INDICATED SENSITIVITY IS ATTAINABLE.

Figure E-2. Mean (50 Percent Confidence) POD for Ultrasonic Inspection of Field Components, #1 FBH (1/64 In. Diameter) Calibration

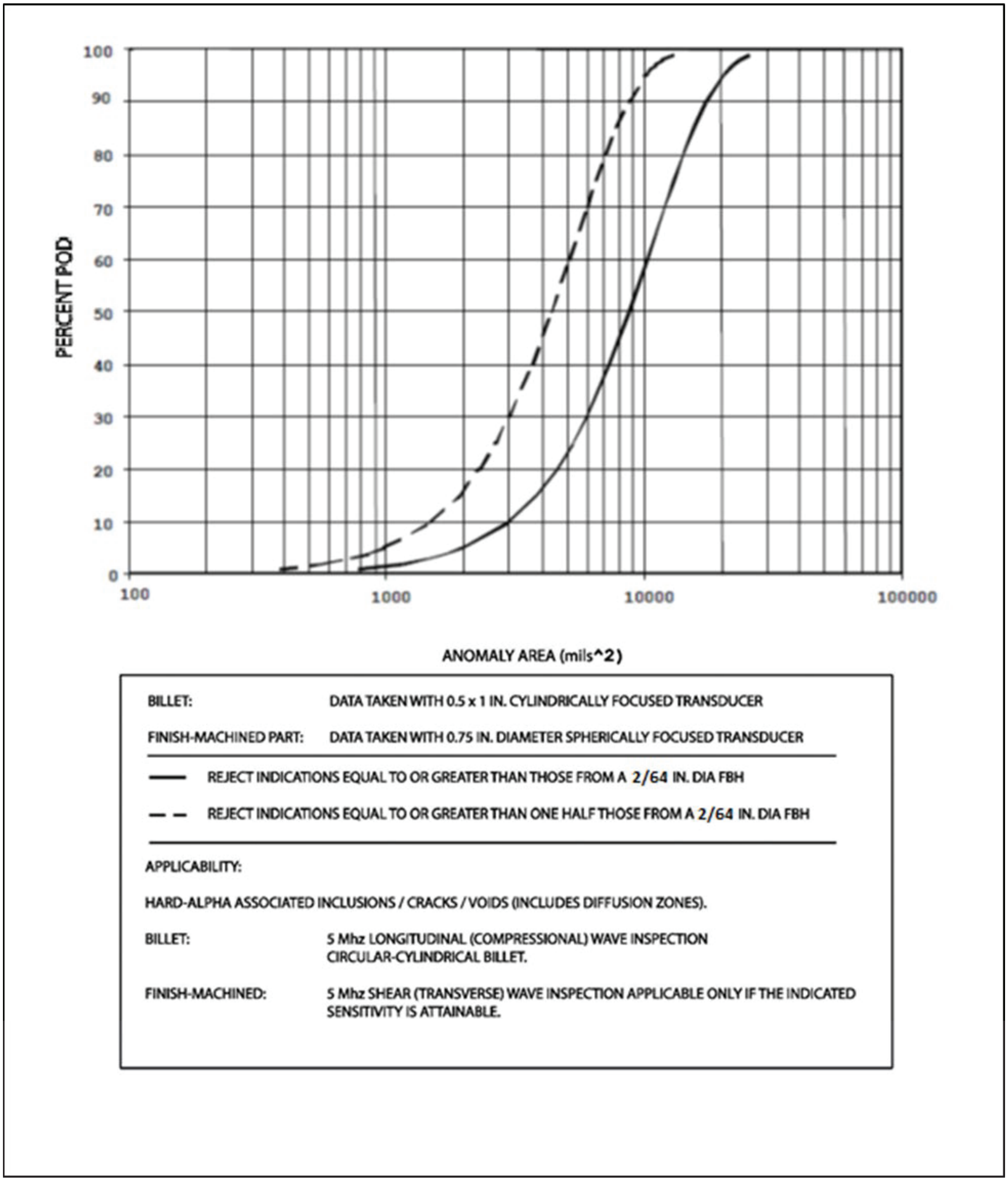


Figure E-3. Mean (50 Percent Confidence) POD for Ultrasonic Inspection of Field Components, #2 FBH (2/64 In. Diameter) Calibration

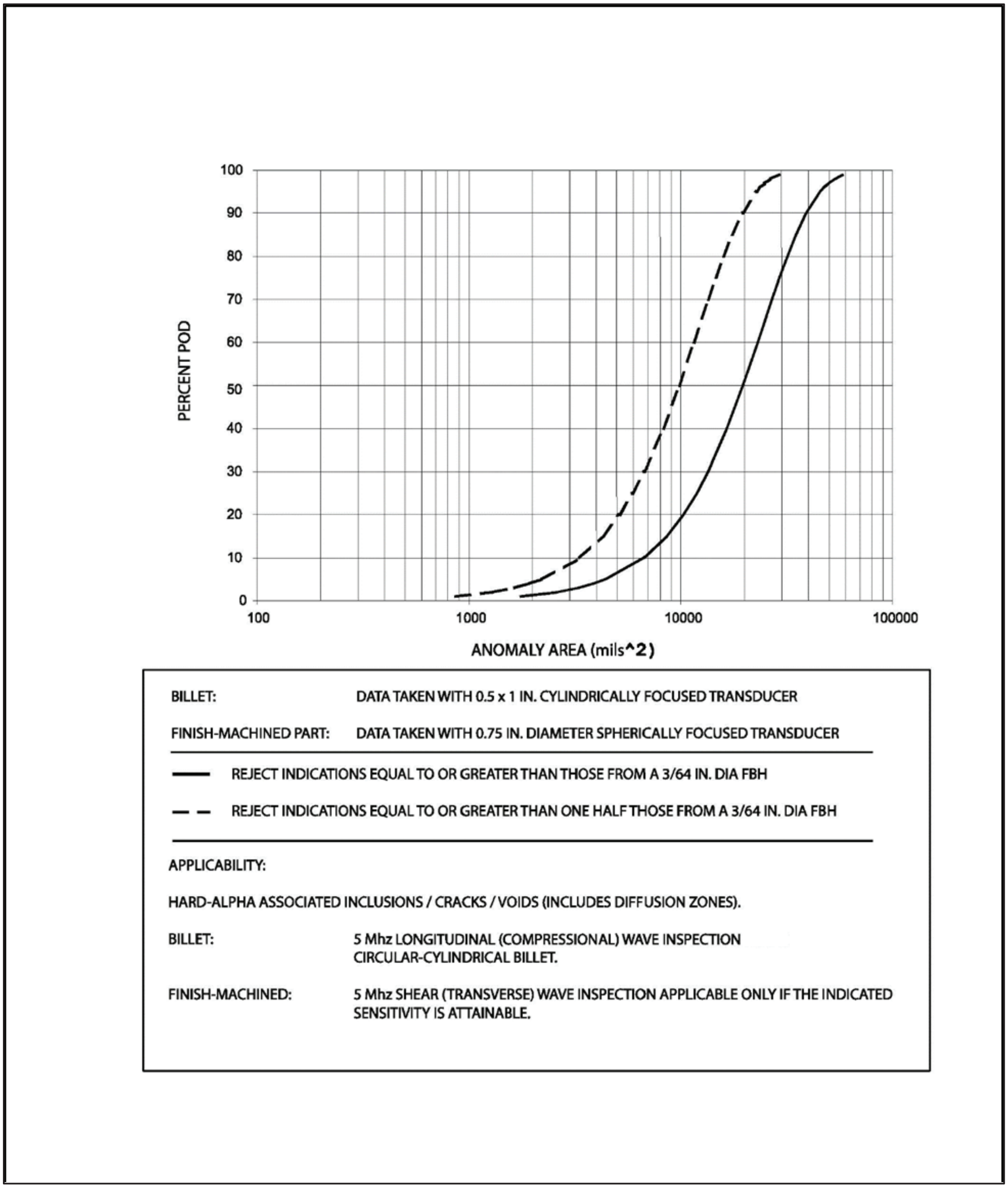


Figure E-4. Mean (50 Percent Confidence) POD for Ultrasonic Inspection of Field Components, #3 FBH (3/64 In. Diameter) Calibration

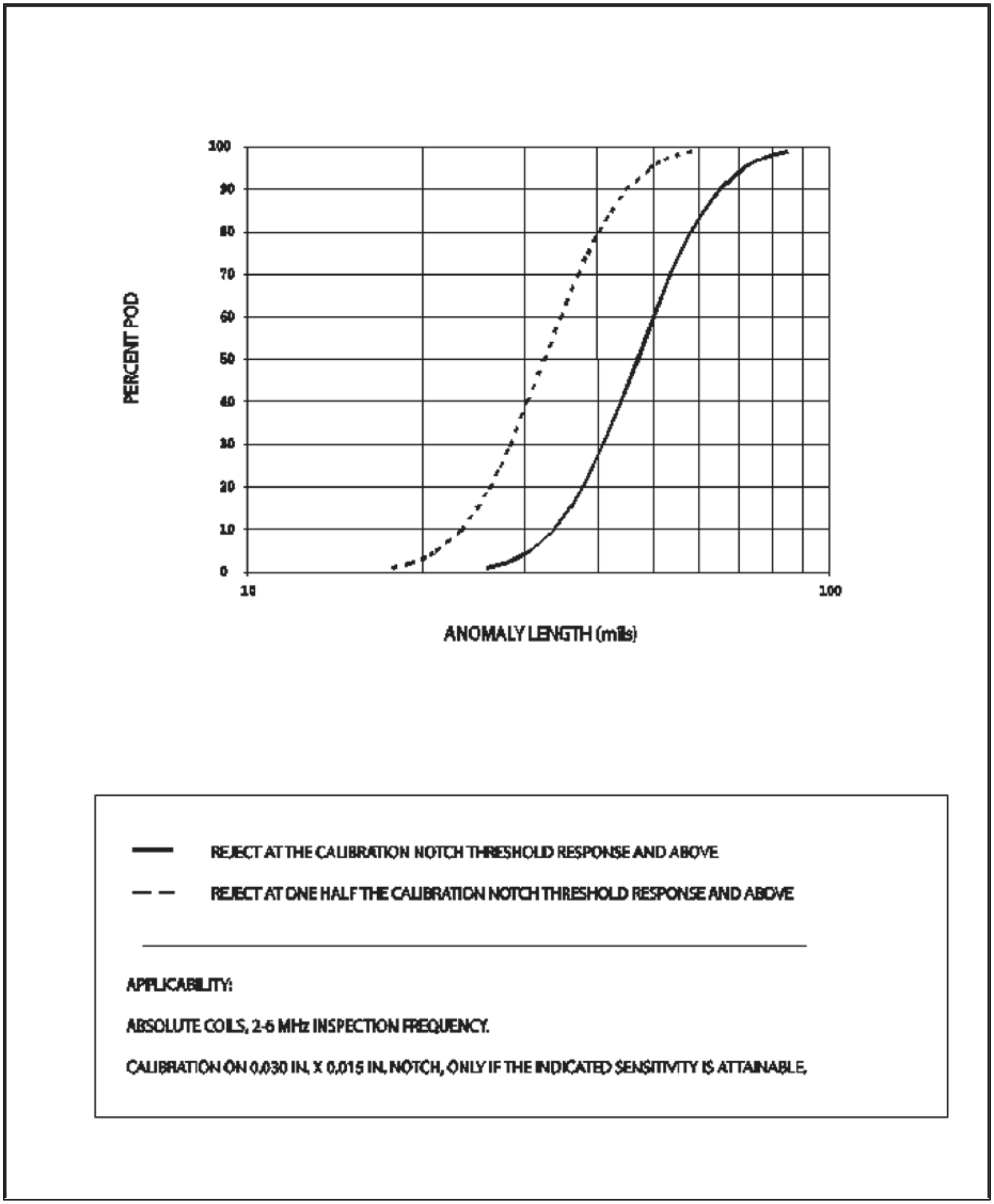


Figure E-5. Mean (50 Percent Confidence) POD for Eddy Current Inspection of Finish Machined Components

APPENDIX F. DEFINITIONS

These definitions are for the purpose of this AC only.

- **Component Event Rate**. The number of events for a given titanium rotor component stage for each flight cycle, calculated over the projected life of the component.
- **Damage Tolerance**. An element of the life management process that recognizes the potential existence of component imperfections. The potential existence of component imperfections is the result of inherent material structure, material processing, component design, manufacturing, or usage. Damage tolerance addresses this situation through the incorporation of fracture resistant design, fracture-mechanics, process control, or nondestructive inspection.
- **Default Probability of Detection (POD) Values**. Values representing mean probabilities of detecting anomalies of various types and sizes under specified inspection conditions consistent with good industry practice.
- **Design Target Risk (DTR) Value**. The standard against which probabilistic assessment results, stated in terms of component event rates and engine-level event rates, as defined above, are compared.
- **Directed Inspection**. Inspections where specialized processing instructions have been provided and the inspector has been instructed to pay attention to specific critical features.
- **Event** A rotor structural part separation, failure, or burst with no regard to the consequence.
- **Full-Field Inspection**. The general inspection of a component without special attention to any specific features.
- **Hard Alpha**. An interstitially stabilized alpha phase region of substantially higher hardness than the surrounding material. This comes from very high local nitrogen, oxygen, or carbon concentrations that increase the beta transus and produce the high hardness, often brittle, alpha phase. A high interstitial defect is also commonly called a Type I defect, low-density inclusion (LDI), or a hard alpha often associated with voids and cracks.
- **Inspected Material**. The portion of the total volume of a component that is actually inspected under the described conditions. Inspected material does not guarantee anomaly free material.
- **Inspection Opportunity**. An occasion when an engine is disassembled to at least the modular level and the hardware in question is accessible for inspection, whether or not the hardware has been reduced to the piece part level.

- **Maintenance Exposure Interval**. Distribution of shop visits (in-flight cycles), new or last overhaul, since an engine, module, or component is exposed to as a function of normal maintenance activity.

- **Mean POD**. The 50 percent confidence level POD versus anomaly size curve.

- **Module**. A combination of assemblies, subassemblies, and parts contained in one package, or arranged to be installed in one maintenance action.

- **Probabilistic (Relative Risk) Assessment**. A fracture-mechanics based simulation procedure that uses statistical techniques to mathematically model and quantitatively combine the influence of two or more variables to estimate a most likely outcome or range of outcomes for a product. Since not all variables may be considered or may not be capable of being accurately quantified, the numerical predictions are used on a comparative basis to evaluate various options having the same level of inputs. Results from these analyses are typically used for design optimization to meet a predefined target, or to conduct parametric studies. This type of procedure is distinctly different from an absolute risk analysis, which attempts to consider all significant variables and is used to quantify, on an absolute basis, the predicted number of future events having safety and reliability ramifications.

- **Probability of Detection (POD)**. A quantitative statistical measure of detecting a particular type of anomaly over a range of sizes using a specific nondestructive inspection technique under specific conditions. Typically, the mean POD curve is used.

- **Safe-Life**. An LCF-based process where components are designed and substantiated to have a specified service life, stated in operating cycles, operating hours, or both. Continued safe operation up to the stated life-limit is not contingent on each unit of a given design receiving interim inspections. When a component reaches its published life-limit, it is retired from service.

- **Soft-Time Inspection Interval**. The number of flight cycles since new, or the most recent inspection, after which a rotor or engine part in an available module must receive the inspection specified in the AL section of the ICA.

- **Stage**. The rotor structure that supports and is attached to a single aerodynamic blade row.

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☐ Recommend paragraph___________on page_______________be changed as follows:

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