U.S. Department
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Advisory Circular

Subject: GUIDANCE MATERIAL FOR AIRCRAFT ENGINE LIFE-LIMITED PARTS REQUIREMENTS

Date: 02/24/17
Initiated By: ANE-111

AC No: AC 33.70-1
Change: 1

1. Purpose. This advisory circular (AC) change clarifies the Interim Surface Damage Tolerance and Service Damage Monitoring requirements. The AC provides guidance for demonstrating compliance with the engine life-limited parts integrity requirements of Title 14, Code of Federal Regulations (14 CFR) 33.70.

2. Principal Changes.

a. Paragraphs 4.a – 4.c, 8.d.(7)(d), 8.d.(7)(e), 8.d.(7)(e)1, 8.d.(7)(e)2, 3, and 4, 8.e.(1), 8.e.(2), and 11.a. are changed.

b. The AC change number and the date of the change are shown at the top of each applicable page. The change bar in the right or left margin indicates where the change is located. The changes described may shift the original text.

Page Control Chart

Removed Pages	Dated	Inserted Pages	Dated
2	7/31/09	2	02/24/17
15	7/31/09	15	02/24/17
16	7/31/09	16	02/24/17
22	7/31/09	22	02/24/17

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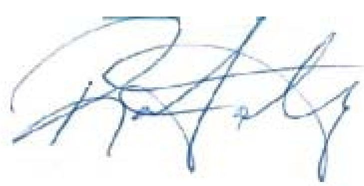

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Advisory Circular

Subject: GUIDANCE MATERIAL FOR AIRCRAFT ENGINE LIFE-LIMITED PARTS REQUIREMENTS

Date: 7/31/09

Initiated By: ANE-111

AC No: 33.70-1

1. PURPOSE. This advisory circular (AC) provides definitions, guidance, and acceptable methods, but not the only methods, that may be used to demonstrate compliance with the engine life-limited parts integrity requirements of § 33.70 of Title 14 of the Code of Federal Regulations (14 CFR part 33). Section 33.70 contains requirements applicable to the design and life management of propulsion system life-limited parts including high-energy rotating parts.

2. APPLICABILITY.

a. The guidance provided in this document is directed to engine manufacturers, modifiers, foreign regulatory authorities, part manufacturers who hold Parts Manufacturer Approval (PMA) authority, and Federal Aviation Administration (FAA) designated engineering representatives.

b. This material is neither mandatory nor regulatory in nature and does not constitute a regulation. It describes acceptable means, but not the only means, for demonstrating compliance with the applicable regulations. The FAA will consider other methods of demonstrating compliance that an applicant may elect to present. Terms such as “should”, “shall”, “may”, and “must” are used only in the sense of ensuring applicability of this particular method of compliance when the acceptable method of compliance in this document is used. While these guidelines are not mandatory, they are derived from extensive FAA and industry experience in determining compliance with the relevant regulations. On the other hand, if the FAA becomes aware of circumstances that convince us that following this AC would not result in compliance with the applicable regulations, we will not be bound by the terms of this AC, and we may require additional substantiation as the basis for finding compliance.

c. This material does not change, create any additional, authorize changes in, or permit deviations from existing regulatory requirements.

3. RELATED REGULATIONS.

a. Section 33.4, Instructions for Continued Airworthiness.

b. Section 33.15, Materials.

c. Section 33.19, Durability.

d. Section 33.27, Turbine, compressor, fan, and turbo-supercharger rotors.

e. Section 33.63, Vibration.

f. Section 33.75, Safety analysis.

4. RELATED GUIDANCE.

a. AC 33.4-1, Instructions for Continued Airworthiness.

b. AC 33.4-2, Instructions for Continued Airworthiness: In-Service Inspection of Safety Critical Turbine Engine Parts at Piece-Part Opportunity.

c. AC 33.14-1, Damage Tolerance for High Energy Turbine Engine Rotors (Amdt. 33-10, Eff. 3/26/84).

5. DEFINITIONS. For the purpose of this AC, the following definitions apply:

a. Approved life. The mandatory replacement life of a part that is approved by the Administrator and listed in the Airworthiness Limitation Section (ALS) of the Instructions for Continued Airworthiness (ICA).

b. Attributes. Inherent characteristics of a finished part that determines its capability to achieve the approved life without failure.

c. Damage tolerance. An element of the life management process that recognizes the potential existence of component imperfections, which 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, and nondestructive inspection.

d. Design Target Risk (DTR). The relative risk of a failure caused by material, manufacturing or service induced anomalies and the standard against which probabilistic assessment results (stated in terms of component event rates and/or engine level event rates) are compared. 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 with the same level of inputs. Results from these analyses are typically used for design optimization to meet a predefined target, or to conduct parametric studies. This type of procedure differs from an absolute risk analysis, which attempts to consider all significant variables, and is used to quantify the predicted number of future events with safety and reliability ramifications.

e. Engine life-limited parts. Engine rotor and major static structural parts whose primary failure is likely to result in a hazardous engine effect. For the purposes of § 33.70, a hazardous engine effect is any of the conditions listed in § 33.75.

f. Engine flight cycle. The flight profile or combination of profiles on which the approved life is based.

g. Engineering plan. A plan that includes the assumptions, technical data and actions required to establish and maintain the life capability of an engine life-limited part. The engineering plan is established and executed as part of the pre and post-certification activities.

h. Failure. Separation of the part into two or more pieces or into a condition so that it is no longer whole or complete. Examples of failures include disk or case bursts.

i. Fixed process. A manufacturing method used to produce a part that, once established, cannot be changed without engineering approval and alteration of the engineering plan. A fixed process ensures that a part is produced by a consistent, stable and repeatable process.

j. Feature. A unique location, structural shape, or surface of a component or part. For a disk, a feature would be blade slots, bore or web locations. Other examples are grooves, slots, or holes. Each unique feature is usually produced using a different primary machining process and practice.

k. ICA. Instructions for Continued Airworthiness as required by § 33.4.

l. Life limit. An operational service exposure limit characterized by the application of a finite number of flights or flight cycles. For rotating parts, it is equal to the minimum number of flight cycles required to initiate a crack equal to approximately 0.030 inches in length by 0.015 inches in depth. For life-limited pressure-loaded static parts, the life limit may be based on the crack initiation life plus a portion of the residual crack growth life.

m. Life management. A series of interrelated engineering, manufacturing, and service support activities that ensure that life-limited engine parts are removed from service prior to the development of a hazardous condition.

n. Likely to result. Given that the part has failed, regardless of the probability of occurrence, what are the possible consequences on the engine and/or aircraft? The word "possible" used in the context of this definition, means it can occur but does not include consequences which are so remote that they are, for practical purposes, impossible.

o. 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 a detectable crack initiation typically within 10E+05 cycles. A detectable crack initiation is defined as 0.030 inches in length by 0.015 inches in depth.

p. Manufacturing plan. A plan that identifies the part specific manufacturing process constraints which must be included in the manufacturing definition (drawings, procedures, specifications, etc.) necessary to consistently produce each engine life-limited part with the attributes required by the engineering plan.

q. Primary failure. Failure of a part that is not the result of prior failure of another part or system.

r. Repairable limits. Damage that can be repaired so the part retains its current approved life limit.

s. Residual crack growth life. The number of cycles required for a crack of a specified starting size to grow to failure.

t. Safe life. A cyclic fatigue based process in which life-limited components are designed, manufactured, substantiated, and maintained 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 parts be removed from service prior to the development of an unsafe condition (that is, crack initiation). The safe life approach only applies to parts which define crack initiation as the limit of the useful life, such as rotating parts.

u. Serviceable limits. Damage that can be tolerated without impacting the approved life of the part.

v. Service management plan. A plan that defines the in-service maintenance processes and the limitations to repair associated with each engine life-limited part such that the part will maintain the attributes required by the engineering plan. These processes and limitations become part of the ICA.

6. INTRODUCTION.

a. Since the failure of an engine life-limited part is likely to result in a hazardous engine effect as defined in § 33.75, applicants should meet specific integrity requirements by executing a series of life management activities. The life management requirements, as defined in § 33.70, necessitate the development and execution of an engineering plan, a manufacturing plan, and a service management plan for each life-limited part. These three plans form a closed-loop system that links the assumptions made in the engineering plan, to how the part is manufactured, and to how the part is maintained in service. Engineering, manufacturing, and service management must function as an integrated system and recognize the effects of actions in one area on the entire system.

b. The engineering plan defines the assumptions, technical data, and actions required to establish and maintain the life capability of each part. The engineering plan is established prior to the introduction of the part into service.

c. To produce parts with the characteristics required by the engineering plan, the applicant should have a consistent and repeatable manufacturing method. The manufacturing plan highlights the parameters that are significant to attaining the life of the part and that should not be changed without verification and engineering approval. The parameters generally involve the manufacturing process steps, controls, and constraints, such as the drawings, procedures, specifications, and machining instructions required to produce and inspect a part using a fixed process to meet the design intent as defined by the engineering plan.

d. The service management plan ensures that the operational service assumptions and life determined by the method in the engineering plan remain valid. It also defines the part limitations associated with service maintenance, overhaul, and repair. These service limitations are conveyed to the maintenance facilities through the ICA. The service management plan applies a comparable level of control to the service aspects of part life management as the manufacturing plan does for the manufacturing processes.

7. GENERAL.

a. Life System Approval.

(1) For an applicant to use a life system, the FAA must first approve the system. The applicant should submit a formal written document to the FAA for approval that identifies the techniques and controls to be used to establish and maintain the life limits. This document will remain on file with the FAA. Proposed changes to life system content must be submitted to the FAA for approval. Modifications must be approved prior to use.

(2) The FAA will evaluate the applicant’s technical approach, process controls, experience, and conformance to accepted practices. Based on this evaluation, the FAA will assign a “safety factor” which may reduce the approved life-limits. Safety factors can range from 1.0 (no life reduction) to a substantial reduction.

b. Certification Process Overview. The applicant determines the safe life based on the approved techniques on file with the FAA. The FAA will approve, if appropriate, an approved life that may be less than the safe life. A list of life-limited parts and the approved life for each part must be included in the ALS of the ICA as required by § 33.4. The approved life is the part’s mandatory retirement life.

c. Identification of Engine Life-Limited Parts.

(1) Engine life-limited parts are those engine rotating and major static structural parts whose primary failure is likely to result in a hazardous engine effect. A hazardous engine effect is any of the conditions listed in § 33.75. Engine life-limited rotating parts usually include, but may not be limited to, disks, spools, spacers, hubs, and shafts. Static structural parts usually include, but may not be limited to, high-pressure cases and non-redundant engine mount components. To ensure a hazardous engine effect does not occur, an operating limitation or life

limit must be established for each engine life-limited part. The operating limitation or life limit should specify the maximum allowable number of flight cycles when the part must be removed from service. Identification of engine life-limited parts per § 33.70 is focused on parts whose primary damage mechanism is controlled by low cycle fatigue.

(2) If a part is made of various sub-parts that are finally integrated in an inseparable manner into a unique part, and any one of the sub-parts is identified as an engine life-limited part, then the entire part is treated as an engine life-limited part.

d. Attributes of a Part. Attributes include, but are not limited to: size, shape, material mechanical properties, material microstructure, material anomalies, residual stress, surface condition, and geometric tolerances. Processes such as alloy melting practice, ingot conversion to billet or bar, forging, casting, machining, welding, coating, shot peening, finishing, assembly, inspection, storage, repair, maintenance, overhaul and handling may influence the attributes of the finished part. Environmental conditions experienced in service may also affect the attributes.

e. Content of a Plan. The engineering, manufacturing, and service management plans should provide clear information for the management of the engine life-limited part. “Plan” in the context of § 33.70 does not necessarily mean that all the required technical information must be contained in a single document. When relevant information exists elsewhere, the plan may reference, as appropriate, documents such as drawings, material specifications, and process specifications. These references should be clear, uniquely identify the referenced document, and allow the history of the individual part number to be traced. The referenced documents should be available for examination if required by the appropriate authority.

8. GUIDANCE FOR DEFINING AN ENGINEERING PLAN.

a. Introduction. The engineering plan consists of a set of comprehensive life assessment processes and technologies that ensure each engine life-limited part can be removed from service before hazardous engine effects can occur. These processes and technologies address the design, test validation, and certification requirements. The plan defines those manufacturing and field management processes and attributes that must be controlled to ensure the established life is achieved and maintained during service deployment.

b. Elements of the Engineering Plan. The engineering plan should address the following subjects:

(1) Analytical and empirical engineering processes used to determine the safe life. These processes include:

- The projected or actual aircraft flight profiles used to establish the safe life. The safe life should reflect service usage profiles associated with specific applications and account for environmental factors.
- The mechanical and aerodynamic loads that will be applied to the part.
- Thermal and structural analyses.

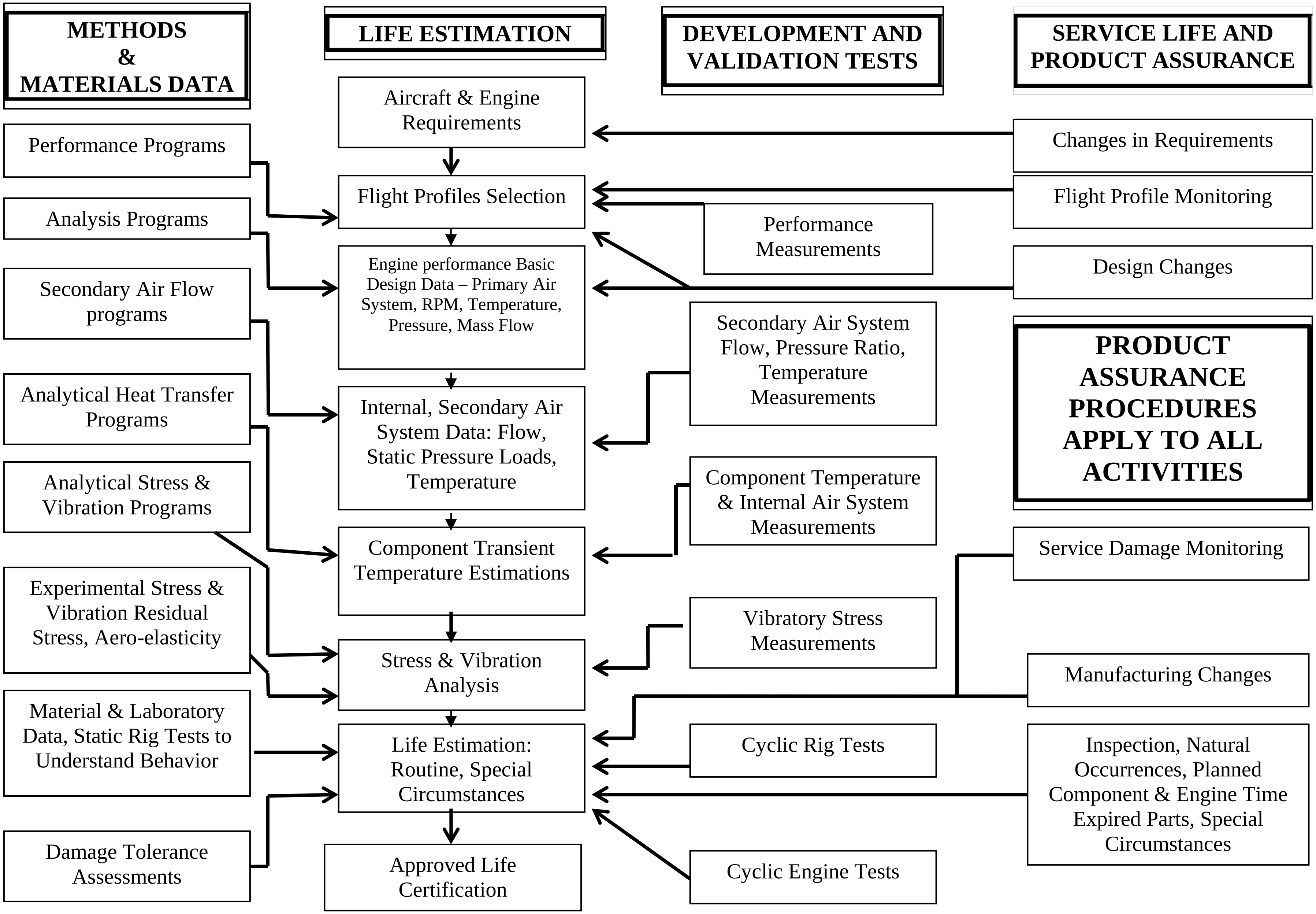
(2) Structured specimen, component and engine development, and certification testing to confirm the part operating conditions and to enhance confidence in the safe life.

(3) Identification of the attributes which must be provided during manufacture of the part and maintained during service operation. Any in-service inspections identified as critical elements to the overall part integrity should be incorporated into the service management plan.

c. Establishment of the Part Life. Determining the life capability of an engine life-limited part involves the consideration of many factors, each of which may have a significant influence on the final results. There can also be considerable variation in the methods used to establish the life limits for engine parts, many of which provide acceptable results. Paragraphs 8.d. and 8.e of this AC outline the essential elements of a system which are required to determine satisfactory life limits.

d. Establishment of Safe Life for Rotating Parts. The following figure illustrates a representative process used to establish the safe life for rotating parts:

Figure 1. Representative Process to Establish Approved Life Limits.



(1) Flight Profiles.

(a) To establish a safe life, the applicant needs to establish an appropriate flight profile (or combination of profiles) and consider the expected range of ambient conditions and operational variations to determine the service environment. The engine flight cycles should include the various flight segments that describe a complete flight (or flights). For example, for fixed wing aircraft applications this may include segments such as start, idle, taxi, takeoff, climb, cruise, approach, landing, thrust reverse and shutdown. The power requirements for each flight segment are based on the power required by the aircraft application(s). The hold times at the various flight segments should correspond to the limiting installation variables (aircraft weight, climb rates, etc.). Prior to service, the applicant should predict the flight profiles and the corresponding flight segments based on anticipated operator usage, and require coordination with the aircraft manufacturer and potential operators. During service, actual flight profiles may be recorded and may differ from those originally predicted which may alter or reduce the safe life. Profiles should be conservative and based on realistic use of full rated power. When the engine manufacturer cannot obtain adequate knowledge of the operation of the aircraft, especially for older aircraft, the flight profile(s) should be based on conservative projections.

(b) The applicant should validate and maintain the accuracy of the engine flight cycle over the life of the design. The extent of the validation depends on the approach taken in the development of the engine flight cycle. For example, a conservative flight cycle where all the variables are placed at the most life damaging value would require minimum validation. A flight cycle that attempts to accurately represent the actual flight profile, but is inherently less conservative, would require more extensive validation. Applicants may apply further refinements to the engine flight cycle when significant field operational data is obtained.

(c) Flight profiles are defined as the power required versus time, and serve as the input or the boundary conditions for the next step.

(2) Engine Performance. For each flight condition or flight segment, the applicant should determine the corresponding internal performance parameters, i.e., rotor speeds, internal pressures and temperatures. The performance parameters should be adjusted for production tolerances, control tolerances, installation trim procedures, as well as for engine deterioration that can be expected between heavy maintenance intervals. The applicant should also consider the range of ambient temperature and takeoff altitude conditions encountered during the engine's service life, as well as the impact of cold and hot engine starts.

(3) Secondary Air System Analysis.

(a) The applicant must establish the pressure, thermal and mechanical loads that must be sustained by the life-limited parts. This requires heat transfer and structural analyses that depend on boundary conditions which are derived from the internal performance parameters. The boundary conditions are determined for each flight condition using analytical and empirical engineering processes.

(b) The applicant may use aerodynamic design software based on well established aerodynamic design principles and theory to determine the flow path interstage data—gas temperatures, pressures and mass flow. In the case of a compressor and turbine, this should be the detailed interstage data associated with each individual blade and vane row. Based on this information, the applicant should determine the gas loads and air temperatures applied to the airfoils.

(c) The interstage data serves as boundary conditions for the secondary airflow system analysis. This software predicts the air temperature, pressure and air flow within the engine case and the rotor cavities, including the cavity recirculation, hot gas ingestion and leakage paths used as the boundary conditions for the heat transfer analysis. The cavity pressures are also used as boundary conditions for the structural analysis.

(d) The applicant must ensure the accuracy of the secondary airflow system software by calibrating the software using engine and rig testing.

(4) Heat Transfer Analysis. The applicant must determine the temperature levels associated with each life-limited part to ensure the cyclic stresses and strains produced by the thermal loads/temperature gradients are addressed adequately. To ensure the most damaging stresses are determined, the applicant must determine the component steady state and transient temperatures for each segment of the flight profile so that a complete temperature profile for each flight profile is determined. The heat transfer analyses usually require the use of sophisticated software tools which use the boundary conditions determined by the aerodynamic design and internal flow analyses. The analytical model should incorporate the appropriate thermal material properties and requires knowledge of the various heat transfer coefficients derived from the boundary conditions and empirical correlations. The applicant should correlate and verify experimentally the steady state and transient component temperatures during engine development testing.

(5) Stress Analysis.

(a) Stress analysis is part of the process used to identify the life-limiting locations and the life limit for each life-limited part. The stress analysis techniques include analytical and empirical processes that are used to determine the stress-strain distributions for each life-limited component. These techniques must be capable of identifying the cyclic stresses and strains for each potential life-limiting location and of evaluating the effects of engine rotor speed, mechanical and pressure loads, thermal gradients, assembly preloads and loads applied by mating parts for the entire flight cycle. The applicant should focus particular attention on the concentrated stress locations such as bores, holes, changes in section, flanges, welds and attachment slots. The level of analysis should be sufficient to fully define the stress-strain state versus time for the entire flight profile and should be capable of predicting the three dimensional (3-D) stress-strain state. This is usually accomplished with the use of two dimensional (2-D) axisymmetric and three dimensional finite element techniques.

(b) The applicant should validate stress analysis techniques by experimental measurements or other acceptable means.

(c) The applicant should conduct studies that identify the proper use of stress analysis techniques, and identify the steps required to achieve accurate results. For finite element techniques, examples include:

- Situations that require the use of axisymmetric (2-D) techniques;
- Situations that require the use of non-axisymmetric (3-D) techniques;
- Mesh density requirements;
- Control of element aspect ratio, and
- Method of computing potential stress errors.

The stress analysis techniques must be capable of determining the actual true minimum and maximum stresses-strains at the life-limiting locations. This determination should account for the non-linear inelastic material behavior based on the actual stress-stain curves. An acceptable alternative would be for the applicant to ensure the stress analysis techniques used to analyze each part are consistent with those used to analyze the fatigue tests used to establish the life of the part. If the stress analysis techniques are based on purely elastic behavior, then the applicant should ensure the fatigue test results are representative of engine operating conditions. The applicant may use various notch models, such as Neuber or Glinka, or inelastic finite element techniques.

(6) Crack Initiation Life.

(a) The applicant should employ a procedure that combines the stress-strain and temperature histories with the appropriate material and cyclic fatigue test data to establish the low cycle fatigue crack initiation life for the minimum property part. Also, the applicant should consider plasticity and creep related effects.

(b) The crack initiation life model for each material is based on test data obtained from cyclic fatigue testing of laboratory, sub-component/feature based tests, or component tests. The model should account for the manufacturing processes that affect the low cyclic fatigue capability, including fabrication from the production grade materials and manufacturing methods. The applicant should perform sufficient testing to evaluate the effects of elevated temperatures and hold times, as well as interaction with other material failure mechanisms such as high-cycle fatigue and creep. Appropriate service experience gained through a successful program of parts retirement, precautionary sampling inspections, or cyclic component tests may be included to calibrate the life prediction system. The life prediction system should also account for environmental effects, such as vibration, corrosion and cumulative damage.

(c) Test data should be reduced using appropriate statistical techniques to account for inherent scatter and should be expressed in terms of an acceptable part risk level, which is 1 cracked part out of 1000 (B.1 life) or alternately 1 in 740 (-3 sigma). Part fatigue life should be quoted in terms of the minimum number of flight cycles required to initiate a crack approximately 1/32" or 0.030" (0.762 mm) in length.

(d) When the fatigue life is based on a cyclic test of a specific part or parts, the applicant must correct the test results for inherent fatigue scatter and for the differences between the test and engine operation. The factors used to account for scatter should be justified. To use this approach, applicants should design the test to reproduce, as nearly as possible, the engine critical operating conditions in terms of the cyclic stresses, strains, and temperature level at the life-limiting feature, such as the, bore, rim, or blade attachment slot. The applicant should use sufficient analytical and empirical tools so the differences between the engine conditions and the cyclic test are understood, and the safe life can be adjusted to account for the differences. If the test is terminated by burst or complete failure, then crack initiation for this particular test may be defined using the appropriate crack growth calculations and/or fracture surface observations. An alternate approach would be to use the number of cycles at the last clean inspection to define the crack initiation point. This approach requires an inspection technique with a level of detection capability consistent with that used by the engine industry for rotating parts.

(7) Damage Tolerance Assessments. The applicant should perform appropriate damage tolerance assessments to minimize the potential for failure from material, manufacturing, and service-induced anomalies within the approved life of the part. Service experience with gas turbine engines has demonstrated that material, manufacturing and service-induced anomalies do occur, and they can potentially degrade the structural integrity of the life-limited parts. Historically, the life determination process has been founded on the assumption that life-limited parts do not contain anomalies. Consequently, this methodology has not explicitly addressed the occurrence of such anomalies, although some level of tolerance for anomalies is implicitly built into the methodology using design margins, factory and field inspections, etc. Damage tolerance assessments, however, explicitly address the anomalous condition(s) and complement the safe life approach. The intent of damage tolerance assessments is to supplement the existing safe life methodology; they are not intended to allow life-limited parts to remain in service beyond the limits established by the safe life approach or to allow rotating parts to return to service with cracks.

(a) Type of anomalies.

1 Material anomalies. Material anomalies consist of abnormal discontinuities or non-homogeneities introduced during the production of the raw material or the melting process. Examples of material anomalies are: hard alpha in titanium; oxide/carbide (slag); stringers in nickel alloys; and contaminant ceramic particulates in powder metallurgy materials unintentionally generated during powder manufacturing.

2 Manufacturing anomalies. Manufacturing anomalies include anomalies produced in the conversion of the ingot to billet and billet to forging steps, as well as anomalies generated by the metal removal and finishing processes used during manufacture and/or factory repair. Examples of conversion related anomalies are forging laps and strain induced porosity. Examples of metal removal related anomalies are: tears due to broaching; arc burns from various sources; and disturbed microstructure due to localized overheating of the machined surface or to inadvertent contact with a tool or fixture.

3 Service-induced anomalies. Applicants should consider service-induced anomalies such as non-repaired nicks, dings and scratches, and corrosion. Applicants should use

similarity of hardware design, installation, and exposure and maintenance practice to determine relevance of the experience.

(b) Probabilistic Damage Tolerance Risk Assessments (PDTRA). The probabilistic approach to damage tolerance assessment is one of two elements necessary to appropriately assess damage tolerance. The second element is service damage monitoring (see paragraph 8.d.(7)(e) of this AC). AC 33.14-1 includes an example of the probabilistic process that applies to hard alpha material anomalies in titanium alloy rotor components. The probabilistic damage tolerance risk assessment is fracture mechanics-based and typically includes the following primary elements:

1 Anomaly size and frequency distributions. A key input in the damage tolerance assessment is the size and rate of occurrence of anomalies. This information may be statistical in nature and may be presented in a form that plots the number of inclusions that exceed a particular size in a specified amount of material. Anomalies should be treated as sharp propagating cracks from the first stress cycle, unless there is sufficient data to indicate otherwise.

2 Anomaly growth analysis. This determines the number of cycles for a given anomaly to grow to a critical size. This prediction should be based on knowledge of part stress, temperature, geometry, stress gradient, anomaly orientation, and material properties. The analysis approach should be validated against relevant test data. In this context, anomaly growth may be based solely on crack propagation, or a combination of crack initiation (i.e. incubation) and crack propagation, depending on the nature of the anomaly/damage.

3 Inspection techniques and intervals. Manufacturing and in-service inspections are options available to reduce the risk of fracture from inherent and induced anomalies. The applicant should identify the intervals for each specified in-service inspection. Historical engine removal rates and module and part availability data could serve as the basis for establishing an inspection interval. The manufacturing inspections assumed in the damage tolerance assessments should be incorporated into the manufacturing plan. Likewise, the assumed in-service inspection procedures and intervals should be integrated into the service management plan and included, as appropriate, in the ALS of the ICA.

4 Inspection Probability of Detection (POD). POD of the individual inspection processes, such as eddy-current, penetrant fluid or ultrasonic, used to detect potential anomalies should be based on the statistical review of sufficient quantities of relevant testing or experience. The relevance of the data should be based on the similarity of parameters such as:

- Size, shape, orientation, location, and chemical or metallurgical character of the anomaly;
- Surface condition and cleanliness of the parts;
- Material being inspected, such as its composition, grain size, conductivity, and surface texture;
- Variation of inspection materials or equipment such as the specific penetrant fluid and developer and equipment capability or condition;
- Specific inspection process parameters, such as scan index; and

- Inspector's capabilities and limitations, such as visual acuity, attention span, and training.

5 Risk Prediction and Allowable Risk. The inputs are integrated using risk assessment software which predicts the relative probability of failure (POF) for each part. The predicted POF is compared to specific allowable design target risk values. Note the allowable DTRs can be found in advisory circulars which address specific materials and/or anomaly types. Designs that satisfy the allowable DTR values will be considered in compliance with the damage tolerance requirements. Part manufacturers have a variety of options to reduce the POF and achieve the level of relative risk allowed by the DTR. These options include, but are not limited to:

- Component redesign
- Material change
- Material process improvements
- Manufacturing process improvements
- Manufacturing inspection improvements
- Enhanced in-service inspections, and
- Life limit reduction.

(c) Appropriate Damage Tolerance Assessments

1 Interim Compliance Options. When an industry or company specific PDTRA approach has been established and accepted by the FAA, it may be used to meet the intent of the "appropriate damage tolerance assessments" of § 33.70. The FAA acknowledges that key elements of this approach, such as the anomaly size and frequency distributions, standardized analysis techniques, and the relative allowable risk targets are not available in every case. In these instances, a range of compliance options may be considered such as:

- A simplified conservative probabilistic approach.
- A deterministic fracture mechanics approach.
- Comparison to successful historical experience based on crack growth rate calculations.
- Design margins based on crack growth rate calculations.
- Fatigue testing of simulated damage.
- Application of damage tolerance concepts.

2 Appropriate Use of Interim Compliance Options and Interim Surface Damage Tolerance Requirements. When new information is developed and approved that allows the application of the probabilistic approach to a particular disk/rotor feature or anomaly type, the interim guidance provided by paragraphs 8.d.(7)(c)1 and 8.d.(7)(d) of this AC do not apply.

3 Appropriate use of Probabilistic Risk Assessment Techniques. The use of probabilistic risk assessment techniques should not be considered an alternate approach to meet the intent of § 33.70. As required by the rule, life limits must be based on the minimum number

of flights required to initiate a crack as described in the previous paragraphs, and is normally the only acceptable means to determine rotating part life limits. The exception is when the risk of failure from an anomalous condition is higher than acceptable, and the life limit is lowered to control the risk of failure. In this case, probabilistic risk assessment tools may be used to address continued airworthiness issues associated with part life shortfalls and certain part conditions that cannot be eliminated by the best available manufacturing processes and inspections techniques. Probabilistic risk assessment tools may not be used to relax existing well-established industry best practices. In addition, use of probabilistic risk assessment tools to reject improved manufacturing and inspection techniques, or other changes of similar nature, will require careful consideration and may need to meet higher standards. Alternate approaches must be discussed with and approved by the FAA on a case-by-case basis.

(d) Interim Surface Damage Tolerance Requirements. Currently, the required input data (anomaly size and frequency distributions, etc.) have not been developed to fully implement the probabilistic approach in all cases. This information is not available for all the various anomaly types and all required rotor features/locations. When an appropriate probabilistic approach is not available, applicants should adhere to the following interim guidance, which reflects industry benchmarked design criteria that ensure a minimum level of damage tolerance is built in to new rotor designs. Rotating component surfaces must possess a residual crack growth life equal to at least 3,000 damage tolerance cycles or a number of damage tolerance cycles equal to 50% of the part certified life, whichever is less, assuming an initial surface crack of 0.030 inches long and 0.015 inches deep and/or a corner crack equal to 0.015 x 0.015 inches. The damage tolerance cycle used in this assessment is the major stress-cycle (min-max-min) from the missions used in the LCF certification analysis for standard day conditions. These calculations should be based on the use of linear elastic fracture with cracks placed in the most unfavorable orientation and location and may use compressive residual stresses and inelastic stresses. Applicants must identify any additional assumptions associated with the residual crack growth life calculations. These assumptions must be discussed with and approved by the FAA on a case-by-case basis.

(e) Service Damage Monitoring. The overall objective of Service Damage Monitoring is to review data obtained from field operation of the type design engine to determine if there are anomalous conditions that require corrective action. Appropriate actions may include assessment of the impact of damage observed on one part/location on other parts/locations.

Applicants should determine if surface damage that has been detected is consistent with the serviceable and repairable limits and to determine if additional actions are required to prevent failure and rectify any potential unsafe conditions which may be identified. Service damage monitoring consists of the following steps:

1 Determine the serviceable and repairable surface damage limits using a process approved by the FAA and summarized within the service management plan. Damage size limits should be a function of part, part location, and damage type. Damage should include, but is not limited to, nicks, dents, and scratches. The serviceable and repairable limits should be published in the ICA.

2 Establish a monitoring process to record damage that meets all of the following criteria; (a) is inconsistent with or exceeds the repairable limits, and (b) is made available to the type certificate holder or supplemental type certificate holder through existing reporting channels. Document the monitoring process in the service management plan. This activity should record at a minimum the damage size, type, and location observed during service inspections for each life-limited part.

3 Assess damage meeting the criteria defined in paragraph 2 above. This assessment should consider the following, as a minimum:

- The impact of the observed damage on the life of the damaged part.
- The likelihood for recurrence of similar damage.
- Whether the damaged part was found during a field inspection.
- Whether the damage is likely to go undetected and escape to the field.
- Recommended corrective actions to identify, prevent, or eliminate the source of the damage.

4 During the service life of the part, the damage information obtained by the damage monitoring process, as well as the corrective actions implemented, should be reported to the authorities during continued airworthiness discussions.

e. Establishment of Life Limits - Static Parts.

(1) This section applies to major static structural parts whose primary failure is likely to result in one of the hazardous engine effects listed in § 33.75. It does not apply to static parts whose failure is not likely to result in a hazardous engine effect.

(2) The general principles used to establish life limits for static parts are similar to those used for rotating parts. However, for pressure-loaded static parts, the point at which a part must be removed from service may differ from rotor parts. For rotor parts, life limits are based on the initiation of a crack. For pressure-loaded static parts, the approved life may be based on the crack initiation life, plus a portion of the residual crack growth life, providing the following provisions are met:

- The crack growth analysis technique is experimentally verified.
- The useable portion of residual crack growth life maintains a safe margin to failure.
- Mandatory inspections are incorporated into the service management plan and the ICA if there is any dependence on crack detection.
- The reliability of the crack detection technique has been verified.
- All regulations must be met assuming the presence of the maximum predicted size crack that can occur within the approved life of the part. In some cases, it may be necessary to limit the crack size allowed in service in order to meet regulations other than § 33.70, such as the blade containment requirement in § 33.19.

(3) Other major structural static parts besides rotating and pressure-loaded static parts may be identified as life-limited parts. Under these circumstances, applicants should discuss the methodology for determining the life of the part with the FAA certification office which must approve its use. Applicants should use the general principles for rotating and static pressure loaded parts as a guide.

(4) The following table provides an overview of the various lifing elements contained within the rotating part and the static part methodologies:

Table 1. Overview of Lifing Elements.

Rotating Part Element	Applicable to Static Parts	Comments
Flight Profiles	Yes	
Engine Performance	Yes	
Internal Flow Analysis	Yes	
Heat Transfer Analysis	Yes	
Structural Analysis	Yes	Flight maneuver loads required.
Crack Initiation Life	Yes	Large number of options available. Range from a cyclic test of a single component to a fully developed crack initiation model.
Damage Tolerance Assessment	No	See additional comments in paragraph 8.e.(7).
Service Life Certification	Yes	

(5) Life-limited static parts may be repaired and returned to service providing the life limit is re-established using methods equivalent to the methods used to establish the life of a new part.

(6) The cyclic loads that must be supported by static parts also differ from those of rotating parts. For rotating parts, the major loads usually involve centrifugal forces and temperature gradients, while the minor loads include applied pressure loads. For pressure-loaded static parts, the major loads usually involve internal pressure and flight maneuver loads as well as thermal gradients.

(7) Certain static part construction techniques, such as welding or casting, contain inherent anomalies. For these cases, the applicant should consider a fracture mechanics-based approach as part of the methodology to establish the life of the part. This approach should be based on an understanding of the type and size of the anomalies that will be present in the part. In these instances, the applicant may base the life limit on the crack initiation life plus a portion of the residual crack growth life, providing a safe margin to failure/burst can be maintained. The applicant should experimentally validate the cycles required to initiate a crack from an anomaly

and the crack growth analysis techniques. If the anomaly is assumed initially to be a crack, then only the crack growth analysis techniques require experimental verification.

(8) In determining the life of the part, the applicant should consider the temperature of the part, the temperature gradients, and any significant vibratory loads or other loads (for example, flight maneuver loads), as well as the pressure loads.

(9) Manufacturing and service inspections are options available to reduce fracture potential. The applicant should incorporate the manufacturing inspections that are deemed necessary into the manufacturing plan. If the approved life limit includes reliance on the detection of cracks, the reliability of the crack detection techniques must be considered. Any dependence upon crack detection must result in mandatory inspection techniques and intervals being included in the service management plan and in the ALS of the ICA. Engine removal rates and module and piece part availability data may serve as the basis for establishing the inspection interval.

f. Certification of the Approved Life.

(1) This element requires the applicant to submit the part life, based on approved techniques, to the FAA with sufficient supporting data. The applicant is responsible for supplying sufficient data to support the part life. The FAA may approve, if appropriate, an approved life that is less than the part life. A list of the life-limited parts and their approved life must be included in the engine shop manual in the ALS of the ICA as required by § 33.4. The approved life is the mandatory retirement life.

(2) The engine shop manual must contain an approved life for each life-limited part, even if the safe life and/or the approved life are extremely long and exceed the design lifetime of the aircraft. This will ensure part usage is recorded and tracked properly.

g. Maintaining the Approved Life.

(1) At certification, the approved life of the part is based on predicted engine operation, material behavior, and environment. After certification, the applicant may need to check the accuracy of these predictions, recognizing that many aspects of the lifing system may change during its life. For example, the engine's usage and its operating environment may change after a change of ownership. The applicant should use service feedback to confirm any assumptions made in the engineering plan remain valid or to determine if modifications are required. The engineering plan should describe not only the basis of the part's approved life but also those actions subsequent to certification needed to ensure the approved life is appropriate throughout the operational life of the engine.

(2) The applicant must regularly review the assumptions made when establishing the approved life. The engineering plan should detail when these reviews should occur, and what information is necessary to complete the reviews. Aspects that should be considered include, but are not limited to:

- The frequency of approved life reviews.
- Detailed inspection of service exposed parts including retired parts.

- Review of flight profile.
- Findings during maintenance.
- Engine development experience.
- Lessons learned from other engine projects.
- Any service events.

h. Influencing Parts. Engine life-limited parts are part of a complex system in which other engine parts can affect the life-limited parts, including their life capability. Therefore, the engineering plan must consider these other parts and particularly any changes to them. Examples of influencing parts include a turbine blade, a mating flange or seal, and a static part that impacts the environment (temperatures, pressures, etc.) around a life-limited part. Examples of changes to these parts include a heavier blade; a new mating part with a different coefficient of thermal expansion; orifices and clearances affecting cooling air flow; and geometric or material changes to a static part that modify the thermal response and/or the mechanical response of the part.

9. GUIDANCE FOR DEFINING A MANUFACTURING PLAN.

a. Introduction. The manufacturing plan is a portion of the overall integrity process intended to ensure the life capability of the part. The engineering plan includes assumptions about how engine life-limited parts are designed, manufactured, operated, and maintained. Each can affect the part's life. Therefore, it is essential for the applicant to ensure the attributes required by the engineering plan remain valid and are achieved during manufacture.

b. Elements of a Manufacturing Plan. The part specific manufacturing plan should consider the attributes of the part delivered by the manufacturing process, and should highlight the processing parameters that affect the life of the part. The plan should also identify the process parameters that should not be changed without proper verification and engineering approval. Many of the parameters may be included by reference to other documents (see paragraph 7.e. of this AC). The parameters may include, but are not limited to:

- Material controls including zoned areas that require special properties.
- Manufacturing method specifications.
- Manufacturing process steps and sequence.
- Cutting parameters and scatter allowed.
- Inspection method and sensitivity.
- Special part rough machining methods or finishing method(s).
- Methods intended to improve fatigue capability or minimize induced anomalies.
- Process validation to qualify the impact of the manufacturing method variation on the part's life capability.
- Compliance with microstructural requirements.
- Surface finish.
- Residual stress profile

- Manufacturing controls to ensure that parts are produced by a consistent and repeatable process.
- Traceability records for each part.
- Review of non-conforming parts to ensure the deviation does not adversely impact the life of the part.

c. Development and Verification of the Manufacturing Plan.

(1) The manufacturing plan should be reviewed and verified by the key engineering and manufacturing personnel with the following technical skills:

- Engineering (Design and Lifing).
- Material Engineering.
- Non-Destructive Inspection.
- Quality Assurance.
- Manufacturing Engineering (Development and Production).

(2) These personnel should evaluate and approve process validation, the rules for change control, non-conformance disposition, and corrective actions to ensure the manufacturing product is consistent with the design assumptions of the engineering plan. The intent is to ensure:

- Manufacturing processes are developed and applied with the appropriate level of oversight to ensure the part life capability required in the engineering plan is consistently achieved.
- Substantiation programs are agreed to up-front and executed as part of the process validation.
- Changes to the manufacturing processes and practices are visible and are made with cross-functional review and approval.
- Non-conformances are reviewed by the appropriate personnel with the required skill mix prior to disposition.
- Corrective action is implemented for non-conformances that have been detected.

(3) The level of detail in the plan may vary depending on the specific process step being considered, the sensitivity of the particular process step, and the level of control required to achieve the required life capability.

(4) Example. A process specification exists to control the drilling of holes. If the use of this specification produces a hole that meets the life capability requirements for a flange bolt hole, then the plan may simply note that this flange bolt hole will be produced according to the standard specification. However, if a rim air hole requires cold expansion following drilling to meet the life requirements, then it may be necessary to reference the cold expansion process specification in addition to the hole drilling specification.

10. GUIDANCE FOR DEFINING A SERVICE MANAGEMENT PLAN.

a. Introduction. The service management plan is part of the process to maintain the integrity of engine life-limited parts throughout their service life. The engineering plan includes assumptions about the way in which life-limited parts are manufactured, operated and maintained. Each can affect the life of the part. It is, therefore, essential to ensure these assumptions remain valid. The service management plan conveys the constraints for in-service repair, maintenance, and overhaul to remain consistent with the assumptions made in the engineering plan.

b. Elements of a Service Management Plan. The part-specific service management plan should consider the part attributes that engineering has identified as significant for part life, and should not be changed by the processes applied to the part during service. The service management plan should include the means to monitor the service of life-limited parts to ensure the operational assumptions remain valid. The plan may include, but is not limited to, the following information:

- Maintenance and overhaul limitations.
- Repair processes limitations.
- Operator’s responsibility to maintain service records traceable to a particular engine and part, as required by FAA regulations.
- Inspection interval (if required).
- Inspection procedure (if required).
- Monitoring operational flight profiles.
- Damage and repairable limits.
- Periodic technical reviews of service and related experience.

c. Determining the Acceptability of Repair, Maintenance and Overhaul Processes.

(1) Repair, maintenance, and overhaul processes should be reviewed by personnel with the following technical skills:

- Engineering (Design and Lifing).
- Material Engineering.
- Non-Destructive inspection.
- Quality Assurance.
- Product Support Engineering.
- Repair Development Engineering.

(2) The skills needed for this cross-functional review are consistent with those needed to evaluate the manufacturing plan. The review should include process validation, change control, non-conformance, and corrective actions to ensure that all repair, maintenance, or overhaul processes are consistent with engineering requirements. The following benefits are derived from the review:

- Repair, maintenance, and overhaul processes and practices are developed with the appropriate level of oversight, and their possible impact on the life of the part is considered. Substantiation programs are agreed to up-front and executed as part of the validation process.
- Changes to the processes and practices are visible to all parties and are made with cross-functional review and approval.
- Non-conformances are reviewed by the appropriate skill mix prior to disposition.
- Corrective action is implemented for non-conformances which have been detected.

(3) To ensure the service management processes are properly implemented and controlled, the applicant should clearly define the limitations to repair, maintenance and overhaul procedures in the ICA. These procedures should also include clearly defined limitations associated with these processes and practices to ensure that engine critical life-limited parts maintain the required attributes consistent with those assumed in the engineering plan. This is necessary since inappropriate repair or maintenance could affect the integrity of the part and result in a hazardous effect.

d. Static Parts Service Management. Due to potential differences in the approach to determining the life of static parts, especially of pressure cases, the applicant should include additional information in the shop manual. The applicant should place this information, which is in addition to the approved life, in the ALS. The additional information may include, but is not limited to:

- A periodic inspection interval.
- The inspection method(s) to be used.
- A detailed description of the area(s) to be inspected.
- Acceptance and rejection criteria associated with inspection results.
- Acceptable repair method(s), if applicable.
- Other instructions deemed necessary to ensure that inspections are executed properly.
- Required maintenance and the limitations associated with maintenance.

11. AIRWORTHINESS LIMITATION SECTION.

a. The Airworthiness Limitation Section (ALS) of the engine manuals required by § 33.4 sets out the mandatory replacement times, inspection intervals, and related procedures necessary for type certification. The engine design engineering and service management plans required by § 33.70 also highlight the importance of the limits to in-service maintenance and repair of life-limited parts identified in the ALS. Since any maintenance or repair could theoretically affect the integrity of a life-limited part in a hazardous manner, an applicant may want to use the ALS to advise operators of the consequences of repairs to life-limited parts. If an applicant elects to include such an advisory statement, we recommend that it read similar to the following.

> "The following airworthiness limitations have been developed based on engineering analysis that assumes this product will be operated and maintained using the procedures and inspections provided in the Instructions for Continued Airworthiness supplied with this product by the type certificate holder. Repairs or alterations to engine life-limited parts using other data warrant additional analyses to assess the potential effect on airworthiness characteristics and these limitations."

Caution: Applicants should not attempt to incorporate any statement into the ALS that limits or eliminates an operator's option to use FAA-approved repairs, alterations, or PMA parts in an engine. Such a statement would be contrary to FAA's policies and regulations.

b. For engines with One-Engine-Inoperative (OEI) ratings, the ALS should include a method to track the number of cycles of operation at the OEI ratings because these ratings operate at higher speeds and temperatures than non-OEI operating conditions. Applicants may accomplish this by adding a finite number of cycles to the expended life of the affected engine life-limited parts or by using appropriate life reduction factors for each of the OEI power excursions.

//signed by Francis A. Favara//
Francis A. Favara
Manager, Engine and Propeller Directorate
Aircraft Certification Service

ADVISORY CIRCULAR FEEDBACK FORM

If you find an error in this AC, have recommendations for improving it, or have suggestions for new items/subjects to be added, you may let us know by (1) complete the form online at https://ksn2.faa.gov/avs/dfs/Pages/Home.aspx or (2) emailing this form to mailto:9-AWA-AVS-AIR-DMO@faa.gov.

Subject: AC 33.70-1 Date: __________

Please mark all appropriate line items:

☐ An error (procedural or typographical) has been noted in paragraph _______ on page _______.

☐ Recommend paragraph _______ on page _______ be changed as follows:

☐ In a future change to this AC, please cover the following subject:
(Briefly describe what you want added.)

☐ Other comments:

☐ I would like to discuss the above. Please contact me.

Submitted by: ________________________________ Date: __________________