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

Advisory Circular

Subject: Damage Tolerance of Axial Blade Slot Features in High-Energy Turbine Engine Rotors

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Initiated By: AIR-625

AC No: 33.70-5

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.

1.1.1 Purpose and Scope.

This AC provides definitions, guidance, and acceptable methods, but not the only methods, that may be used to demonstrate compliance with requirements in § 33.70 related to the integrity of engine life-limited parts. Section 33.70 contains requirements applicable to the design and life management of propulsion system life-limited parts, including high-energy rotating parts.

1.1.2 Damage Tolerance Approach.

1.1.2.1 This AC presents a damage tolerance approach to address manufacturing- and operationally induced anomalies in turbine engine rotating-part axial blade slot features. Applicants can integrate this approach with the existing "safe-life" process for high-energy rotors to create an enhanced life-management process. This approach supplements, rather than replaces, the existing safe-life approach and methodology (see paragraph 2.1.1).

1.1.2.2 In the context of damage tolerance, this AC does not permit operation beyond the life limits specified in the component manual under the existing safe-life approach, which limits useful rotor life to the minimum number of flight cycles required to initiate a crack. The procedures in this AC exclude rotor failure modes that demonstrate full containment of high-energy debris; applicants do not need to include those failure modes in the overall risk assessment.

1.2 Applicability.

1.2.1 The guidance provided in this AC is for aircraft engine manufacturers, modifiers, foreign regulatory authorities, Federal Aviation Administration (FAA) certification engineers, and FAA designees.

1.2.2 If this document is utilized by persons other than FAA employees or the Administrator's designees, it is a guidance document. Its content is not legally binding in its own right and will not be relied upon by the Department as a separate basis for affirmative enforcement action or other administrative penalty. Conformity with the guidance document is voluntary only. Nonconformity will not affect rights and obligations under existing statutes and regulations.

1.2.3 The FAA will consider other means of demonstrating compliance that an applicant may elect to present. Terms such as "should," "may," and "must" are used only in the sense of ensuring the applicability of this particular method of compliance when the acceptable method of compliance in this document is used. If the FAA becomes aware of circumstances in which following this AC would not result in compliance with the applicable regulations, the FAA may require additional substantiation or design changes as a basis for finding compliance.

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

1.3 **Related Reading Material.**

1.3.1 Title 14, Code of Federal Regulations (14 CFR).

The following 14 CFR regulations are related to this AC. You can download the full text of these regulations from the Federal Register website at eCFR.

- 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 Advisory Circulars.

The following ACs are related to the guidance in this AC. The latest version of each AC referenced in this document is available on the FAA website at FAA Advisory Circulars and on the Dynamic Regulatory System.

- AC 33-3, *Turbine and Compressor Rotor Type Certification Substantiation Procedures*.
- AC 33.14-1, Change 1, *Damage Tolerance for High Energy Turbine Engine Rotors*.
- AC 33.70-1, Change 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*.
- AC 33.70-3, *Damage Tolerance for Material Anomalies in Titanium Life-Limited Turbine Engine Rotors*.
- AC 33.70-4, *Fatigue Life of Nickel Powder Rotating Life-Limited Parts*.

1.3.3 FAA Report and Test Case.

DOT/FAA/TC-23/8, *Guidelines to Minimize Manufacturing Induced Anomalies in Critical Rotating Parts – 2022 Revision*, is related to the guidance in this AC. The latest version of this report is available at the FAA website and the US Department of Transportation ROSA P website. You can access the neutral files containing the test case geometry at AC33.70-5 Axial Blade Slot Test Case Geometry.

1.3.4 ASTM.

ASTM International (ASTM) E 1049-85, *Standard practices for cycle counting in fatigue analysis*, is related to the guidance in this AC. Unless otherwise specified, use the latest FAA-accepted revision for guidance. If the document is revised after the publication of this AC, you should verify that the FAA accepts the subsequent revision or update as an acceptable form of guidance. The documents are available online at E1049 Standard Practices for Cycle Counting in Fatigue Analysis.

1.3.5 Society of Automotive Engineers (SAE) International.

The following SAE documents are related to the guidance in this AC. Unless otherwise specified, use the latest FAA-accepted revision for guidance. If the document is revised after the publication of this AC, you should verify that the FAA accepts the subsequent revision or update as an acceptable form of guidance. The documents are available online at the SAE website.

- SAE/FAA Committee on Uncontained Turbine Engine Rotor Events, *Report No. AIR 1537*, Data Period 1962-1975.
- SAE/FAA Committee on Uncontained Turbine Engine Rotor Events, *Report No. AIR 4003*, Data Period 1976-1983.
- SAE/FAA Committee on Uncontained Turbine Engine Rotor Events, *Report No. SP-1270*, Data Period 1984-1989.

1.3.6 Presentations.

- “Development of Anomaly Distributions for Aircraft Engine Titanium Disk Alloys.” Technical paper presented by the Aerospace Industries Association (AIA) Rotor Integrity Sub-Committee at the American Institute of Aeronautics and Astronautics Conference, April 1997.
- “Development of Anomaly Distributions for Machined Holes in Aircraft Engine Rotors.” Technical paper presented at the American Society of Mechanical Engineers (ASME) Turbo Expo, Barcelona, Spain, May 2006.

1.4 Definition of Key Terms.

See appendix H for a list of definitions applicable to this AC.

1.5 Background.

1.5.1 Damage Tolerance Requirements.

1.5.1.1 As required by § 33.70(a), applicants must perform appropriate damage tolerance assessments to evaluate the potential for failure from material, manufacturing, and service-induced anomalies within the approved life of the component. Service history with gas turbine engines has shown that such material, manufacturing, and service-induced anomalies can occur and may weaken the structural integrity of rotor life-limited parts.

1.5.1.2 Several methods to meet this requirement have been introduced in AC 33.70-1 Change 1, AC 33.70-2, and AC 33.70-3. The methodology described in chapter 2 of this AC was first introduced in AC 33.14-1 to address the potential presence of hard alpha anomalies in titanium rotors.

1.5.2 Introduction of Damage Tolerance Methodology.

Because developing the necessary technical elements, such as data collection, analysis, and methodology development, is complex and time-consuming, the FAA is introducing the surface damage tolerance assessment methodology for manufacturing and in-service anomalies in phases. This AC presents a damage tolerance approach for addressing manufacturing and operationally induced anomalies in axial blade slot features in rotor parts (see appendix E for information about the axial blade slot features).

CHAPTER 2. ENHANCED LIFE MANAGEMENT PROCESS

2.1 Overview.

2.1.1 Safe-Life Approach.

The safe-life approach has been effective based on historical experience and continues to provide a solid foundation for further improvement. Modifications to industry-standard life management procedures should enhance, not replace, the current safe-life approach.

2.1.2 Enhanced Life Management Process.

The enhanced life management process incorporates damage tolerance, building upon the existing conventional life management system. This enhanced life management process is expected to further reduce the occurrence of uncontained rotor failures, improving flight safety (see figure 2-1).

2.2 Showing Compliance to an Acceptable Design Target Risk (DTR).

2.2.1 Damage Tolerance Assessment.

The enhanced life management process, shown in figure 2-1 of this AC, requires damage tolerance assessments for rotating, life-limited part designs. These will be in the form of fracture-mechanics-based probabilistic risk assessments, with the results compared to specified DTR values (see paragraph 3.6 for more information about DTR values). Designs that meet these DTR values comply with the damage tolerance requirements of § 33.70 (see chapter 3 for more information about damage tolerance assessments).

2.2.2 Options for Meeting DTR.

For designs that do not meet the DTR requirement, engine manufacturers have a variety of options to show compliance with an acceptable DTR value, including:

- Component Redesign: Modifying the design to improve durability and resistance to failure.
- Material Changes: Switching to stronger or more durable materials that reduce the likelihood of crack initiation or propagation.
- Material Process Improvements: Enhancing how materials are processed to reduce the introduction of defects.
- Manufacturing Process Improvements: Upgrading manufacturing techniques to improve consistency and reduce the risk of defects.
- Manufacturing Inspection Improvements: Implementing better inspections during manufacturing to catch and correct defects early.
- Enhanced In-Service Inspections: Increasing the frequency or thoroughness of inspections during service to identify and address issues before they lead to failure.

- Life Limit Reductions: Reducing the life limit of components to ensure they are replaced before critical defects develop.

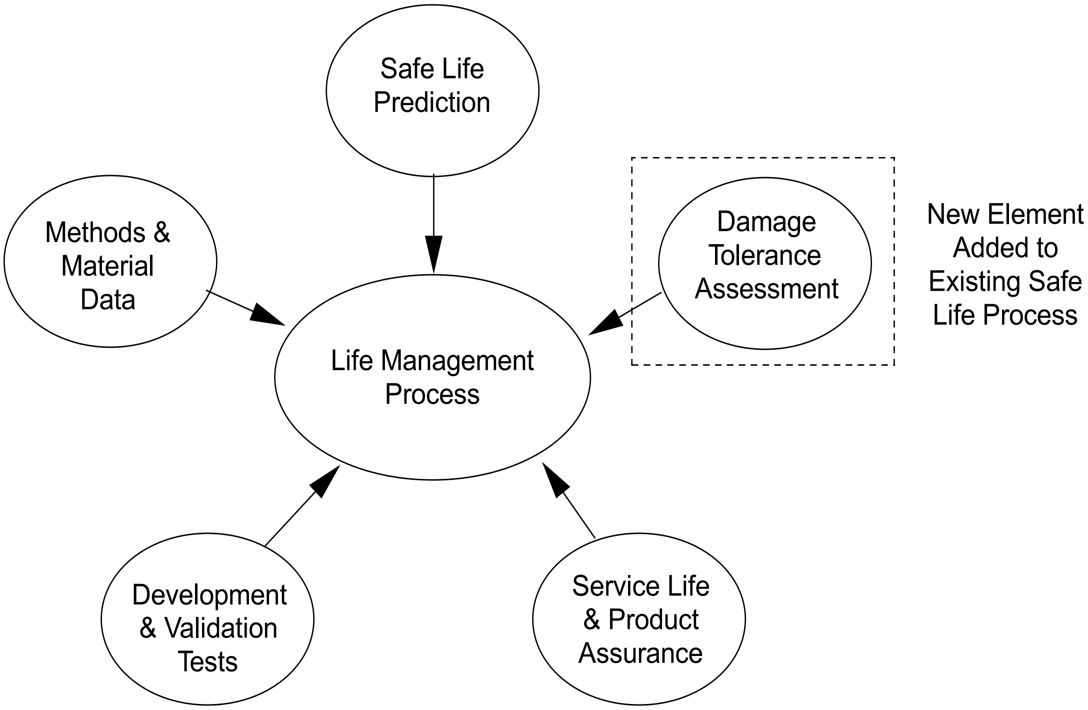


Figure 2-1. Enhanced Life Management Process

CHAPTER 3. DAMAGE TOLERANCE ASSESSMENTS

3.1 **Approach.**

3.1.1 Introduction to PDTRA Methodology.

As described in AC 33.70-1, probabilistic damage tolerance risk assessment (PDTRA) is an acceptable method to assess the ability of a component to tolerate anomalies. The results of these assessments form the basis for evaluating the relative damage tolerance capabilities of candidate part designs, helping the engine manufacturer to balance its designs for both enhanced reliability and customer impact. The results will be compared against DTR values (see paragraph 3.6 in this chapter).

3.1.2 Evaluating and Achieving Compliance with DTR.

The need for further risk-reducing actions by the engine manufacturer depends on whether the design under consideration meets the DTR value. If the target is met, the design complies with § 33.70. To meet the DTR, manufacturers can use various methods, including parametric studies that analyze the effects of key variables like inspection methods, inspection frequency, hardware geometry, hardware processing, material selection and life limit reduction. The manufacturer may make changes to the design, field management of the part, or both, to achieve the DTR value.

3.1.3 Applying PDTRA in the Design Phase.

PDTRA will usually be performed during the engine component detail design phase. Paragraph 3.2 defines a probabilistic surface damage tolerance (PSDT) assessment methodology applicable to manufacturing and service-induced anomalies in axial blade slot features and provides a process to refine a design to achieve the desired DTR value.

3.2 **Methodology.**

3.2.1 Probabilistic Risk Assessments.

Probabilistic risk assessments can be performed using various methods, including Monte Carlo simulation or numerical integration techniques. To ensure consistent assessment results when conducting a PDTRA, use the standardized inputs and default data presented in this AC.

3.2.2 Standardized Inputs.

A list of standardized inputs is provided under paragraph 3.2.3 with default input data outlined in paragraphs 3.3 and 3.4. No further validation is required for applicability or accuracy when using default data in probabilistic assessments. However, when this data is used, applicants should follow the guidelines accompanying this data to ensure applicability. When using inputs other than these default values, additional validation may be necessary to verify applicability, adequacy, and accuracy.

3.2.3 Inputs for Blade Slot Risk Assessments.

Probabilistic risk assessments for blade slots should incorporate the following inputs as part of a basic analysis.

3.2.3.1 Stress and Temperature.

- These variables influence crack propagation life predictions. Engine cycles for design low cycle fatigue (LCF) certification, or actual usage (if known), should be used to establish the stress and temperature distributions. Surface assessments should incorporate the appropriate surface and near surface stress distributions, including the effects of stress concentrations.
- The method described in this AC has been calibrated based on industry experience but does not consider the effect of shot peening or the resulting beneficial residual stresses on the crack propagation lives. No crack growth credit should be taken for beneficial surface residual stresses.

3.2.3.2 Number of Blade Slots.

A higher number of blade slots raises the chances of surface damage in axial blade slots and raises the probability of component failure.

3.2.3.3 Material Cyclic Crack Growth Rate Data.

Use the average crack growth rate properties of the base material as the default condition to calculate crack propagation life.

3.2.3.4 Crack Propagation Life Predictions.

- The predicted number of cycles for a given size crack to grow to a critical size is based on predicted stresses, temperatures, geometry, stress gradient, crack orientation, and material properties. Linear elastic fracture mechanics should be used for the calculation of propagation life. Default conditions should assume anomalies sampled from the distribution in paragraph 3.2.3.5 behave like sharp propagating cracks and are oriented in the worst orientation relative to the stress field. Crack growth rates depend on stress-temperature conditions.
- The method described in this AC has been calibrated assuming a “prescribed TMF” (thermo-mechanical fatigue) approach (see figure A-14 and table A-6 in appendix A), which should be used for consistency with the TMF method. This approach prescribes:
    - Cycle pairs are extracted using a standardized stress rainflow extraction method (see ASTM E 1049-85, paragraph 1.3.4).

- The crack growth rate at the maximum temperature of the paired cycle is used to compute crack growth life.

3.2.3.5 **Anomaly Distribution.**

The method described in this AC has been calibrated using the default anomaly distribution in paragraph 3.3 of this chapter.

3.2.3.6 **Manufacturing Methods.**

The method described in this AC is calibrated predominantly for axial blade slots manufactured using broaching methods, with some milled slots also included. Controls and techniques specific to blade slot forming operations and blade slot edge formation and finishing can influence damage tolerance assessments. Since the PSDT methodology in this AC xmay be relevant to slot formation methods other than broaching or milling, refer to appendix F of this AC for definitions and additional guidance.

3.2.3.7 **Inspection Probability of Detection (POD).**

Inspection at time of manufacture and during maintenance in service can impact component risk. The default POD information used to calibrate the method in this AC, along with instructions, are provided in paragraph 3.5. The default POD information is only appropriate for in-service inspections, because the sampled anomalies are treated as actively growing cracks from the first cycle.

3.2.3.8 **Maintenance Exposure Interval.**

When assessing inspection benefits, the exposure intervals for the engine, module, or specific component can be considered in the analysis.

3.2.4 Calibration.

3.2.4.1 The applicant should calibrate its analytical prediction tools by performing the industry test case detailed in appendix A of this AC.

3.2.4.2 The test case in appendix A consists of a probabilistic analysis of a simulated nickel turbine disk with a two-lobed firtree slot, using specified inputs and scenarios. Table A-6 in appendix A provides acceptable ranges for test case results. Test case results outside of these ranges may indicate deficiencies with either the probabilistic assessment technique or the assumptions made in the stress analysis, considering that the speed and temperature distribution are specified.

3.2.5 Output.

Surface-induced anomaly assessments for axial blade slots.

3.2.5.1 **Applicability.**

This procedure was specifically developed for field cracking or failures, or both, of axial blade slots, including but not limited to:

- Axial blade slots in nickel and titanium life-limited parts,
- Broached and milled axial blade slots,
- Slot bottom surface and edge features as shown in figures E-2 and E-3 in appendix E.

Note: While the methodology discussed in this AC was developed based on titanium and nickel axial blade slots, it can also apply to axial blade slots made from other materials (such as steel) subject to the determination of appropriate input data.

Note: This procedure may also apply to axial blade slots manufactured by other means than broaching or milling subject to the determination of appropriate input data.

Note: This procedure can be extended to other lower-risk locations within the axial blade slot not highlighted in figures E-2 and E-3 in appendix E. For the purposes of this AC, lower-risk locations are those where a crack would not grow into the disk but would instead cause the release of the blade post and two blades. These other locations would use the same exceedance curve, frequency, manufacturing credits, and DTR. If the original equipment manufacturer (OEM) has experience to show a reduced number of cracking or fracture events in the lower-risk locations, it may be acceptable to lower the frequency accordingly.

3.2.5.2 **Blade Slot Assessment.**

The probabilistic assessment for a set of axial blade slots should be calculated over the entire anticipated service life of the component. This result, expressed as the probability of fracture per component, is called the predicted “blade slot event rate.” This event rate should be compared to the blade slot DTR value to determine whether the design is acceptable.

3.2.6 Long-Term Risk Management, Inspection, and Manufacturing Practices.

3.2.6.1 The FAA encourages engine manufacturers to incorporate fracture-resistant design concepts where possible. Credit may be given for such design features if they clearly demonstrate, through both analysis and testing, a reduction in the risk of rotor failure due to the presence of unanticipated anomalies. These credits can be determined using the probabilistic risk assessment methods outlined in this AC, supported by data that validates the effectiveness of the fracture-resistant features.

3.2.6.2 Because the design of an aircraft turbine engine rotor is a lengthy process involving numerous iterations, each of which can substantially alter the initial design risk value, it is important that the design features satisfy the appropriate DTR value at the time of engine certification.

3.2.6.3 Some risk assessments will be conducted several years after the engine enters service due to in-service problems, changes in engine service usage, improvements in analytical predictive tools, or changes in engine component materials. In these instances, it is important to note that the DTR values should be satisfied throughout the life of the hardware.

3.2.6.4 In conjunction with probabilistic assessments and fracture-resistant designs, surface and edge inspections of axial blade slots play a critical role in ensuring the ongoing integrity of rotor parts. These inspections, which evaluate geometry, surface condition, and material quality, are widely used throughout the industry. Existing inspections should not be discontinued, even when advanced damage tolerance analysis is employed.

3.2.6.5 Established best practices define how to conduct process validation and prepare the associated manufacturing control plan (see paragraph 1.3.3). These process validation and manufacturing control plans are mandatory, regardless of whether you apply manufacturing credits in the PSDT to meet the DTR.

3.3 **Default Input - Anomaly Distributions.**

3.3.1 Overview of Anomaly Distributions.

A key input associated with PDTRA assessments is the size distribution of potential anomalies. This type of information is statistical in nature and can be presented in a form that specifies the number, or rate, of anomalies that exceed a particular size.

3.3.2 Anomaly Distributions for Axial Blade Slots.

3.3.2.1 Anomaly distributions that apply to axial blade slots in disks have been developed to characterize the size (depth) distribution and frequency of potential anomalies (see appendix B). The distributions apply to axial blade slots machined in titanium or nickel rotor components.

3.3.2.2 The anomaly distributions contained in appendix B may be used to determine compliance with paragraph 3.6 of this chapter. The anomaly distributions in appendix B were used to calibrate this PDTRA method for a broad range of OEM field experience in terms of both product type and commercial usage over several decades.

3.4 Manufacturing Credits for Manufacturing-Induced Anomaly Distributions.

3.4.1 Manufacturing Process Validation and Controls.

To encourage the use of best practices when manufacturing axial blade slots in rotor life-limited parts, a process has been established to take credit for manufacturing process validation and controls that reduce the risk of blade slot surface and blade slot edge damage during manufacture. This process quantifies the benefits of:

- Process validation to modern standards (see paragraph 1.3.3).
- Process validation and control plan, machine condition, fluid and fluid condition, tooling and setup validation, fluid monitoring, and process monitoring during the processes used to produce the axial blade slot surface.
- Process validation and control plan, semi-automated and automated edge processing of the axial blade slot edges.
- Inspection of axial blade slot surface and edge geometry.
- Non-destructive inspection of axial blade slot surfaces and periodic metallographic cutups and etch inspection.

3.4.2 The allowable manufacturing credit is a function of which of the above available actions are employed during blade slot manufacture. Calculation of manufacturing credit is outlined in appendix F. The manufacturing-induced probabilistic damage tolerance approach has been calibrated including the benefits of enhanced manufacturing validation and process controls. Hence, the credit is applied as a reduction factor to the results of the manufacturing-induced probabilistic assessments prior to comparing with the axial blade slot feature DTR.

3.5 Default Input – Nondestructive Evaluation (NDE) POD.

3.5.1 Detection of Geometric vs. Non-Geometric Anomalies.

3.5.1.1 Detection of non-geometric anomalies, such as highly distorted grain structure, white or amorphous layer, and bent grains, which have dominated the experience of cracking in rotors, is quite distinct from detecting cracks and geometric anomalies such as nicks or dents. Cracks that may develop from non-geometric anomalies can be detected by conventional methods, such as eddy current, penetrant, or ultrasonic inspection when the component is inspected at a shop visit.

3.5.1.2 These methods, however, may be of very limited benefit at new manufacture. If credit for non-geometric anomaly inspection at new manufacture is claimed, applicants must justify the detection capability of the technique on the target anomaly types. The default POD data supplied in this AC in appendix D only refers to the detection of cracks and is not necessarily applicable to non-geometric anomalies.

3.5.2 Parameters Influencing NDE Detection Capabilities.

NDE process capabilities, such as eddy current, penetrant, or ultrasonic inspection, for the detection of local material anomalies (discontinuities or potential anomalies), is a function of numerous parameters, including the anomaly's size, shape, orientation, location, and chemical or metallurgical character. In addition, the following parameters should be considered when assessing the capabilities of an NDE process:

- Material being inspected (e.g., composition, grain size, conductivity, surface condition—such as cleanliness, peened vs. unpenned, damaged vs. undamaged—and surface texture).
- Inspection materials or instrumentation (e.g., specific penetrant and developer, inspection frequency, instrument bandwidth, and linearity).
- Inspection parameters (e.g., scan index).
- Inspector attributes (e.g., his or her visual acuity, attention span, and training).

3.5.3 Applicability of Default POD Data.

The default POD data in this AC represent inspection capabilities measured under typical, well-controlled conditions. These values are provided to assist in selecting NDE techniques for damage-tolerant inspections. However, though properly applied inspections should result in capability similar to these default values, these values only apply under the conditions in which they were obtained (see appendix C). POD curves are provided in appendix D:

3.5.3.1 Appendix D, Figure D-1. Mean POD for Fluorescent Penetrant Inspection of Finished-Machined Surfaces.

3.5.3.2 Appendix D, Figure D-2. Mean POD for Eddy Current Inspection of Finish Machined Surfaces.

3.5.4 POD Curves and Figures.

For more information on using POD data, refer to appendix A for an example and appendix C for NDE applicability guidelines.

3.6 Design Target Risk.

3.6.1 Discussion of DTR.

The DTR is a benchmark relative risk level selected to enhance the overall safety of high-energy rotating components.

3.6.2 Application to Manufacturing-Induced Anomalies.

Designs must meet the specified feature DTR for manufacturing-induced anomalies to be considered acceptable under the methods set forth in this AC. Manufacturing-induced anomalies include damage during blade insertion and removal in assembly and overhaul. Manufacturing-induced anomalies do not cover damage size or frequency unique to engine service operations.

3.6.3 DTR Values.

The DTR values for axial blade slots are specified in table 3-1.

Table 3-1. Allowable Design Target Risk for Axial Blade Slots

Component Feature	**DTR (events per component published service lifetime)**
Axial Blade Slots Set	2.0 E-05

CHAPTER 4. "SOFT TIME INSPECTION" ROTOR LIFE MANAGEMENT

4.1 Approach.

4.1.1 Overview of the Life Management Process.

The life management process encompasses a wide spectrum of design, manufacturing, and product support issues. This section addresses only one facet of that process, the assurance of structural integrity using inspection techniques and intervals derived from a damage tolerance (fracture mechanics-based) assessment. The goal of the inspection philosophy described in this AC is to address anomalous conditions without allowing operation beyond the safe-life limit specified in the Airworthiness Limitations Section (ALS) of the Instructions for Continued Airworthiness (ICA).

4.1.2 Managing Higher-Than-Desired Risk Levels.

If probabilistic assessments indicate risk levels higher than the desired target, there are many strategies to reduce the predicted risk to the appropriate level. However, this chapter addresses only the in-service inspection option.

4.1.3 Use of Industry Data on Uncontained Fracture Experience.

Industry data on uncontained fracture experience, summarized in SAE reports AIR 1537 (1959 through 1975), AIR 4003 (1976 through 1983), and SP1270 (1984 through 1989), was used by the FAA to guide the development of the inspection philosophy. These reports indicate that maintenance-induced uncontained failure rates were comparable to the failure rates for anomalous conditions (material and manufacturing). This data suggests that additional inspection requirements, if not properly integrated into the regular engine maintenance schedule, would have no net benefit in reducing uncontained failure rates.

4.1.4 General Inspection Philosophy.

4.1.4.1 The inspection philosophy presented here evolved from the desire to easily integrate inspections into the operation of the engine yet still achieve measurable reduction in the uncontained failure rates. The inspection philosophy incorporates the use of opportunity inspections rather than mandatory inspections at "not to exceed" intervals.

4.1.4.2 These opportunity inspections occur due to the "on-condition" maintenance practices used by operators today. Though opportunity inspections occur at random intervals, they can be treated statistically and used effectively to lower the calculated risk of an uncontained event.

4.1.5 Opportunity Inspections.

Opportunity inspection refers to those instances when the hardware in question is available in a form such that the specified inspection can be performed. This condition is generally viewed as being reduced to the piece part; however, opportunity inspections can be performed on assembled modules. For example, an eddy current inspection

(ECI) of a disk bore may be specified on an assembled module whenever the module is available. This inspection is an opportunity inspection based on module availability rather than piece part availability.

4.1.6 Forced Inspections Through Disassembly.

4.1.6.1 The methods provided by this AC may use opportunity inspections to meet the DTR levels. However, in some instances, the probabilistic analysis may indicate an unacceptable risk level when using just opportunity inspections and some additional action may be required to meet the DTR. One of the options to mitigate this risk is to mandate inspections by specifying the disassembly of modules or engines when a cyclic life interval has been exceeded.

4.1.6.2 There are many options on how to implement forced disassembly. Options range from mandatory engine removal and subsequent teardown at not to exceed cyclic limits ("hard-time" limits) to 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 includes the use of the piece part soft-time inspection option and only suggests that forced disassembly of modules be considered when necessary to meet the DTR levels.

4.1.7 On-Condition Maintenance Practice Philosophy.

4.1.7.1 The soft-time inspection philosophy retains the "on-condition" maintenance practice and minimizes the impact of additional module disassembly. The inspection requirement exists only after the engine has been removed from the aircraft for a reason other than the inspection itself and is in a sufficient state of disassembly to allow access to the module containing the component in question.

4.1.7.2 An available module containing a component with cycles since last inspection (CSLI) in excess of the soft-time interval must be disassembled to a condition that allows inspection by the procedure specified by the engine manufacturer. The engine manufacturer must evaluate the risk associated with components that become available for inspection before the soft-time interval to determine if the CSLI can be reset.

4.1.8 Maintenance Impact of Soft-Time Intervals.

The maintenance impact of the soft-time intervals should be considered during the design phase using probabilistic analysis summarized in chapter 2, along with the anticipated engine removal rate and the module and piece part availability. This approach ensures that designs not only meet the design target but also result in acceptable soft-time intervals and procedures if required.

4.1.9 Establishing Interval Limits with 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 requirement is not intended to affect the current practice of forced inspection programs to address safety of flight concerns that arise in the course of engine operation and maturation. These safety of flight concerns should continue to be addressed through aggressive inspection programs, which are communicated using service bulletins and Airworthiness Directives.

4.1.10 Communication and Implementation of Inspection Assumptions.

4.1.10.1 Applicants should recognize that the inspection assumptions made in the probabilistic risk assessment must be communicated to and implemented accurately in the field by using the ALS of the ICA. These assumptions must also be validated by the review of engine removal rates and module and piece part availability data. For example, the ALS must specify an eddy current inspection if that was an assumption in setting the original soft-time interval.

4.1.10.2 Similarly, the amount of inspected material should correspond to the analysis assumptions. Likewise, 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, such as a modified inspection plan, is required.

4.1.11 The soft-time inspection interval and reference to the corresponding inspection procedures must be specified in the ALS of the ICA. This information must be provided for all rotor parts with specified retirement life limits that require any inspection plans beyond opportunity inspections to meet the DTR levels. The required inspection information should also be included in the individual ALS of the ICA with the other rotor inspection requirements. The manufacturer must also provide the necessary information to focus the prescribed inspections to those areas of highest relative risk.

4.1.12 Non-destructive inspection(s) at manufacture cannot be accounted for in the analysis to lower the probability of failure/fracture (POF) value before the application of manufacturing credits (see restriction 5 in appendix F).

4.2 Inspection Scenarios.

The following scenarios clarify the actions that should be taken during a maintenance inspection opportunity (see appendix H.13). Note that the inspection plans may vary for each component based on the outcome of the probabilistic assessments.

4.2.1 Maintenance Opportunity - Hardware Available for Opportunity Inspection.

Hardware available in the condition to perform a specified opportunity inspection must be inspected according to the procedures specified in the ALS of the ICA. This inspection is mandatory.

4.2.2 Maintenance Opportunity - Module Below Soft Time Interval.

Hardware accessible in the assembled or partially disassembled module may be nondestructively inspected by the procedures specified in the ALS of the ICA. The CSLI may be reset to zero, provided the engine manufacturer has assessed the risk impact associated with this action. This is a discretionary inspection.

4.2.3 Maintenance Opportunity - Module Exceeding Soft Time Interval.

Hardware listed in the ALS of the ICA must undergo nondestructive inspection whenever the module is accessible, particularly when the CSLI for any hardware exceeds the inspection cycle limit. This inspection is mandatory.

4.2.4 Soft Time Inspection Interval Example.

An example of how to develop a soft time inspection interval is provided in chapter 5 of AC 33.70-3.

APPENDIX A. MANUFACTURING-INDUCED ANOMALY CALIBRATION TEST CASE FOR AXIAL BLADE SLOTS

A.1 **Introduction.**

A.1.1 Purpose of the Test Case.

This appendix provides instructions for calibrating a probabilistic risk assessment methodology for manufacturing-induced anomalies in axial blade attachment slots. This includes damage associated with blade insertion and removal during assembly and overhaul. It does not specifically include damage in terms of size or frequency unique to the service operation of the engine.

A.1.2 Scope of Input Data.

This appendix includes all the input data required to complete the test case, such as analysis guidelines, component geometry, boundary conditions, material property data, and inspection efficacy. The input data should be used to compute the POF of a feature within the defined cyclic life interval. An applicant must demonstrate the acceptability of their probabilistic process by meeting the POF criteria defined in table A-8.

A.2 Test Case Input Data.

A.2.1 Problem Description and Geometry.

The test case geometry, shown in figure A-1, consists of two components: a turbine disk and a blade. Both parts are made from a nickel-based superalloy, with the blade assumed to be solid and isotropic. The blade applies centripetal forces to the disk, but no aerodynamic or pressure loads are applied. In the finite element analysis, the blade should be constrained to prevent axial movement out of the attachment slot.

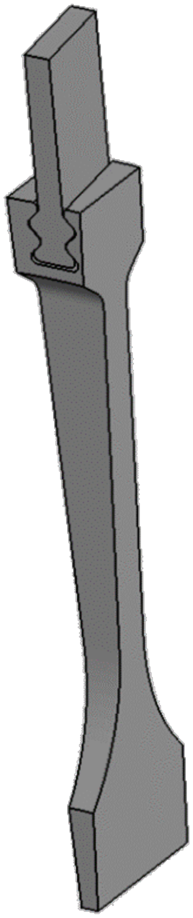


Figure A-1. Representation of Test Case Blade and Disk Geometry

A.2.2 Test Case Geometry Details.

An isometric view and drawings of the disk and blade are shown in figures A-2 through A-8. Dimensions are provided in both Imperial and International System of Units (SI units). The disk features a two-lobe firtree, with 72 equally spaced slots.

A.2.2.1 Figure A-2 provides an isometric view of a 5-degree sector of the test case geometry, showing the disk and blade for the component under assessment.

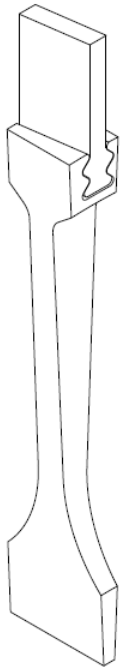
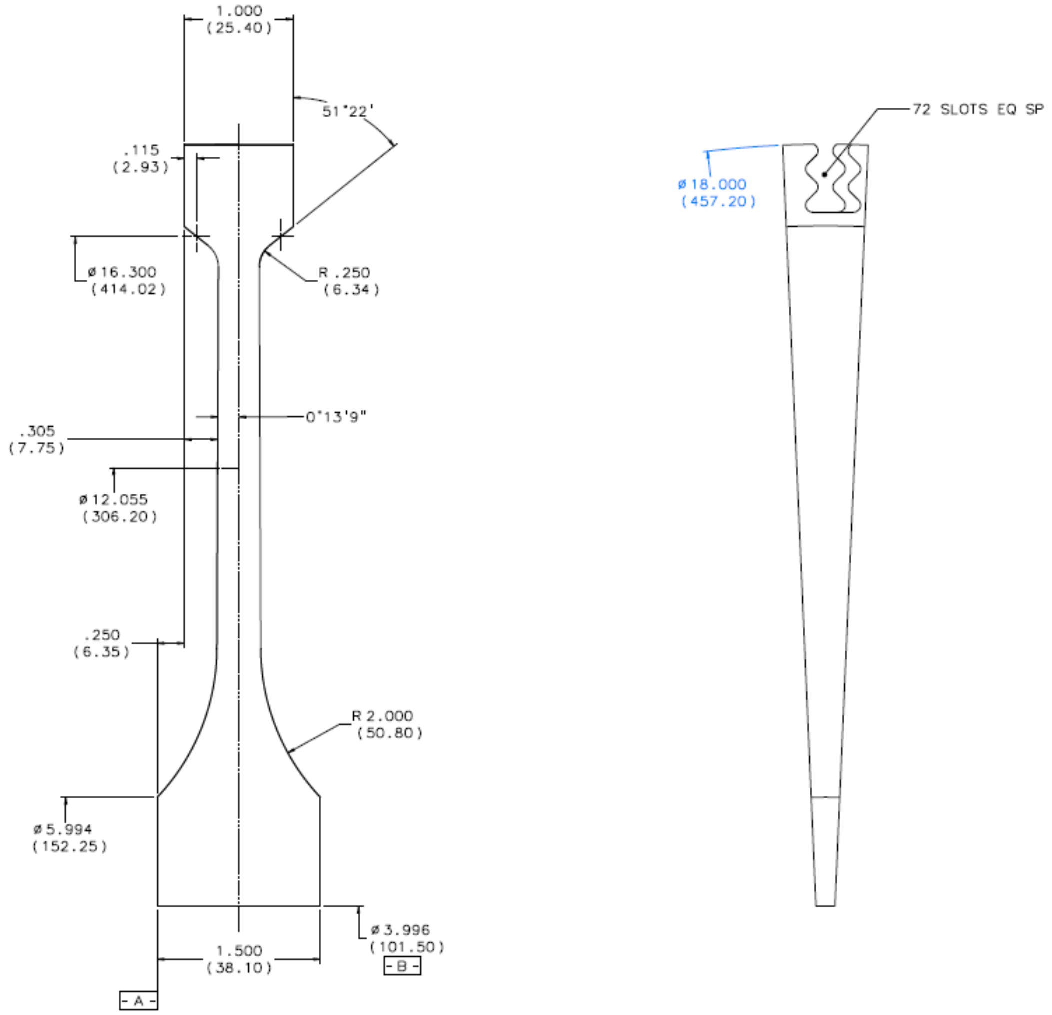


Figure A-2. Test Case Geometry Definition: Isometric View of 5 Degree Sector Showing Disk and Blade

A.2.2.2 Figure A-3 provides an axisymmetric profile view of the disk, with dimensions specified in both inches and millimeters.



ALL DIM APPLY BOTH SIDES UOS

Figure A-3. Test Case Geometry Definition: Disk Axisymmetric Profile in Inches and (Millimeters)

A.2.2.3 Figure A-4 shows a radially inward view of the test case geometry, highlighting an 8-degree broach angle. This view provides critical details of the angular orientation, ensuring a precise understanding of the broaching direction for axial blade slot geometry shown in figure A-5.

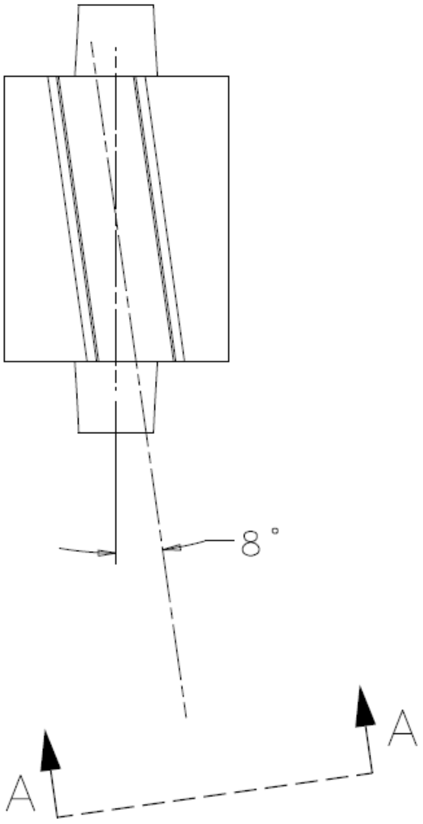


Figure A-4. Test Case Geometry Definition: View Looking Radially Inward Showing 8.0 Degree Broach Angle

A.2.2.4 Figure A-5 presents the A-A view of the disk broach slot profile, displaying key dimensions in inches and millimeters.

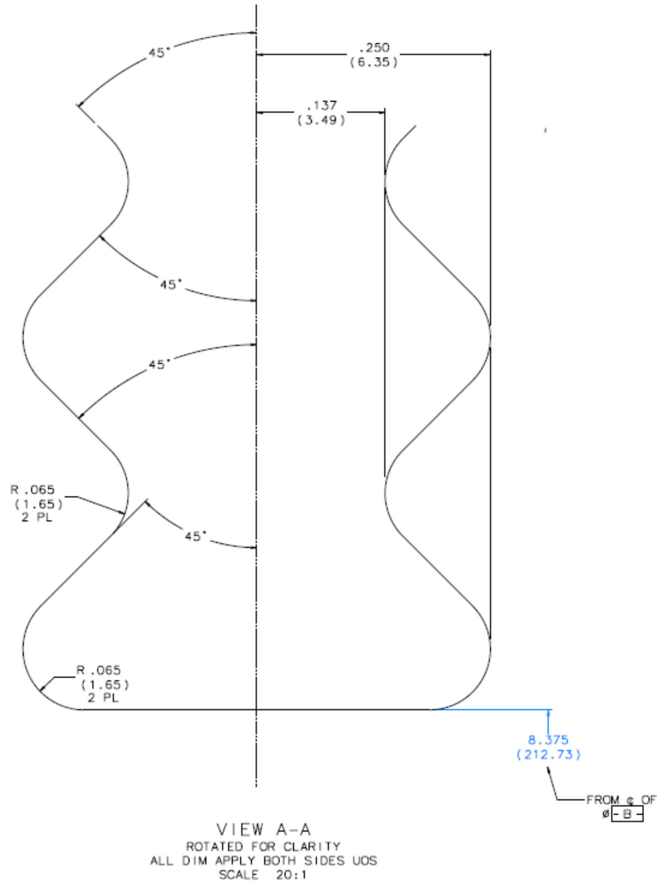


Figure A-5. Test Case Geometry Definition: View A-A of Disk Broach Slot Profile in Inches and (Millimeters) Not to Scale

A.2.2.5 Figure A-6 illustrates the axisymmetric view of the blade, providing key height and width dimensions in inches and millimeters.

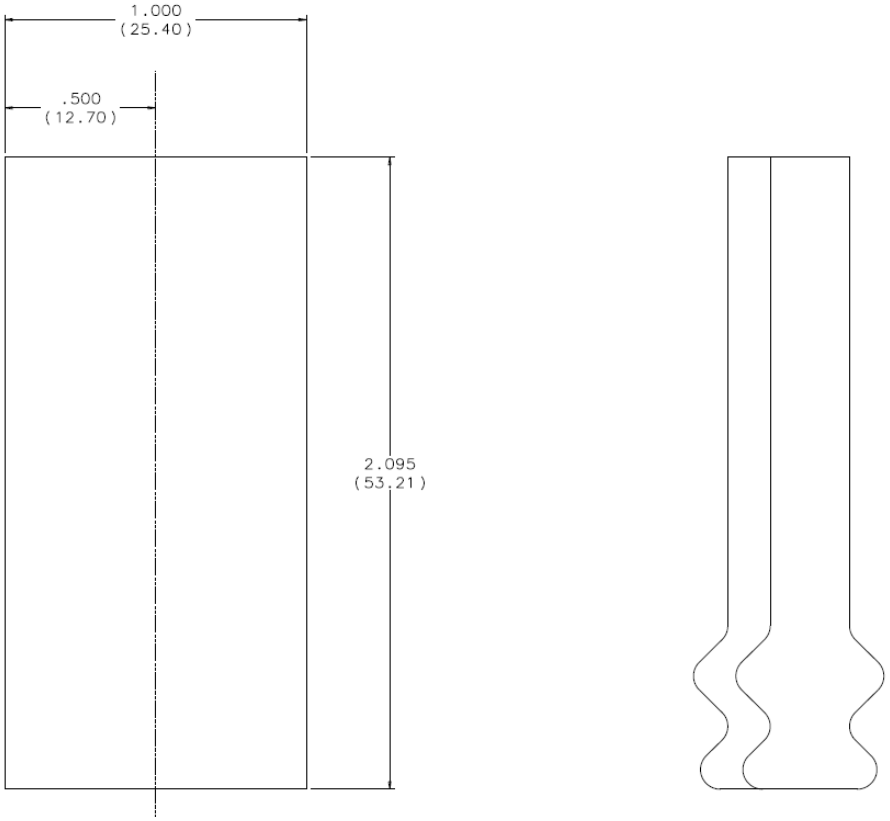


Figure A-6. Test Case Geometry Definition: Axisymmetric View of Blade Showing Height and Width in Inches and (Millimeters)

A.2.2.6 Figure A-7 provides a radially inward view of the blade, illustrating the broach angle and blade thickness in inches and millimeters.

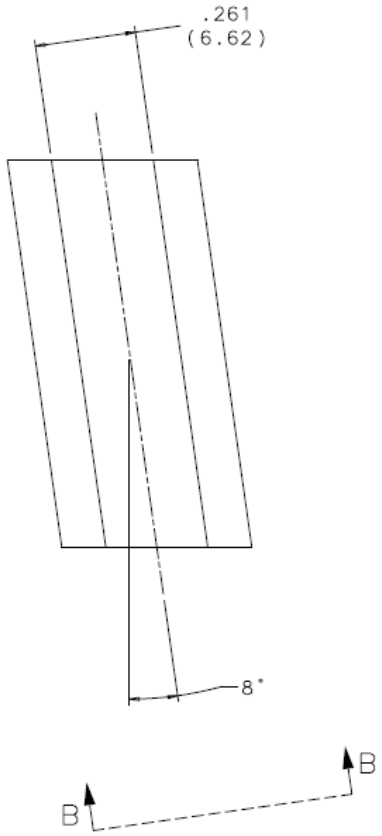


Figure A-7. Test Case Geometry Definition: View of Blade Looking Radially Inward Showing Broach Angle and Blade Thickness in Inches and (Millimeters)

A.2.2.7 Figure A-8 displays the blade attachment profile (View B-B), illustrating the dimensions in both inches and millimeters.

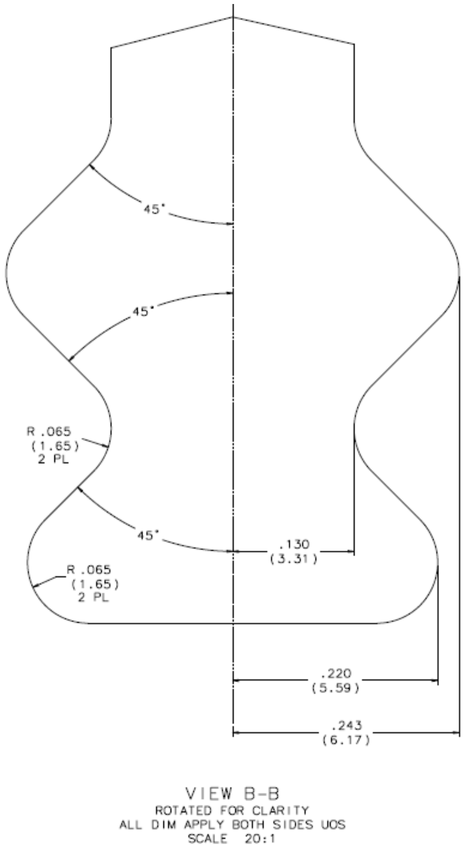


Figure A-8. Test Case Geometry Definition: View B-B Showing Blade Attachment Profile in Inches and (Millimeters) Not to Scale

A.2.3 Mission Profile Definition.

The stresses and corresponding life capability at the disk’s slot bottom are primarily driven by the disk’s rotational speed but also from the rotor thermal gradient. This test case simulates multiple phases of a typical commercial revenue service operation, capturing changes in disk rotational speed and rotor stress due to thermal contributions through the mission profile. The mission profile is defined by 11 unique time points. A time and disk speed history profile defining these mission points is shown in figure A-9 and table A-1.

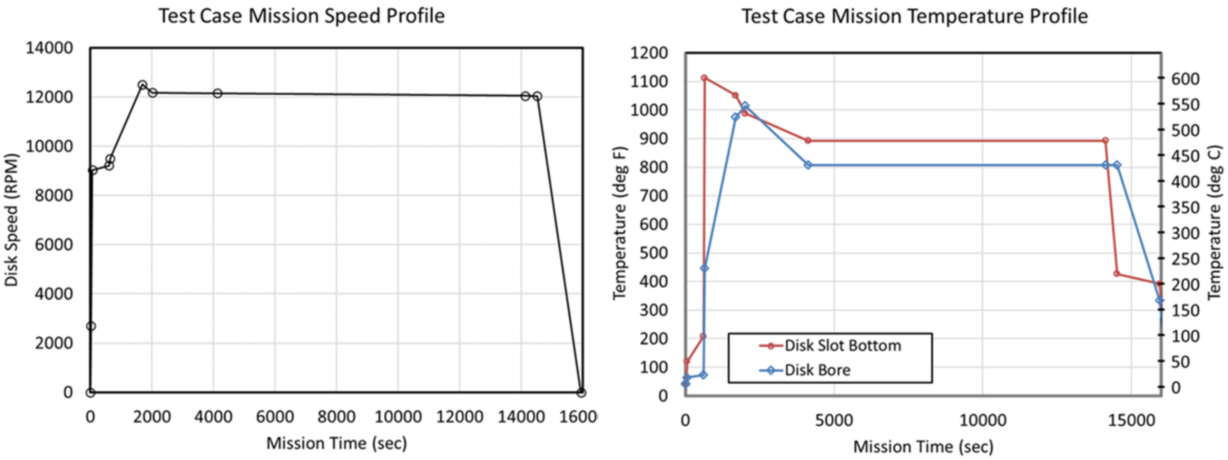


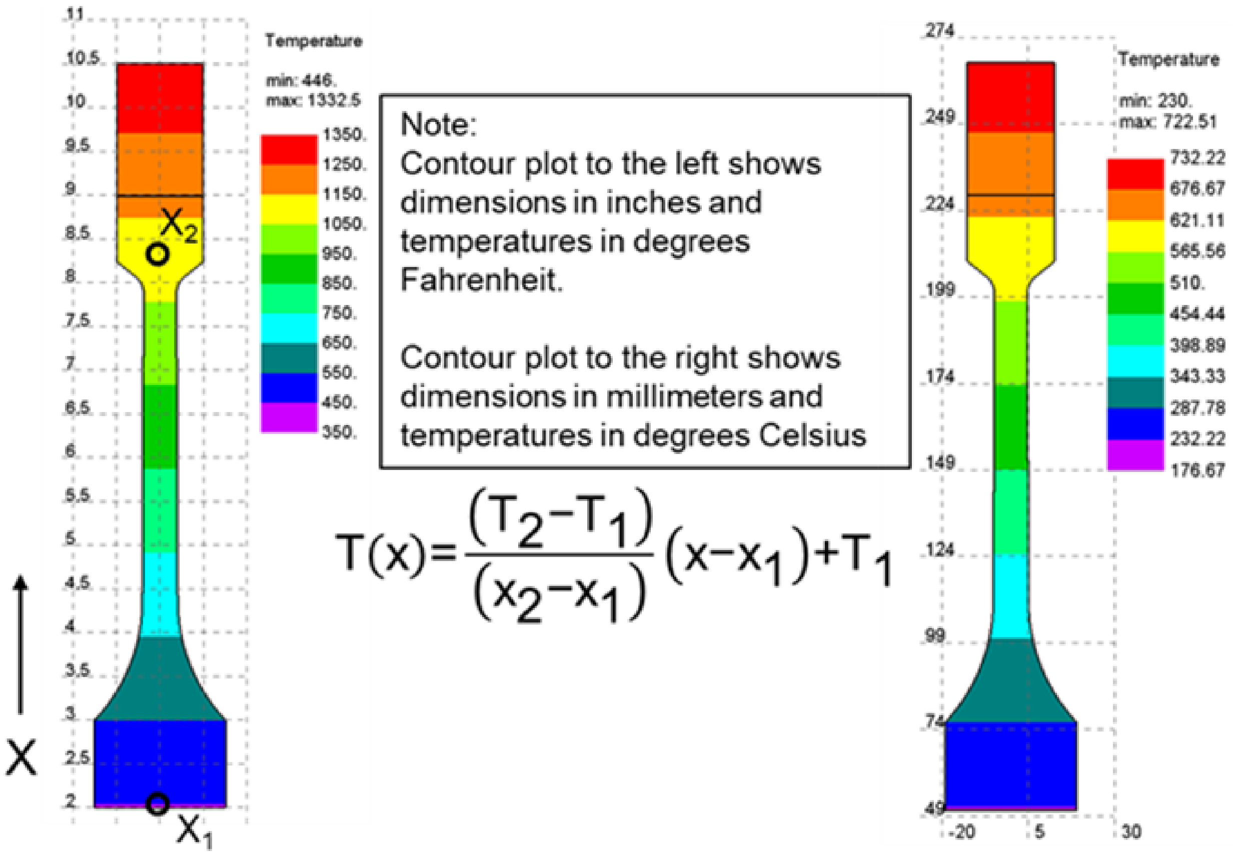
Figure A-9. Disk Speed and Temperature over Test Case Flight Profile

Table A-1. Tabulated Disk Speeds and Temperatures for Test Case Flight Profile

Time sec	Disk Bore Temperature Radius = 2.0 in deg F	Disk Slot Bottom Temperature Radius = 8.38 in deg F	Disk Bore Temperature Radius = 50.8 mm deg C	Disk Slot Bottom Temperature Radius = 212.77 mm deg C	Rotational Speed RPM
0	42.8	42.8	6.0	6.0	0.0
18	42.8	42.8	6.0	6.0	2708.8
60	64.4	120.2	18.0	49.0	9029.5
608	73.4	208.2	23.0	97.9	9211.1
642	446.0	1,112.0	230.0	600.0	9504.1
1689	975.2	1,050.8	524.0	566.0	12512.6
2008	1,014.8	987.8	546.0	531.0	12182.3
4127	807.8	892.2	431.0	477.9	12158.6
14127	807.8	892.2	431.0	477.9	12046.4
14517	807.8	426.7	431.0	219.3	12042.0
15947	334.4	392.0	168.0	200.0	0.0

A.2.4 Thermal Gradients and Mission Points.

A unique linear radial thermal gradient is used for each mission point. Temperatures at two different radial points (disk bore and slot bottom) are provided as a reference; temperatures at all other radial stations vary linearly, proportional to the radius of interest. No axial or circumferential thermal gradients are assumed. An example of this radial temperature gradient is shown in figure A-10 for time point t = 642 seconds.



Note:
Contour plot to the left shows dimensions in inches and temperatures in degrees Fahrenheit.

Contour plot to the right shows dimensions in millimeters and temperatures in degrees Celsius

$$T(x)=\frac{(T_2-T_1)}{(x_2-x_1)}(x-x_1)+T_1$$

Figure A-10. Example of Test Case Linear Thermal Gradient at t=642s

A.2.5 Material and Crack Growth Data.

A.2.5.1 Material Properties Overview.

The stress analysis for this test case requires material properties for the disk and blade. Both components use the same alloy. Relevant material properties include Young's modulus of elasticity (E), material density (ρ), coefficient of thermal expansion (α), and Poisson's ratio (ν). Except for density, all properties vary with temperature. The reference temperature for zero thermal expansion is 68°F (20°C). See table A-2.

Table A-2. Test Case Physical Material Properties

Temperature (deg F)	Elastic Modulus (ksi)	Coef of Thermal Expansion 1E-6/°F	Poisson's Ratio
32	29000	6.90	0.290
68	29000	6.90	0.290
500	27600	7.50	0.297
700	26600	7.80	0.299
900	25700	8.00	0.303
950	25600	8.05	0.304
1000	25500	8.10	0.305
1100	24400	8.20	0.308
1150	24400	8.20	0.308

Temperature (deg C)	Elastic Modulus (MPa)	Coef of Thermal Expansion 1E-6/°C	Poisson's Ratio
0.0	199948.0	12.42	0.29
20.0	199948.0	12.42	0.29
260.0	190295.3	13.50	0.297
371.1	183400.5	14.04	0.299
482.2	177195.3	14.40	0.303
510.0	176505.8	14.49	0.304
537.8	175816.3	14.58	0.305
593.3	168232.1	14.76	0.308
621.1	168232.1	14.76	0.308

A.2.5.2 Material Properties.

The material density is defined as 0.29 lbm/in^3 (8027 kg/m^3). These material properties are representative of a commonly used alloy, but they have been modified specifically for this test case. These properties should not be used for detailed engineering design or certification.

A.2.5.3 Cyclic Crack Growth Data.

In addition to the physical data, cyclic fatigue crack growth properties necessary for crack growth calculations are provided. The crack growth assessments are based solely on cyclic crack growth without considering time-dependent effects or load interactions. The crack growth rates per cycle, as a function of the change in stress intensity (da/dN vs dK), are given using temperature-dependent constants fitted in the form of the sigmoidal model shown in equation A-1. Applicants may convert the provided model into an equivalent format suitable for their own analysis tools, such as:

- Tabular Input
- Hyperbolic Sine
- Nasgro equation
- Simple Paris law (if cyclic threshold is not considered).

$$\frac{da}{dN} = \exp(B)\left(\frac{Keff}{Kth}\right)^{P}\left[\ln\left(\frac{Keff}{Kth}\right)\right]^{Q}\left[\ln\left(\frac{Kcr}{Keff}\right)\right]^{D}$$

Equation A-1. Test Case Cyclic Crack Growth Rate

A.2.5.4 **Crack Growth Rates.**

The crack growth rates described in paragraph A.2.5.3 are displayed in tables A-3 and A-4. For reference:

- The cyclic crack growth threshold is denoted as Kth.
- The material fracture toughness is denoted as Kcr.

A.2.5.5 **R Ratio Corrections and Walker Model.**

R ratio corrections are applied using the Walker model, where the effective stress intensity Keff, is defined in equation A-2.

$$Keff = Kmax(1 - R)^{m}$$

Equation A-2. Walker model

Where:

- R is the stress intensity ratio, R=Kmin/Kmax
- $Kmax\ and\ Kmin$ = stress intensities at max and min stress points of the cycle pair.
- m is the Walker exponent.

A.2.5.6 **Temperature-Dependent Walker Exponent.**

The Walker exponent m varies with temperature, and its values are provided in tables A-3 and A-4. Depending on the computed R ratio:

- Use the m- column if R is negative.
- Use the m+ column if R is positive or zero.

Table A-3. Test Case Cyclic Crack Growth Rate Parameters (deg F)

Temperature (deg F)	Kth (ksi*sqrt(in))	Kcr (ksi*sqrt(in))	B	P	Q	D	m+	m-
32	5.0025	67.0	-15.062	0.517	1.668	-2.523	0.6845	0.0976
75	5.0025	67.0	-15.062	0.517	1.668	-2.523	0.6845	0.0976
500	7.00	67.0	-14.000	0.900	1.200	-1.800	0.6462	0.1401
700	7.94	67.0	-13.500	1.080	0.980	-1.460	0.6282	0.1601
900	8.88	67.0	-13.000	1.260	0.760	-1.120	0.6102	0.1801
1000	9.35	67.0	-12.750	1.350	0.650	-0.950	0.6012	0.1901
1100	9.82	67.0	-12.501	1.440	0.540	-0.780	0.5922	0.2001
1150	9.82	67.0	-12.501	1.440	0.540	-0.780	0.5922	0.2001

Table A-4. Test Case Cyclic Crack Growth Rate Parameters (deg C)

Temperature (deg C)	Kth (MPa*sqrt(m))	Kcr (MPa*sqrt(m))	B	P	Q	D	m+	m-
0.0	5.4970	73.6	-18.735	0.517	1.668	-2.523	0.6845	0.0976
23.9	5.4970	73.6	-18.735	0.517	1.668	-2.523	0.6845	0.0976
260.0	7.69	73.6	-17.673	0.900	1.200	-1.800	0.6462	0.1401
371.1	8.72	73.6	-17.173	1.080	0.980	-1.460	0.6282	0.1601
482.2	9.76	73.6	-16.673	1.260	0.760	-1.120	0.6102	0.1801
537.8	10.27	73.6	-16.423	1.350	0.650	-0.950	0.6012	0.1901
593.3	10.79	73.6	-16.174	1.440	0.540	-0.780	0.5922	0.2001
621.1	10.79	73.6	-16.174	1.440	0.540	-0.780	0.5922	0.2001

A.2.5.7 Elastic-Plastic Finite Element Analysis.

For notched locations where local plasticity may occur, it is common to "shake down" elastic stresses before performing crack growth analyses. Alternatively, a full elastic-plastic finite element analysis can be conducted. If plasticity is considered, the material's stress-strain properties (listed in tables A-5 and A-6) should be referenced and used along with the Ramberg-Osgood or Ludwick's model given in equation A-3.

$$\varepsilon_{total} = \varepsilon_{elastic} + \varepsilon_{plastic} = \frac{\sigma}{E} + \left(\frac{\sigma}{K}\right)^{\frac{1}{n}}$$

Equation A-3. Ramberg-Osgood Stress Strain Relationship

Table A-5. Test Case Material Constants to be Used for Considerations of Plasticity (deg F)

Temperature (deg F)	E (ksi)	K (ksi)	n
32	29,000	205.00	0.0500
68	29,000	205.00	0.0500
500	27,600	202.00	0.0500
700	26,600	200.00	0.0500
900	25,700	195.00	0.0500
950	25,600	200.00	0.0580
1000	25,500	205.00	0.0660
1100	24,400	210.00	0.0750
1150	24,400	210.00	0.0750

Table A-6. Test Case Material Constants to be Used for Considerations of Plasticity (deg C)

Temperature (deg C)	E (MPa)	K (MPa)	n
0.0	199,955	1413.43	0.0500
20.0	199,955	1413.43	0.0500
260.0	190,302	1392.74	0.0500
371.1	183,407	1378.95	0.0500
482.2	177,202	1344.48	0.0500
510.0	176,512	1378.95	0.0580
537.8	175,823	1413.43	0.0660
593.3	168,238	1447.90	0.0750
621.1	168,238	1447.90	0.0750

A.2.6 Anomaly Distribution Curve.

The anomaly distribution, provided in appendix B, defines the probability of occurrence as a function of anomaly depth. No POF benefit is assumed from manufacturing credits for the component in the test case.

A.2.7 Inspection POD.

The POD curve used to determine the effect of an in-service inspection is shown in table D-1. This table is consistent with figure A4-1 of AC 33.70-2. The test case assumes one directed fluorescent penetrant inspection (FPI) at the component's mid-life (1500 flight cycles). The POD relates the probability of detecting an anomaly to flaw length, using the convention shown in figure A-11.

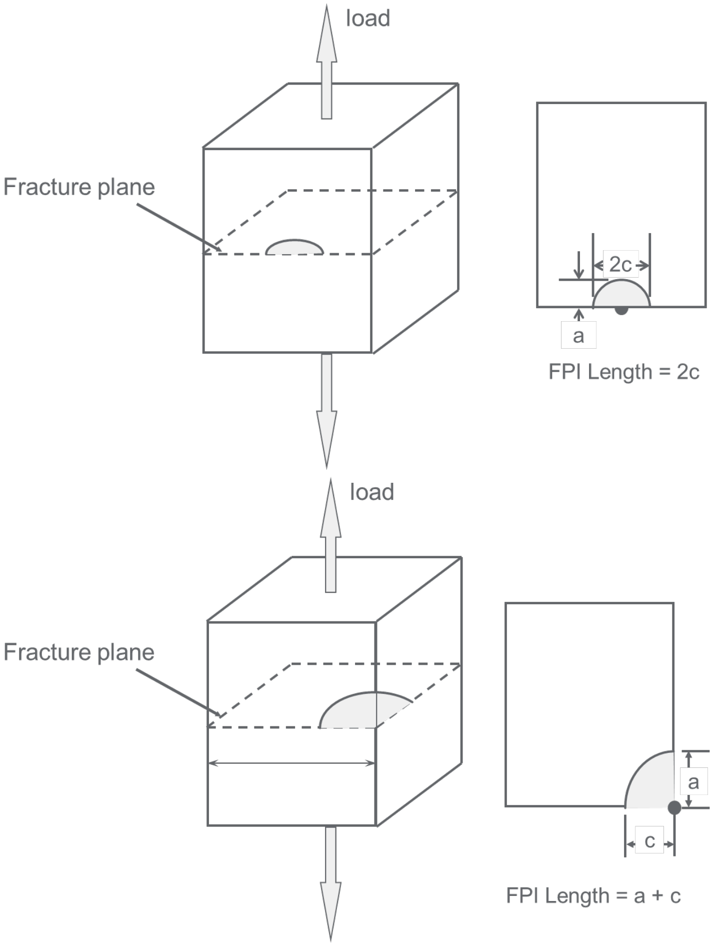


Figure A-11. Test Case Conventions Used for Test Case Inspection Scenario

A.3 Test Case Analysis Guidelines.

Analytical guidelines for probabilistic assessments are provided with the intent to minimize the variations of the manufacturer's results due to analytical assumptions. The test case presented is based on a typical surface anomaly probabilistic fracture-mechanics approach. The blade slot test case considers an anomaly located on the slot surface and on the slot edge (figure A-12). The POF is to be computed for each location. This analytical approach can be broken down into the following steps:

- Stress analysis.
- Slot location definition (maximum principal stress location).
- Crack growth model definition.
- Crack growth calculations.
- Relative risk calculation.

A.3.1 Stress Analysis.

The applicant should follow their own best practices for performing stress analysis for each time point of the mission profile. This includes:

- Selecting the level of mesh refinement.
- Handling blade attachment (assume frictionless contact).
- Accounting for material and geometric non-linearities.

Acceptable results have been obtained using various mesh refinement levels and blade attachment interface methods.

A.3.2 Slot Location Definition (Max Principal Stress Location).

The risk assessment should focus on locations where maximum principal stress occurs during the mission. These locations include:

- Slot surface.
- Slot edge (figure A-12).

The crack's center should be placed at the maximum principal stress location.

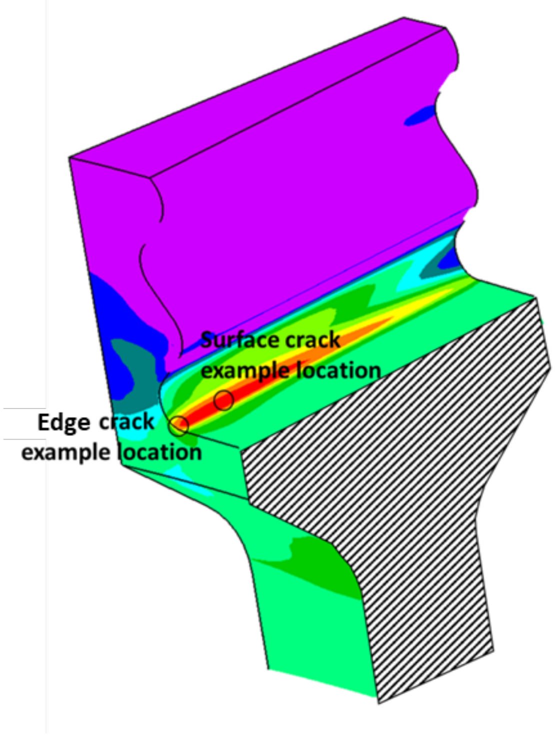


Figure A-12. Test Case Anomaly Placement within Test Case

A.3.3 Crack Growth Model Definition.

For each location defined in figure A-12, develop a crack growth model using the following assumptions:

- Surface Cracks: Use a 2:1 aspect ratio for a semi-circular crack, with surface length (2c) equal to twice the depth (a).
- Corner Cracks: Use a 1:1 aspect ratio for a quarter-circle crack, with surface length (c) equal to the depth (a).
- Orientation of the crack plane should be normal to the maximum principal stress.
- Ensure that plate geometry does not extend outside the physical boundaries of the component.

A.3.4 Crack Growth Calculations.

Perform crack growth calculations based on the predicted stresses and crack growth rate data. These calculations determine the residual life (life to failure from an assumed crack size) for each location. Conduct the calculations for a range of initial crack sizes to ensure that the component service life is covered. These are the guidelines for crack growth calculations:

- Assume all anomalies act as sharp propagating cracks, with no incubation/nucleation life.
- The crack plane should be oriented perpendicular to the maximum principal stress at the crack origin. Once defined the plane should remain fixed.
- Consider the impact of stress gradients.
- Use crack growth rate data provided for the test case.
- The effect of beneficial surface residual stresses, such as shot peening, should not be considered in the test case.
- Use a representative stress intensity factor solution for surface and corner cracks.
- A TMF method is prescribed to ensure consistency. The TMF method is used to consider how fast a crack will grow when the temperature and stress profiles are out of phase i.e., the timepoints associated with the peak stress and temperature in the loading cycle are not the same.

  Note: The TMF method described in this AC consists of a stress rainflow (based on absolute stress) to determine the mission point's pairs (peaks & valleys). Then, for each pair, the higher temperature of the pair's points is used for the crack growth calculation. Figure A-13 shows the normalized (value/maximum) stress and temperature excursions at the slot bottom of the AC test case, where useful mission points were identified using letters A through F. Applying the prescribed TMF method to this mission profile results in the stress pairs and crack growth rate evaluation temperatures given in table A-7.

A.3.5 Relative Risk Calculation.

A.3.5.1 POF for Limiting Locations.

The POF for both limiting locations (slot surface and slot edge) should be calculated based on the following factors:

- The provided anomaly distribution.
- Predicted crack growth life.
- Component service life.
- POD (see paragraph A.2.7).

A.3.5.2 Analysis Assumptions.

For this analysis:

- Consider anomalies as sharp cracks with no incubation life.
- Assume a single FPI at half the component service life.
- Assume 100% of the fleet is inspected.

A.3.5.3 Calculate Relative Risk or POF.

To calculate the relative risk or POF for the component, adjust the POF prediction for a single slot using equation A-4. Assume:

- One anomaly per slot
- 72 slots on the disk.
- Service life of 3000 flight cycles.
- $\mathrm{POF}_{\mathrm{slot}}$ is the probability of fracture of a single slot at or before the component service life.
- No manufacturing credits (value = 1.0).

$$\mathrm{POF}_{\mathrm{component}} = 1 - \left(1 - \frac{\mathrm{POF}_{\mathrm{slot}}}{\text{Manufacturing Credits}}\right)^{\mathrm{N}_{\mathrm{eff}}}$$

Equation A-4. Test Case Component Level POF Calculation

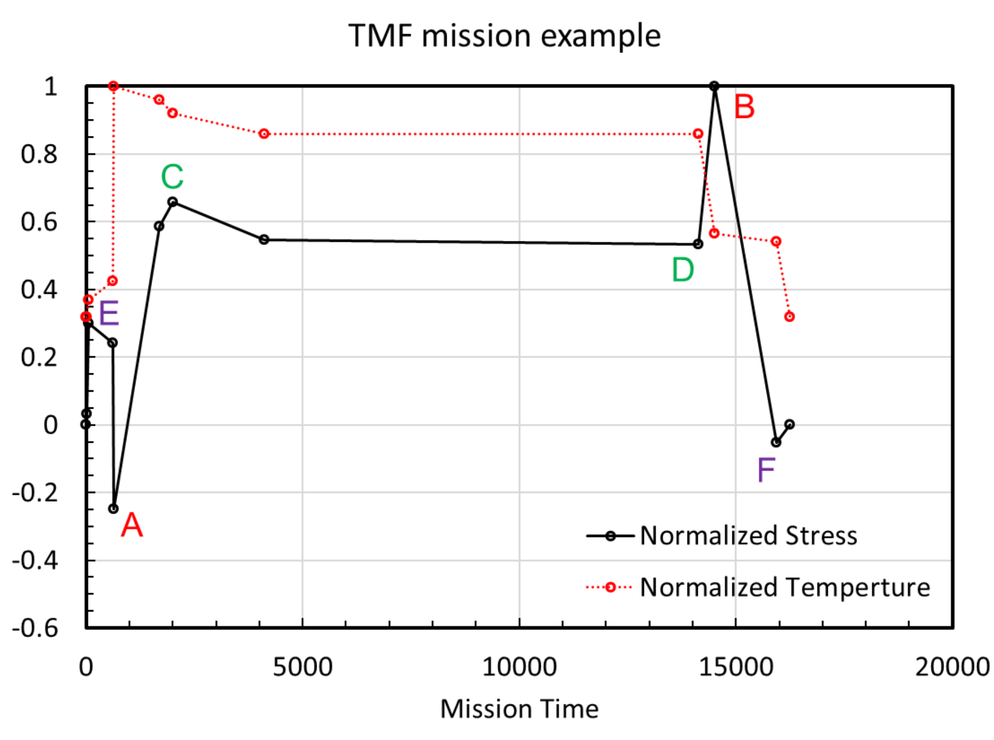


Figure A-13. Test Case TMF Mission Example

Table A-7. Test Case Prescribed TMF Method Results

Pair	Max Stress	Min Stress	Temperature
1	Point B	Point A	Point A
2	Point C	Point D	Point C
3	Point E	Point F	Point F

A.4 Test Case Results.

A.4.1 OEM Results.

This test case has been analyzed independently by several OEMs, and a statistical analysis of their results, given in events per service life, is provided in table A-8 (where m = mean value; s = sample standard deviation).

Table A-8. Test Case Acceptable Component POF Results for the Slot Locations

Location	**Failure Risk Events/Service Life**	**Mean value: m**	**m – 1.65 s**	**m + 1.65 s**
Slot Surface	Without in-service inspection	9.15E-05	8.14E-05	1.03E-04
	With an in-service directed FPI inspection	6.10E-05	4.95E-05	7.52E-05
Slot Edge	Without in-service inspection	4.74E-05	3.74E-05	6.02E-05
	With an in-service directed FPI inspection	1.74E-05	1.06E-06	2.86E-05

A.4.2 Acceptance Criteria.

All results within the range (m-1.65s, m+1.65s) for both conditions are considered acceptable. This range is the interval centered on the mean value covering 90 percent of the result population assuming a log-normal distribution.

A.4.3 Geometry Verification.

Due to the complexity of axial blade slots (figures A-3 through A-8), verifying the geometry used in the finite element analysis is crucial. Based on results from seven independent analyses, the peak surface stress in the axial blade slot should fall within the range of 172 ksi to 177.1 ksi. Paragraph 1.3.3 provides neutral files that contain the test case geometry and may be used to generate the finite element model. Most commercial finite element software packages can read these files directly. If any conflicts arise between the geometry shown in figures A-3 through A-8 and the neutral files, use the neutral file.

APPENDIX B. DEFAULT ANOMALY DISTRIBUTION CURVES.

B.1 Manufacturing Anomaly Distribution Curve for Disk Axial Blade Slots.

B.1.1 Overview of Anomaly Distribution Curve.

This appendix provides the anomaly distribution curve for manufacturing-induced anomalies in axial blade slots of titanium and nickel engine rotors.

B.1.2 Explanation of Probability of Exceedance Curve.

Figure B-1 shows the probability of an exceedance curve for manufacturing-induced anomalies in axial blade slots. This curve represents the likelihood of having an anomaly greater than a given depth in a single disk slot.

- Horizontal Axis: Represents anomaly depth (in inches).
- Vertical Axis: Represents the probability of exceedance, or the chance that an anomaly larger than depth x exists in a single slot.

B.1.3 Tabular Data and Default Anomaly Exceedance Curve Equation.

Table B-1 provides the tabular data corresponding to the curve in figure B-1. The probability of exceedance for different anomaly depths is defined by the following equation:

- Imperial units: $F(x) = 1.97E - 06 * 1.0635 * EXP\,(-61.546 * x)$
- SI units: $F(x) = 1.97E - 06 * 1.0635 * EXP\,(-2.4230 * x)$

Where:

- $x \geq 0.001$ in (or $x \geq 0.0254$ mm) is anomaly depth in inches (or millimeters)
- $F(x)$ is the exceedance probability per slot.

B.1.4 Application of the Exceedance Curve.

The exceedance curve shown in figure B-1 applies to both the slot bottom surface and the slot bottom edge. This distribution is based on a per-slot unit and does not account for size effects such as surface area or edge length at the slot bottom.

Figure B-1. Distribution for Manufacturing Induced Anomalies in Axial Blade Slots

Table B-1. Tabular Data for Figure B-1

Depth (in)	Depth (mm)	Exceedance (-)
0.0010	0.0254	1.970E-06
0.0020	0.0508	1.852E-06
0.0030	0.0762	1.742E-06
0.0040	0.1016	1.638E-06
0.0050	0.1270	1.540E-06
0.0060	0.1524	1.448E-06
0.0070	0.1778	1.362E-06
0.0080	0.2032	1.280E-06
0.0090	0.2286	1.204E-06
0.0100	0.2540	1.132E-06
0.0110	0.2794	1.065E-06
0.0120	0.3048	1.001E-06
0.0130	0.3302	9.413E-07
0.0140	0.3556	8.851E-07
0.0150	0.3810	8.323E-07
0.0160	0.4064	7.826E-07
0.0170	0.4318	7.359E-07
0.0180	0.4572	6.919E-07
0.0190	0.4826	6.506E-07
0.0200	0.5080	6.118E-07
0.0210	0.5334	5.753E-07
0.0220	0.5588	5.409E-07
0.0230	0.5842	5.087E-07
0.0240	0.6096	4.783E-07
0.0250	0.6350	4.497E-07
0.0260	0.6604	4.229E-07
0.0270	0.6858	3.977E-07
0.0280	0.7112	3.739E-07
0.0290	0.7366	3.516E-07
0.0300	0.7620	3.306E-07
0.0350	0.8890	2.430E-07
0.0400	1.0160	1.787E-07
0.0500	1.2700	9.655E-08
0.0600	1.5240	5.217E-08
0.0700	1.7780	2.819E-08
0.0800	2.0320	1.524E-08
0.0900	2.2860	8.233E-09
0.1000	2.5400	4.449E-09

APPENDIX C. DEFAULT PROBABILITY OF DETECTION (POD) APPLICABILITY

C.1 Use of Default Probability of Detection (POD) Data.

C.1.1 Use of Default POD Data.

C.1.1.1 This appendix defines conditions for using accepted estimates of POD for specific anomalies and nondestructive evaluation/inspection techniques. These estimates may be used as default values under appropriately similar conditions.

C.1.1.2 It is important to note that the conditions in this appendix do not guarantee the validity of these POD values. For example, if key inspection parameters, such as penetrant concentration or temperature, are not properly controlled, the penetrant's capability will not be attained—even if the correct penetrant is used. A written plan for controlling and monitoring inspection processes is recommended (see paragraph C.3).

C.1.2 Importance of Inspection Conditions.

If the inspection conditions described in this appendix are not met, inspection capability and reliability will be reduced. In such cases, the default POD values in appendix D would not apply and could lead to an overly optimistic damage tolerance assessment.

C.2 Demonstrating Inspection Capability.

C.2.1 Use of Default ECI POD Curve.

A default POD curve for ECI is provided in appendix D. The use of this default curve must be based on a demonstration that the stated calibration and reject signal levels are achievable on the component being inspected. Conditions such as noise or geometric features should not interfere with these levels. To demonstrate inspectability, the following conditions must be met:

- Proper calibration is maintained.
- Reject signal levels are achieved.
- Conditions such as surface features, depth to be inspected, and proximity to edges are considered.

No further demonstration of capability is required if these conditions are satisfied (see paragraphs C.3 through C.5).

C.2.2 Improving POD Through Demonstration.

For well-controlled inspection techniques, manufacturers may achieve better POD values than the default values. Improved capability may be used if supported by a well-documented demonstration program. Similarly, if inspection conditions fall outside of the default values, a demonstration program may be necessary to establish appropriate POD values.

C.3 General Applicability and Restrictions.

C.3.1 Inspection Process Control.

The inspection process must be controlled and performed in accordance with acceptable procedures, such as those outlined in the engine standard practices manual. Procedures should align with good industrial practices, such as MIL-STDs or equivalent industry standards.

C.3.2 Written Procedures for Inspection Parameters.

Parameters such as coverage, probe indexing, and scanning speeds should be governed by written procedures (see paragraph 3.5 of chapter 3 and paragraphs C.4-C.5 of this appendix). Inspection plans and fixturing should be designed to minimize human and other sources of variability.

C.3.3 Inspector Qualifications.

Inspectors must be fully qualified and trained under one of the following standards:

- NAS410 prEN4179
- MIL-STD-410
- ASNT-TC-1A
- ATA-105
- Equivalent standards

Inspectors must also receive specific training for the inspection method used.

C.3.4 Material and Geometric Considerations.

The default ECI and FPI POD data apply to all materials. However, geometric conditions such as radii and edges may prevent inspection. There are also limitations on the depth of penetration and near-surface resolution. Areas of high compressive residual stress may negatively affect inspection capability, particularly for penetrant inspection. See paragraphs C.4 and C.5 for conditions under which the default data were acquired. Seek advice about the equivalence of alternative conditions from those experienced in NDE.

C.3.5 Surface Conditions.

The default POD data only applies to components with normal surface conditions that have been properly cleaned according to shop manual requirements. No special pre-inspection cleaning or polishing is required.

C.4 ECI: Applicability and Restrictions.

C.4.1 ECI Overview.

ECI is used to detect surface or near-surface anomalies, particularly in engine-run components. The default POD data were acquired under the following conditions:

- Probes containing absolute coils, with inspection frequencies between 2-6 MHz.
- Probe fixtures capable of following surface contours of the component being inspected, with controlled lift-off, scan indexing, and attitude.
- The scan direction was parallel to uniform feature changes.
- Automatic recording or alarm triggering, or both, when inspection thresholds were exceeded.

C.5 Penetrant Inspection (PT/FPI): Applicability and Restrictions.

C.5.1 Penetrant Inspection Overview.

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

- FPI qualified to level 4 (per MIL-I-25135 or equivalent), used with dry powder developer as a minimum.
- Application of penetrant and developer was automated or followed standard practices (e.g., MIL-STD-6866, AMS-2847).
- Parts could be manipulated to present an unimpeded surface view to the inspector.

C.6 Crack Characteristics and Limitations

C.6.1 The default POD data apply to surface-connected, low-cycle fatigue cracks. Cracks are assumed to have a 2:1 aspect (length to depth) ratio. Crack sizes are plotted in terms of the length at the surface. The inspection PODs provided relate the flaw detection probability to the flaw length. Different interpretations are possible for what constitutes the flaw “length”, particularly for corner flaws. For consistency, the flaw length is defined using the convention in figure C-1.

C.6.2 Cracks must not be obscured by oxide, contaminants, etc. Inspected surfaces should be flat or only moderately curved. The choice of the appropriate POD curve from those provided must be based on component demonstration of the attainable inspection sensitivity (see paragraph C.2).

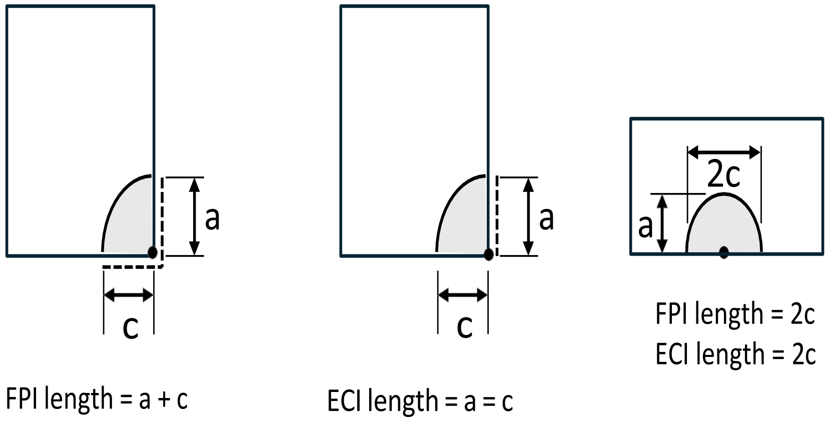


Figure C-1. Crack Dimension Conventions to be Used with POD Curves

APPENDIX D. DEFAULT POD CURVES

D.1 Overview.

This appendix provides default POD curves that can be used for assessing manufacturing-induced anomalies in axial blade slots. The following figures and tables present the relevant POD data for FPI and ECI.

D.1.1 Figure D-1 illustrates the POD for FPI of finish-machined surfaces, with detection probabilities versus anomaly length.

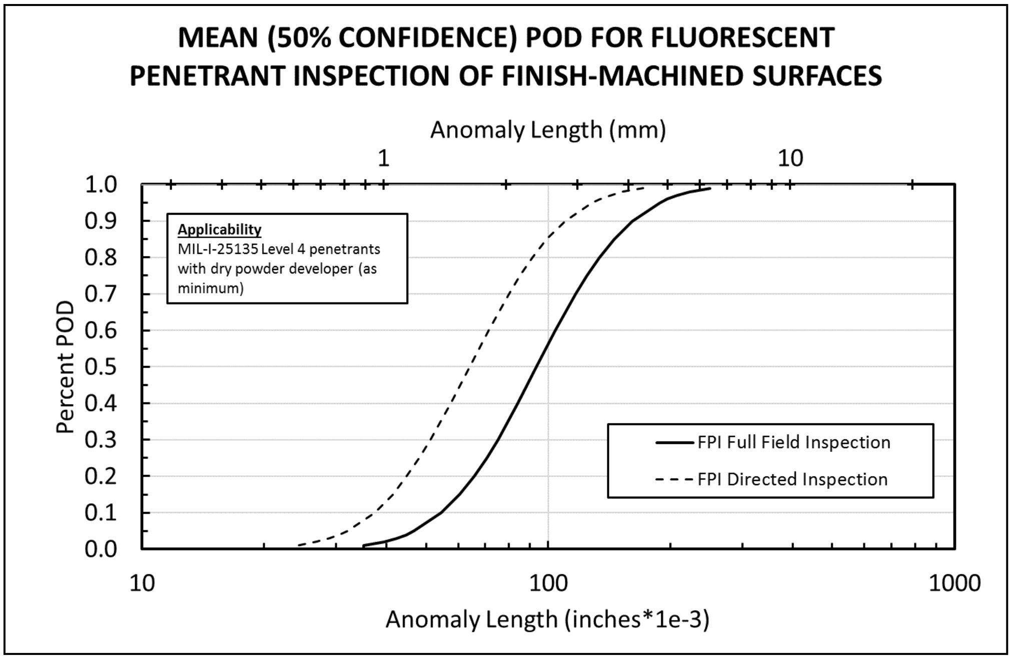


Figure D-1. POD for FPI of Finish Machined Surfaces

D.1.2 Table D-1 provides tabulated data for FPI directed inspection, providing POD values versus anomaly lengths in both inches and millimeters.

Table D-1. Tabulated FPI POD (Directed Inspection)

FPI Directed Inspection		
Length (inches*1e-3)	**Length (mm)**	**Percent POD**
1.595769	0.04053254	1.0E-09
24.00028	0.6096072	1.0E-09
24.00553	0.6097406	1.0E-02
26.93207	0.6840747	2.0E-02
28.97132	0.7358715	3.0E-02
30.60642	0.7774030	4.0E-02
32.00434	0.8129103	5.0E-02
37.30716	0.9476018	1.0E-01
41.37288	1.050871	1.5E-01
44.91788	1.140914	2.0E-01
48.20028	1.224287	2.5E-01
51.35204	1.304342	3.0E-01
57.57499	1.462405	4.0E-01
64.07147	1.627415	5.0E-01
71.30106	1.811047	6.0E-01
79.94166	2.030518	7.0E-01
85.16879	2.163287	7.5E-01
91.39258	2.321372	8.0E-01
99.22348	2.520276	8.5E-01
110.0367	2.794932	9.0E-01
128.2688	3.258027	9.5E-01
134.1273	3.406834	9.6E-01
141.6973	3.599111	9.7E-01
152.4264	3.871630	9.8E-01
171.0088	4.343624	9.9E-01

D.1.3 Table D-2 provides tabulated data for FPI full-field inspection, providing POD values versus anomaly lengths in both inches and millimeters.

Table D-2. Tabulated FPI POD (Full Field Inspection)

FPI Full Field Inspection		
Length (inches*1e-3)	**Length (mm)**	**Percent POD**
1.595769	0.04053254	1.0E-09
35.09967	0.8915315	1.0E-09
35.10289	0.8916135	1.0E-02
39.38237	1.000312	2.0E-02
42.36435	1.076054	3.0E-02
44.75531	1.136785	4.0E-02
46.79948	1.188707	5.0E-02
54.55360	1.385662	1.0E-01
60.49880	1.536670	1.5E-01
65.68272	1.668341	2.0E-01
70.48261	1.790258	2.5E-01
75.09107	1.907313	3.0E-01
84.19100	2.138451	4.0E-01
93.69081	2.379747	5.0E-01
104.2626	2.648270	6.0E-01
116.8975	2.969196	7.0E-01
124.5410	3.163340	7.5E-01
133.6419	3.394505	8.0E-01
145.0930	3.685362	8.5E-01
160.9054	4.086998	9.0E-01
187.5657	4.764168	9.5E-01
196.1323	4.981760	9.6E-01
207.2019	5.262928	9.7E-01
222.8907	5.661425	9.8E-01
250.0637	6.351618	9.9E-01

D.1.4 Figure D-2 illustrates the POD for ECI of finish-machined surfaces, with detection probabilities versus anomaly length.

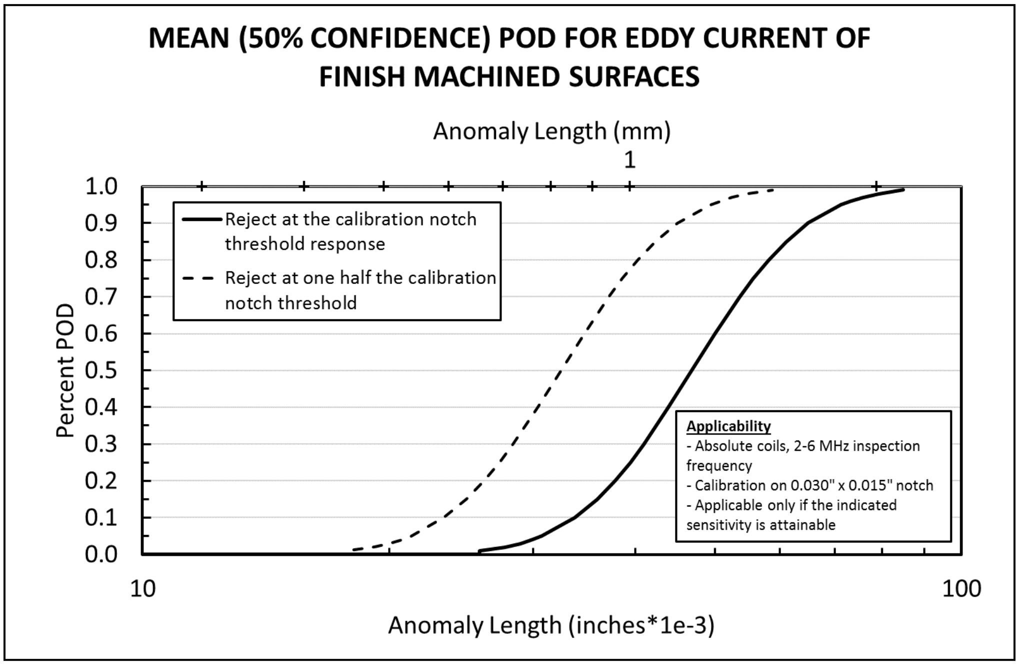


Figure D-2. POD for ECI of Finish Machined Surfaces

D.1.5 Table D-3 provides tabulated data for ECI inspection POD values versus anomaly lengths in both inches and millimeters assuming a 2:1 aspect ratio with rejection at half calibration threshold.

Table D-3. Tabulated ECI POD (Rejection at Half Calibration Threshold)

Reject at one half the calibration notch threshold				
Length (inches*1e-3)	**Length (mm)**	**Depth (inches*1e-3)**	**Depth (mm)**	**Percent POD**
1.595769	0.04053254	0.7978846	0.02026627	1.0E-09
17.86264	0.4537110	8.931319	0.2268555	1.0E-09
17.86855	0.4538611	8.934273	0.2269305	1.0E-02
19.16002	0.4866646	9.580011	0.2433323	2.0E-02
20.02744	0.5086970	10.01372	0.2543485	3.0E-02
20.70572	0.5259252	10.35286	0.2629626	4.0E-02
21.27437	0.5403690	10.63719	0.2701845	5.0E-02
23.34793	0.5930375	11.67397	0.2965188	1.0E-01
24.85996	0.6314431	12.42998	0.3157216	1.5E-01
26.13121	0.6637328	13.06561	0.3318664	2.0E-01
27.27351	0.6927472	13.63676	0.3463736	2.5E-01
28.34183	0.7198825	14.17092	0.3599412	3.0E-01
30.37831	0.7716090	15.18915	0.3858045	4.0E-01
32.41384	0.8233115	16.20692	0.4116558	5.0E-01
34.58577	0.8784785	17.29288	0.4392392	6.0E-01
37.07089	0.9416007	18.53545	0.4708004	7.0E-01
38.52298	0.9784838	19.26149	0.4892419	7.5E-01
40.20698	1.021257	20.10349	0.5106286	8.0E-01
42.26301	1.073481	21.13151	0.5367403	8.5E-01
45.00000	1.143000	22.50000	0.5715000	9.0E-01
49.38604	1.254405	24.69302	0.6272027	9.5E-01
50.74237	1.288856	25.37118	0.6444281	9.6E-01
52.46087	1.332506	26.23044	0.6662531	9.7E-01
54.83590	1.392832	27.41795	0.6964159	9.8E-01
58.79925	1.493501	29.39962	0.7467504	9.9E-01

D.1.6 Table D-4 provides tabulated data for ECI inspection POD values versus anomaly lengths in both inches and millimeters assuming a 2:1 aspect ratio with rejection at calibration threshold.

Table D-4. Tabulated ECI POD (Rejection at Calibration Threshold)

Reject at the calibration notch threshold response				
Length (inches*1e-3)	**Length (mm)**	**Depth (inches*1e-3)**	**Depth (mm)**	**Percent POD**
1.595769	0.04053254	0.7978846	0.02026627	1.0E-09
25.81005	0.6555754	12.90503	0.3277877	1.0E-09
25.81012	0.6555771	12.90506	0.3277886	1.0E-02
27.67559	0.7029599	13.83779	0.3514800	2.0E-02
28.92853	0.7347846	14.46426	0.3673923	3.0E-02
29.90826	0.7596697	14.95413	0.3798348	4.0E-02
30.72965	0.7805330	15.36482	0.3902665	5.0E-02
33.72479	0.8566098	16.86240	0.4283049	1.0E-01
35.90884	0.9120845	17.95442	0.4560422	1.5E-01
37.74508	0.9587251	18.87254	0.4793625	2.0E-01
39.39507	1.000635	19.69754	0.5003174	2.5E-01
40.93820	1.039830	20.46910	0.5199151	3.0E-01
43.87978	1.114546	21.93989	0.5572732	4.0E-01
46.81999	1.189228	23.41000	0.5946139	5.0E-01
49.95722	1.268913	24.97861	0.6344567	6.0E-01
53.54684	1.360090	26.77342	0.6800449	7.0E-01
55.64431	1.413366	27.82216	0.7066828	7.5E-01
58.07675	1.475149	29.03837	0.7375747	8.0E-01
61.04656	1.550583	30.52328	0.7752914	8.5E-01
65.00001	1.651000	32.50000	0.8255001	9.0E-01
71.33540	1.811919	35.66770	0.9059595	9.5E-01
73.29453	1.861681	36.64726	0.9308405	9.6E-01
75.77682	1.924731	37.88841	0.9623657	9.7E-01
79.20741	2.011868	39.60371	1.005934	9.8E-01
84.93224	2.157279	42.46612	1.078639	9.9E-01

D.2 [Reserved.]

APPENDIX E. DEFINITION OF AN AXIAL BLADE SLOT FOR MANUFACTURING ANOMALY ASSESSMENT

E.1 **Definition and Description of Axial Blade Slots.**

E.1.1 General Description of Axial Blade Slots.

Axial blade slots are a set of nominally identical features within the same component, typically one per blade root, located at the same nominal radius, usually in the rim of a disk.

- Each blade slot is positioned radially along the disk rim, providing a mechanical constraint.
- Blade slots are typically located at the same nominal radius for uniformity.
- Figure E-1 provides an example of a component with two axial blade slot features. Each feature consists of a set of axial blade slots.

E.1.2 Common Manufacturing Methods.

Axial blade slots are manufactured using a common method and can have the following configurations:

- Dovetail Root Form: Blades with a dovetail root form, as shown in figure E-2, have a single pair of contact faces.
- Firtree Root Form: Blades with a firtree root form, as shown in figure E-3, have multiple pairs of contact faces.

The blades are assembled into the slots predominantly parallel to the engine’s axis of rotation.

E.1.3 Edge and Surface Features for Assessment.

Edge features extend between the points on either side of the blade slot, associated with the minimum disk post thickness, located radially inboard of the lowest blade-disk contact point.

- Edges to Assess: Assess the edges on both the front and rear faces of the disk.
- Surface for Assessment: The surface within the slot is defined by connecting the extreme points of the edge features.

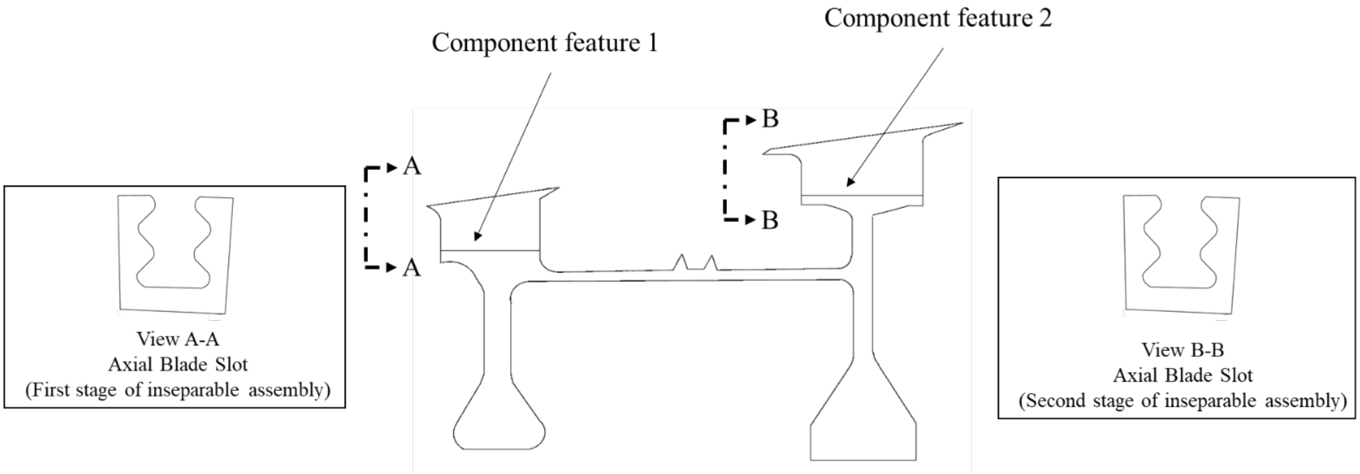


Figure E-1. Example of Axial Blade Slot Component Features

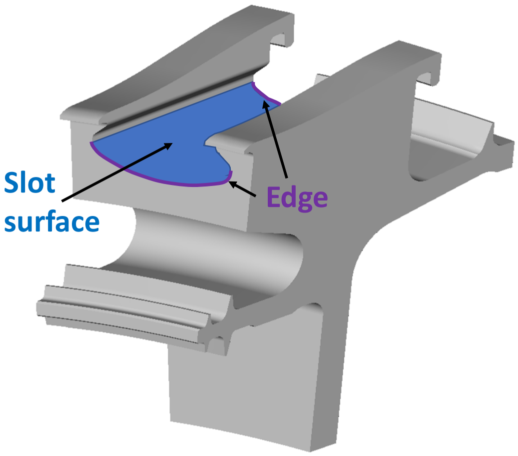


Figure E-2. Example Dovetail Axial Blade Slot Geometry and Definition of the Features Covered by this AC

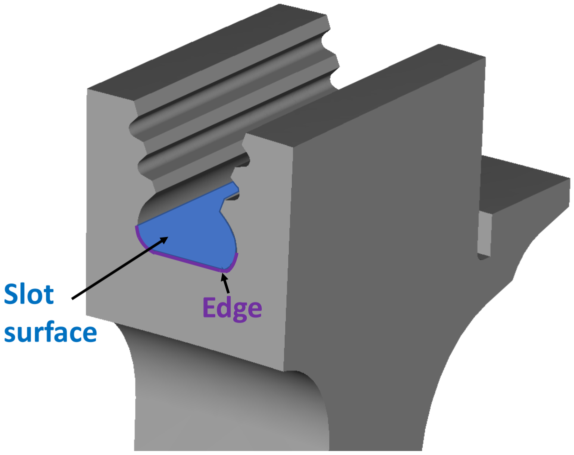


Figure E-3. Example Firtree Axial Blade Slot Geometry and Definition of the Features Covered by this AC

E.2 [Reserved.]

APPENDIX F. MANUFACTURING CREDITS

F.1 Overview of Manufacturing Credits.

F.1.1 This appendix contains the approach for taking credit for enhanced axial blade slot manufacturing processes in the POF calculations to meet the axial blade slots feature DTR. A process and rationale were developed by the AIA Rotor Integrity Steering Committee to establish the manufacturing credits promoting enhanced manufacturing of axial blade slots.

F.1.2 The manufacturing credits are applied in two ways:

- the application of a defined credit specific to the manufacturing process to reduce the actual risk calculated for the part, and
- a reduction in the number of “effective” slots used in the risk calculation.

The manufacturing credits are defined in tables F-1 and F-2. The process for determining the number of effective slots to use in the risk calculation is described below. Tables F-1 and F-2 outline the manufacturing credits.

F.1.3 The approach for calculating the number of effective slots centers on the concept that an automated means of manufacturing should reduce the risk associated with producing a poorly manufactured slot compared to a purely manual process and that the risk associated with manufacturing multiple slots in a disk is further reduced significantly with an automated process.

F.1.4 An expression has been derived that defines an “effective number of slots” (Neff) based on the ratio of the manufacturing credits being claimed for automation compared to the maximum possible credit for automation. If a purely manual process is used to manufacture the axial blade slots, then the effective number of slots is equal to the actual number of slots. Conversely, if a purely automated process is used with full process monitoring, then the effective number of slots can be reduced significantly.

F.2 Calculation of Effective Number of Slots.

F.2.1 The expression for Neff is as follows:

$$Neff = N \; if \; N <= 90$$

$$Neff = 90 + (1 - a) * (N - 90) \; if \; N > 90$$

Where:

- N = actual number of slots.
- a = (Automated manufacturing credits being applied) / (Maximum value of automated manufacturing credits available (15 for edges, 20 for surfaces))

F.2.2 Specifically for edges.

- a = 0 for a manual process
- a = 5/15 = 1/3 for Semi-Automated (Manual Deburr) (table F-2)
- a = 8/15 for Semi-Automated (Manual Finish) (table F-2)
- a = 0.9 for Fully Automated

F.2.3 Specifically for surfaces.

- a = 0 for a manual process
- a = 5/20 = 1/4 for Machine Condition (table F-1)
- a = 10/20 = 1/2 for Machine Condition & Fluid Monitoring (table F-1)
- a = 0.9 for Machine Condition and Fluid Monitoring Process Monitoring

The relationship between Neff and N for this approach is shown in figure F-1. Note that Neff is always rounded up to the nearest integer.

Table F-1. Slot Surfaces – Process Controls, Control Definitions, and Credit Factor

Process control	**Definition**	**Credit Factor**	**Used for:**
Process Validation and Control Plan	The most recent revision of the DOT/FAA/TC-23/8 report (see paragraph 1.3.3) should be used to define an appropriate means of process validation and associated manufacturing control plan. A successful process validation and control plan means the manufacturing intent is met throughout the component production run.	5	Risk reduction
Machine Condition, Fluid & Fluid Condition, Tooling, and Setup Validation	The machine condition is periodically evaluated to validate it is capable of delivering product meeting the manufacturing intent. The fluid is directed to the cutting zone during the machining operation. The fluid condition is maintained. Cutting tool design, material properties, fabrication (new & resharpened) and geometry are controlled. Cutting tool condition is	5	Number of effective slots (see Paragraph F.2) Risk reduction

Process control	**Definition**	**Credit Factor**	**Used for:**
	monitored to preclude excessively worn or broken cutting tools. A cutting trial is used to validate the setup produces acceptable component geometry and prescribed material removal.		
Fluid Monitoring	A real time, automated monitoring strategy which has the capability to ensure the fluid volume and flow to the cutting zone are maintained within validated process limit(s) and can interrupt the process when the established limit(s) are violated. This includes directional control of the fluid without human intervention and maintaining the fluid condition.	5	Number of effective slots (see Paragraph F.2) Risk reduction
Process Monitoring	A real time, automated monitoring strategy which has the capability to identify when the process varies outside the established validated process limit(s) and can interrupt the process when the established validated process limit(s) are violated. Feedback from the monitoring should be used to ensure the process remains within the acceptable validated range. Credit for process monitoring requires the use of fluid monitoring.	10	Number of effective slots (see Paragraph F.2) Risk reduction
Geometry Inspection	Axial Blade Slot Geometry inspection: The credit applies only to the axial blade slot surface and not the edge.	2	Risk reduction

Process control	**Definition**	**Credit Factor**	**Used for:**
Surface Condition Inspection Note: Only one of these credits may be claimed.	Non-Destructive Method: A quantitative non-destructive evaluation method(s) to ensure the surface condition (that is, metallography, finish and residual stress) of the axial slot or slot edge remains within the acceptable range to meet the manufacturing intent. The credit applies only to the location where the inspection is applied.	5	Risk reduction
	Cutup: A representative periodic test sample cutup to ensure the surface metallography of the axial slot or slot edge remains within the acceptable range to meet the manufacturing intent**.**	2	Risk reduction
	Etch: Etchants able to detect distorted surface metallography when combined with an appropriate visual standard reference. Caution: An etched surface can reduce the fatigue capability of the material and should be evaluated as part of the approved lifing method of the component.	2	Risk reduction

Table F-2. Slot Edges – Process Controls, Control Definitions, and Credit Factor

Process control	**Definition**	**Credit Factor**	**Used for:**
Edge Processing Process Validation and Control plan	Process validation of edge processing method(s) shall include upstream operations to ensure incoming edge conditions are not detrimental to the edge processing method(s). A successful process validation and control plan means the manufacturing intent is met throughout the component production run.	5	Risk reduction

Process control	**Definition**	**Credit Factor**	**Used for:**
Edge Processing: Semi-Automated Method of Manufacturing	Manual Deburr and Pre-Form: A manual process is used to deburr and pre-form the edge geometry prior to final edge geometry generation and finishing by automated method(s). The automated method(s) at time of process validation should demonstrate the ability to remove any damage caused by the prior manual preparation method.	5	Number of effective slots (see Paragraph F.2) Risk reduction Note: Only one of these credits may be claimed.
Edge Processing: Manual Finishing	Manual Finishing: An automated deburring and edge break method(s) is (are) used to form the edge geometry and produce a nearly finished edge condition. Final finishing is completed by manual method(s) involving soft tooling such as paper or cloth, without the use of power tools.	8	
Edge Processing: Automated Method of Manufacturing	Automated method(s) is (are) used for deburring, edge geometry generation, and finishing.	15	
Geometry Inspection	Edge Geometry inspection: The credit applies only to the edge and not the axial blade slot surface.	5	Risk reduction
Edge Condition Inspection Note: Only one of these credits may be claimed.	Non-Destructive Method: A quantitative non-destructive evaluation method(s) to ensure the surface condition (that is, metallography, finish and residual stress) of the axial slot or slot edge remains within the acceptable range to meet the manufacturing intent. The credit applies only to the location where the inspection is applied.	5	Risk reduction

Process control	**Definition**	**Credit Factor**	**Used for:**
	Cutup: A representative periodic test sample cutup to ensure the surface metallography of the axial slot or slot edge remains within the acceptable range to meet the manufacturing intent.	2	Risk reduction
	Etch: Etchants able to detect distorted surface metallography when combined with an appropriate visual standard reference. Caution: An etched surface can reduce the fatigue capability of the material and should be evaluated as part of the approved lifing method of the component.	2	Risk reduction

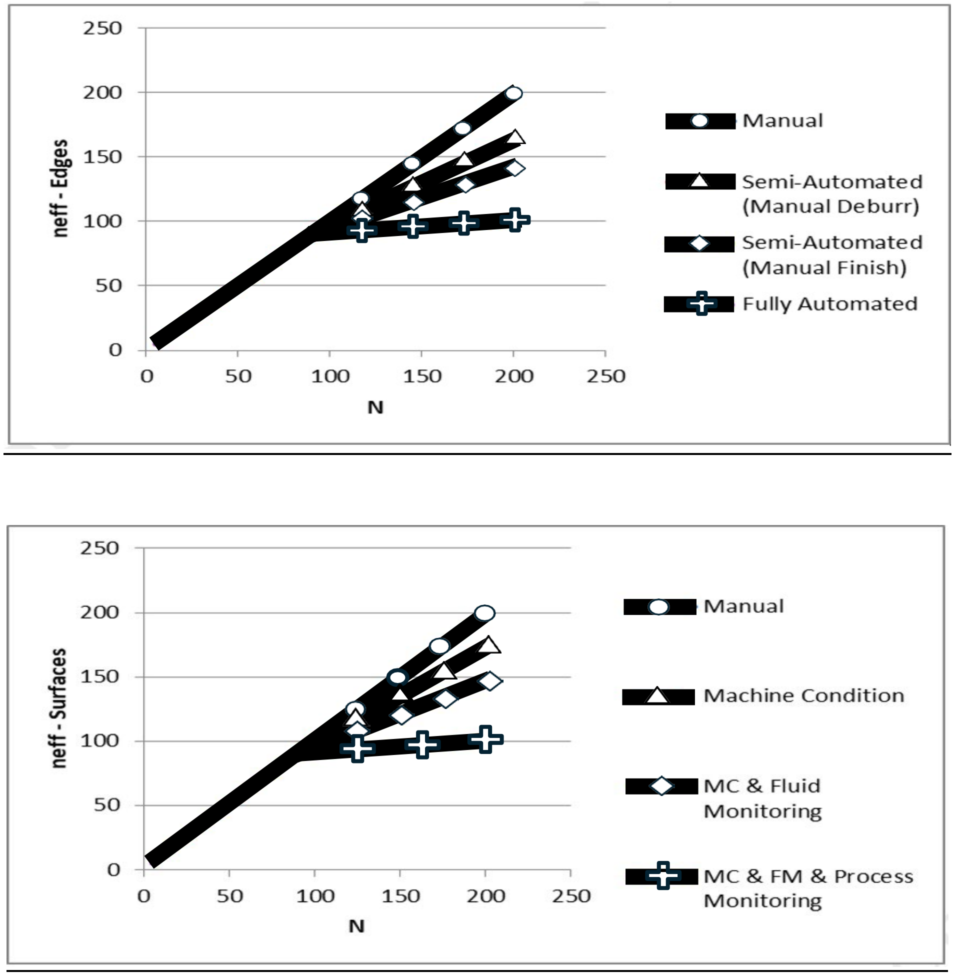


Figure F-1. Number of Effective Slots as a Function of Automated Manufacturing Credits for Axial Blade Slot (Edges and Surfaces)

F.3 Rules for Applying Credits.

F.3.1 Rules.

- Process validation is considered mandatory on machining processes on all future products when using the methods provided by this AC. Use of process validation provides a 5X manufacturing credit as specified in tables F-1 and F-2.
- Use of manufacturing credits including process validation should be part of the certification data submittal.
- Process monitoring should be used in both roughing and finishing operations.
- Surface Credit for Fluid Monitoring cannot be claimed unless Machine Condition, Fluid & Fluid Condition, Tooling, and Setup Validation are also in use.

- Surface Credit for Process Monitoring cannot be claimed unless Fluid Monitoring and Machine Condition, Fluid & Fluid Condition, Tooling, and Setup Validation are also in use.

F.3.2 Restrictions.

- Use of Surface Credits requires a Process Validation and Control Plan.
- Use of Edge Credits requires a Process Validation and Control Plan.
- Surface Credits cannot be used for edges.
- Edge Credits cannot be used for surfaces.
- Non-destructive inspection(s) at manufacture cannot be accounted for in the analysis to lower the POF value before application of manufacturing credits.

F.4 Credit Application Process.

1. Decide which controls are to be applied.
2. Sum the credit values for the combination of controls.
3. Calculate the number of effective slots.
4. Calculate the probability of fracture for the axial slot feature in the disk.
5. Divide the probability of fracture by the sum of the credit values.
6. This reduced probability of fracture should be compared to the DTR.

F.5 Slot Surface Credit Examples.

F.5.1 An axial slot feature with 100 slots, N:

a. Applicable Credits:

Process Validation and Control Plan	5
Total Credit	**5**

Number of Effective Slots: a = 0, Neff = 90 + (1-0)*(N-90) = N = 100

Initial design POF using Neff: 5.0E-4 events per service life

POF with controls is now: 5.0E-4 / 5 = 1.0E-4 events per service life

This is not adequate against Axial Blade Slot DTR.

b. Applicable Credits:

Process Validation and Control Plan	5
Machine Condition, Fluid & Fluid condition, Tooling and Setup validation	5

Fluid Monitoring	5
Surface Condition inspection – nondestructive	5
Total credit	**20**

Number of Effective Slots: a = 10/20=0.5, Neff = 90 – (1-0.5)*(N-90) = 95

Initial design POF using Neff: 4.5E-4 events per service life

POF with controls is now: 4.5E-4 / 20 = 2.25E-5 events per service life

This is not adequate against Axial Blade Slot DTR

c. Applicable Credits:

Process Validation and Control Plan	5
Machine Condition, Fluid & Fluid condition, Tooling and Setup validation	5
Fluid Monitoring	5
Process Monitoring	10
Surface Condition inspection – nondestructive	5
Total credit	**30**

Number of Effective Slots: a = 0.9, Neff = 90 – (1-0.9)*(N-90) = 91

Initial design POF using Neff: 4.0E-4 events per service life

POF with controls is now: 4.0E-4 / 30 = 1.3E-5 events per service life

This is acceptable to Axial Blade Slot DTR.

F.6 Slot Edge Credit Examples.

F.6.1 An axial slot feature with 100 slots, N:

a. Applicable Credits:

Process Validation and Control Plan	5
Total Credit	**5**

Number of Effective Slots: a = 0, Neff = 90 + (1-0)*(N-90) = N = 100

Initial design POF using Neff: 2.5E-4 events per service life

POF with controls is now: 2.5E-4 / 5 = 5.0E-5 events per service life

This is not adequate against Axial Blade Slot DTR.

b. Applicable Credits:

Process Validation and Control Plan	5
Edge Processing: Manual Finishing	8
Total credit	**13**

Number of Effective Slots: a = 8/15, Neff = 90 + (1-8/15)*(N-90) = 95

Initial design POF using Neff: 2.0E-4 events per service life

POF with controls is now: 2.0E-4 / 13 = 1.54E-5 events per service life

This is acceptable against Axial Blade Slot DTR

APPENDIX G. SURFACE (MANUFACTURING INDUCED ANOMALY) DAMAGE TOLERANCE ASSESSMENT FLOWCHARTS

G.1 Overview.

Note: For more details on the steps described in the following figures, refer to chapter 3 and the appendices.

For the purposes of this section, the definition of a “blade slot set” is consistent with the description in appendix E, paragraphs E.1 and E.2.

G.2 Process.

1. Assess the Probability of Fracture for One Blade Slot.
2. Calculate the Probability of Fracture for the Entire Blade Slot Set.

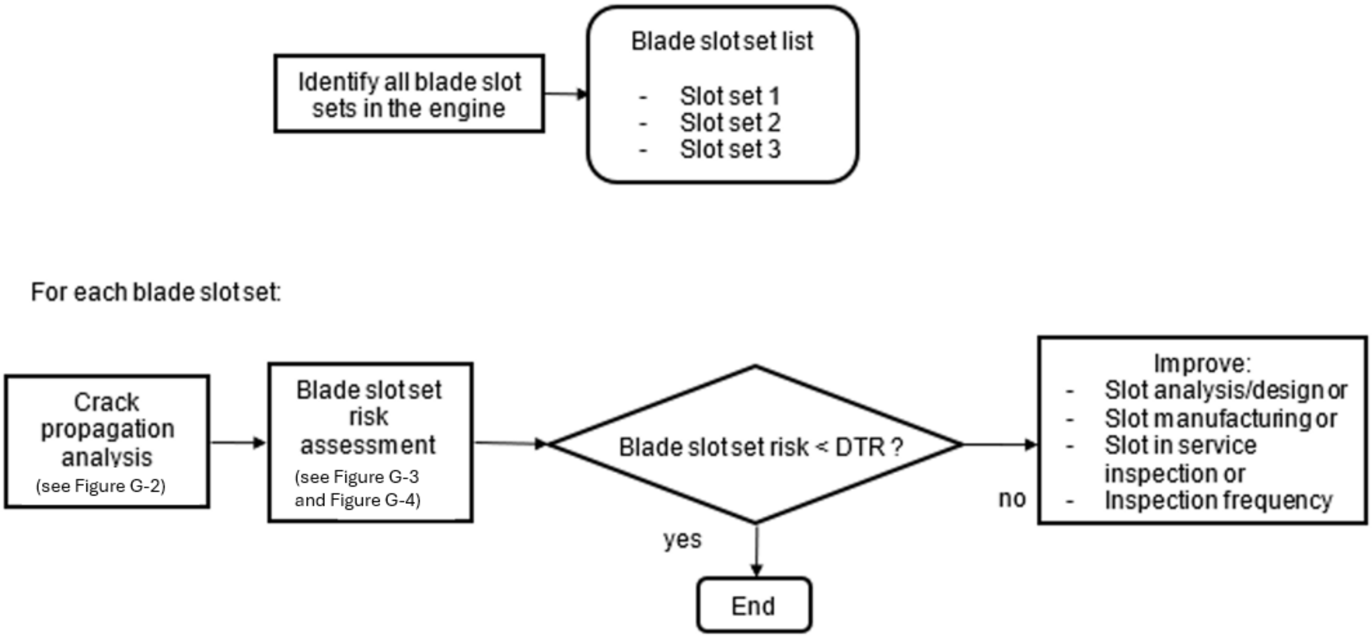


Figure G-1. Surface Damage Risk Assessment Work Flow

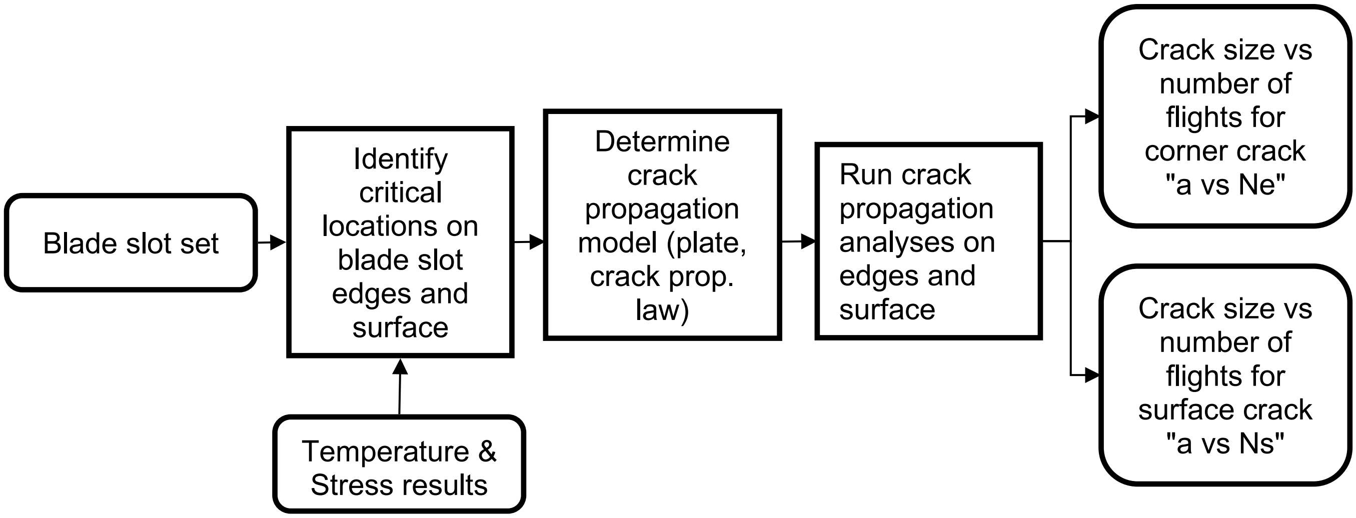


Figure G-2. Crack Propagation Analysis

3. Begin by selecting one slot from the blade slot set.
4. Calculate the probability of fracture for this single blade slot using the established damage tolerance criteria.

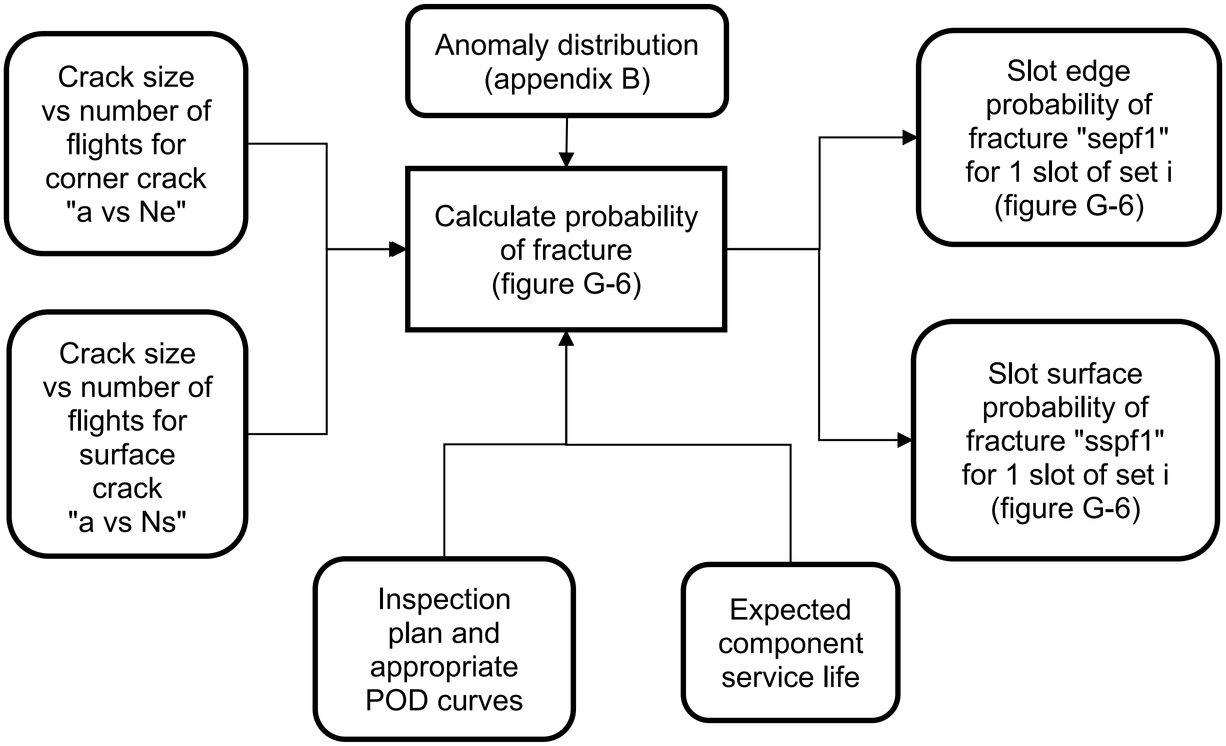


Figure G-3. Feature Risk Assessment (Part 1 of 2)

5. Use the probability of fracture for one slot (from step 1) to calculate the probability of fracture for the entire blade slot set.
6. Apply the appropriate manufacturing credits and effective slot numbers as defined in previous sections to complete the assessment.

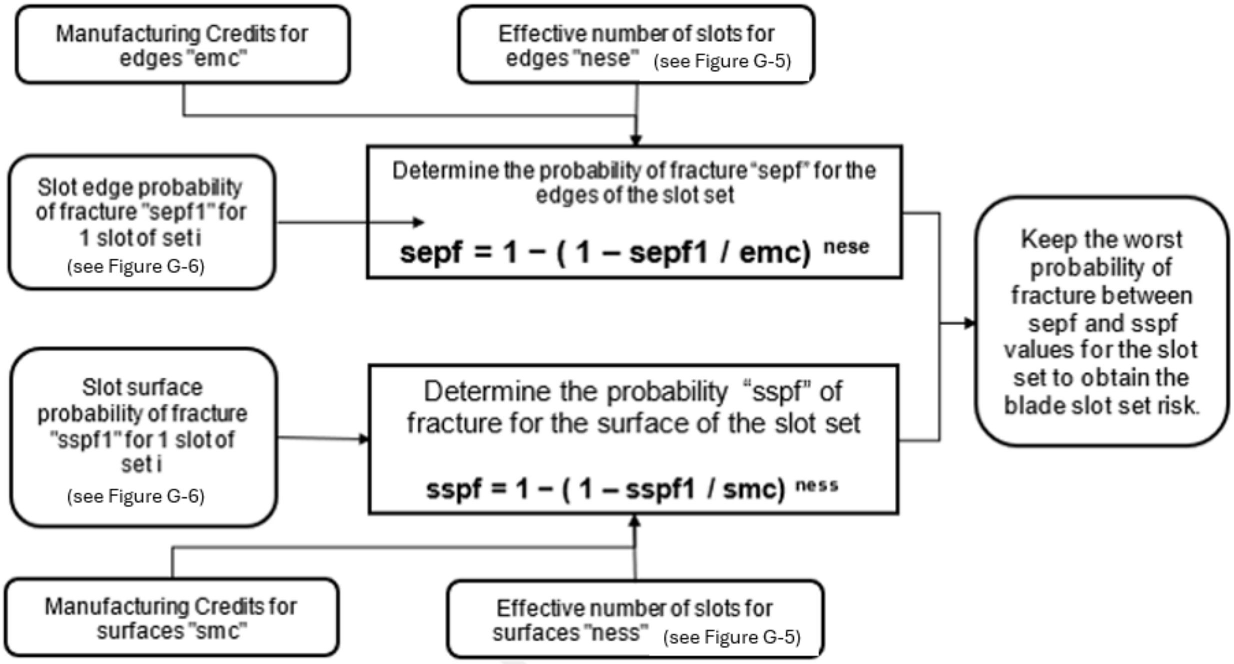


Figure G-4. Blade Slot Set Risk Assessment (Part 2 of 2)

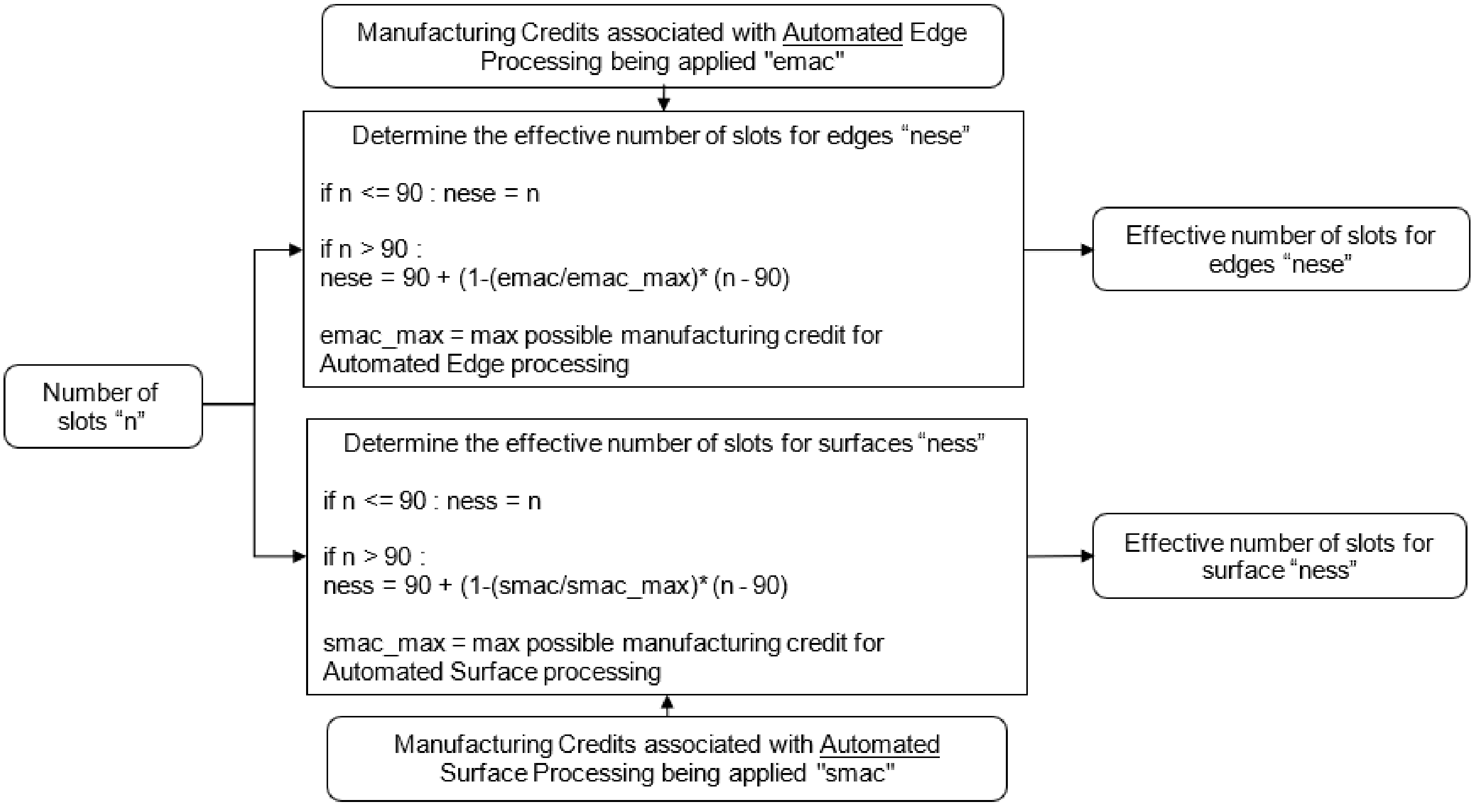
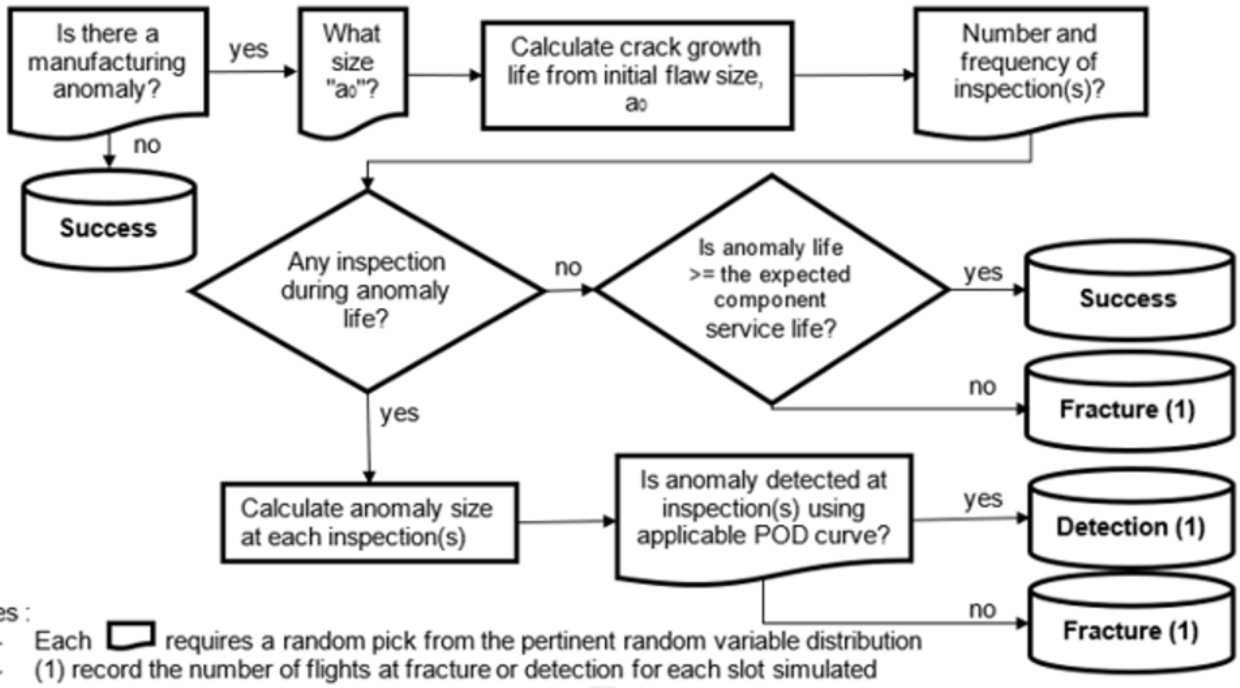


Figure G-5. Determination of the Number of Effective Slots in the Blade Slot Set

The POF calculation is described here following a Monte Carlo simulation process. A large sample of anomalies should be simulated. Each simulation in the sample follows the flowchart below to determine if it:

- fractures before the expected component service life
- meets or exceeds the expected component service life
- is detected with a crack

Probability of fracture before N flight cycles (sepf1, sspf1 from Figure G-3 = (number of fractured slots before N flight cycles) / (total sample size)



Notes :

- Each ▭ requires a random pick from the pertinent random variable distribution
- (1) record the number of flights at fracture or detection for each slot simulated

Figure G-6. Probability of Fracture Calculation

APPENDIX H. DEFINITIONS

The following definitions apply for the purpose of this AC.

H.1 Axial Blade Slot.

Axial blade slots are nominally identical features, with typically one per blade root. They are located at the same nominal radius, usually in the rim of a disk, and their geometry provides a mechanical constraint that positions the blades radially. Appendix E of this AC provides more information.

H.2 Component.

A part that may contain multiple sets of component features.

H.3 Component Feature.

A unique location, structural shape, or surface of a component or part. For a disk, component features are blade slots, bore, or web locations. Other examples are grooves, slots, or holes. Usually, different machining processes and practices are required to produce each unique feature.

H.4 Damage Tolerance.

An element of the life management process that recognizes the potential existence of component imperfections that are 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 non-destructive inspection.

H.5 Default Probability of Detection (POD) Values.

Values representing mean probabilities of detecting anomalies of various types and sizes. These values are accepted as valid provided the inspection is conducted consistent with applicable industry specifications.

H.6 Design Target Risk (DTR).

The relative risk of failure caused by material, manufacturing, and service induced anomalies and the standard against which probabilistic assessment results (stated in terms of feature, component, and engine level event rates) are compared.

H.7 Event.

A rotor structural part separation, failure, or burst, with no assessment of consequence.

H.8 **Exceedance Curve.**

The distribution of anomaly size and the frequency at which anomalies occur.

H.9 **Focused Inspection.**

A component inspection in which the inspector has been instructed to pay special attention to specific component feature(s) or location(s) and the necessary specialized processing instructions have been provided.

H.10 **Full Field Inspection.**

A component inspection without special attention to any specific component feature(s) or location(s).

H.11 **Hard Time Inspection Interval.**

The number of engine flight cycles since new or since the most recent inspection after which a rotor part must be made available and must receive the inspection specified in the airworthiness limitations section (ALS) of the instructions for continued airworthiness (ICA).

H.12 **Hazardous Engine Effects.**

Any of the effects listed in § 33.75(g)(2). Failure of rotating parts usually results in the non-containment of high-energy debris, which is the primary hazardous engine effect addressed by this AC. Disks, hubs, impellers, large rotating seals, and other similar large rotating components represent potential sources of high-energy debris.

H.13 **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.

H.14 **Linear Elastic Fracture Mechanics.**

For the purposes of this AC, linear elastic fracture mechanics is a method used to predict crack growth rates and component lives using the stress intensity factor (K) to characterize the stress state near the tip of a crack caused by a remote load or residual stresses.

H.15 **Low Cycle Fatigue (LCF).**

The process of progressive and permanent local structural deterioration occurring in a material subject to cyclic variations, in stress and strain, of sufficient magnitude and number of repetitions. The process will culminate in detectable crack initiation typically within 10^5 cycles. A detectable crack initiation is defined as 0.030 inches in length by 0.015 inches in depth.

H.16 **Maintenance Exposure Interval.**

A statistical distribution which defines the number of flight cycles between engine shop visits. This interval provides an opportunity to inspect the engine internal parts because the module or parts have been disassembled as a result of normal maintenance activity.

H.17 **Manufacturing Anomaly.**

A surface-related imperfection introduced during the manufacturing process (subsequent to melting) that is considered potentially detrimental to the structural integrity of a life-limited rotating part during its service life.

H.18 **Mean Probability of Detection (POD).**

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

H.19 **Module.**

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

H.20 **Operationally-Induced Anomaly.**

A surface-related imperfection introduced during service operations (both flight operations and maintenance) that is potentially detrimental to the structural integrity of the life-limited rotating part.

H.21 **Part Available.**

A part that can be inspected, as required by the ALS of the ICA, without any further disassembly. Depending on the inspection requirements, some parts may require a fully disassembled "piece part" condition, while other parts may be available for inspection while still in the assembled module.

H.22 **Probability of Detection.**

A quantitative statistical measure for detecting a particular type of anomaly (flaw) over a range of sizes using a specific non-destructive inspection technique under specific conditions. Typically, the mean POD curve is used.

H.23 **Probabilistic Risk Assessment.**

A fracture-mechanics based simulation procedure that uses statistical techniques to mathematically model and combine the influence of two or more variables to estimate the likelihood of various 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. Results from these analyses are typically used for design optimization to meet a predefined target or to conduct parametric studies. This type of procedure differs 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 with safety and reliability consequences.

H.24 Rotor Life-Limited Parts.

Engine rotor parts whose primary failure is likely to result in a hazardous engine effect, which is any of the conditions listed in § 33.75(g)(2).

H.25 Stage.

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

H.26 Safe Life.

A low cycle fatigue-based process in which life-limited components are designed, manufactured, and substantiated to have a specified service life or life limit, which is stated in operating flight cycles, operating hours, or both. The “safe life approach” requires that components be removed from service prior to the development of an unsafe condition (i.e., crack initiation). When a component reaches its published life limit, it is retired from service. The safe life approach only applies to components that define crack initiation as the limit of the useful life such as rotating parts.

H.27 Soft Time Inspection Interval.

The number of engine flight cycles since new, or the most recent inspection, after which a rotor part in an available module must receive the inspection specified in the ALS of the ICA.

OMB Control Number: 2120-0746
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Damage Tolerance of Axial Blade Slot Features
in High-Energy Turbine Engine Rotors

Date: 07/02/2026

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