U.S. Department
of Transportation

Federal Aviation
Administration

Advisory Circular

Subject: GUIDANCE MATERIAL FOR 14 CFR §33.19, DURABILITY, FOR RECIPROCATING ENGINE REDESIGNED PARTS.

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Initiated By: ANE-110

AC No: 33.19-1

Change:

1. PURPOSE. This advisory circular (AC) provides guidance and acceptable methods, but not the only methods, that may be used to demonstrate that redesigned parts for reciprocating engines comply with the requirements of § 33.19 of Title 14 of the Code of Federal Regulations (14 CFR). This AC addresses major type design changes, parts manufacturing approvals (PMA), and supplemental type certificates (STC) for drive system or structural parts in reciprocating engines. Like all AC material, this AC is not, in itself, mandatory and does not constitute a regulation. While these guidelines are not mandatory, they are derived from extensive Federal Aviation Administration (FAA) and industry experience in determining compliance with the pertinent regulations.

2. APPLICABILITY.

a. The guidance provided in this document is directed to engine manufacturers, parts manufacturers, modifiers, foreign regulatory authorities, and Federal Aviation Administration (FAA) engine type certification engineers and their designees. This AC applies to PMA (test and computation), STC, or major type design change certification projects involving reciprocating system or structural parts on reciprocating engines. These parts are used on reciprocating engines certificated under part 33 and installed in aircraft certificated under parts 23, 27, and 29. This AC does not apply to minor type design changes or PMA parts approved by the FAA as being identical to the corresponding engine type design part, as those parts are not considered redesigned.

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. If the FAA later decides that following this AC would result in noncompliance with applicable regulations, the FAA is not bound by the terms of this AC and may require additional substantiation as the basis for finding compliance.

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

3. RELATED REGULATIONS (CFR) AND READING MATERIAL.

a. Related Regulations.

(1) 14 CFR Part 21. Sections 21.33, 21.53, 21.101, 21.115, and 21.303.

(2) 14 CFR Part 33. Sections 33.19, 33.43, 33.49, 33.53, 33.55, 33.57, and Appendix A.

b. Orders and Policy.

(1) Engine and Propeller Directorate Policy, Durability Substantiation of Reciprocating Engine Redesigned Parts (PMA, STC, Type Design Change), dated November 29, 1999.

(2) FAA Order 8110.42A, Parts Manufacturer Approval Procedures, dated March 31, 1999.

(3) FAA Order 8110.4B, Type Certification Process, dated April 24, 2000.

c. Industry Documents.

(1) "The Selection of Steel for Fatigue Resistance" from *ASM Metals Handbook*, Volume 1, 8th edition.

(2) "Aluminum Alloy Castings: Mechanical Properties" from *ASM Metals Handbook*, Volume 1, 8th edition.

(3) "Fatigue Resistance of Steels" from *ASM Metals Handbook*, Volume 1, 10th edition.

(4) "Fatigue Failures" from *ASM Metals Handbook*, Volume 10, 8th edition.

CHAPTER 1. INTRODUCTION

1-1. Background.

a. Today's horizontally-opposed piston engines were first certified in the late 1940s and 1950s. These engines entered service with recommended Time Between Overhaul (TBO) intervals of 500 to 750 hours. These TBOs were recommended by the engine designer and approved by the FAA based on the results of the certification block testing. Successful performance of the block testing was sufficient to substantiate safe operation over the recommended TBO because of the short duration of those initial TBOs, thus meeting the durability requirement of CAR § 13.104. However, over the last 50 years, advances in materials, manufacturing processes, and engineering analysis methods have enabled engine manufacturers to design more durable engines. This has allowed the manufacturers to gradually increase their recommended TBOs for existing engine designs to intervals up to 2000 hours. The FAA approved these TBO increases based on successful service, engineering design, and test experience. New engine designs, however, are still introduced with relatively short TBOs, in the range of 600 hours to 1000 hours, with TBO extensions approved by the FAA after accumulation of successful service experience.

b. Reciprocating system and structural parts have historically been designed to operate with safety factors large enough to ensure that operating stress levels are significantly below their relevant fatigue strengths or endurance limits. Under normal operating conditions, these parts can be expected to have essentially infinite fatigue lives so the engine designer does not normally assign them a service life. This is in contrast to rotor structures in turbine engines, which typically have specified service lives beyond which structural failure is expected.

(1) For turbine engines, finite lives and the hazard to aircraft if a turbine rotor failure occurs require life limits for turbine parts. Life limits are designated as airworthiness limitations for the turbine engine model and the FAA considers them mandatory.

(2) For reciprocating engines, the essentially infinite fatigue lives of drive system and structural parts, along with the reduced hazard to the aircraft in the event of their failure, make life limits and mandatory airworthiness limitations unnecessary. Instead, the reciprocating engine designer establishes recommended periodic engine inspection intervals, called TBOs, which provide for inspection of these drive system and structural parts. These parts are then repaired or replaced as necessary. Their extremely durable nature does not however, diminish the importance of evaluating the fatigue life of these parts. If the engine designer cannot show that the operating stress levels are significantly below the fatigue endurance limit of the material for a drive system or structural part in a reciprocating engine, then the designer should assign a unique service interval to the part to require replacement before the fatigue life expires.

c. The linkage between fatigue lives of parts and engine TBO was originally addressed by civil aviation authorities in CAR § 13.2020, Durability. This requirement was published in August 1941, and applied solely to reciprocating engines, as turbine engines had not yet been introduced in civil aviation. The initial version of the durability requirement stated that: "The wearing surfaces, lubrication system and ***parts subject to fatigue*** shall be so designed and constructed that no unsafe condition will develop ***between overhaul periods*** when the engine is properly installed, operated and maintained in an aircraft" (emphasis added). The wording of this original version of the durability requirement established the unambiguous link between fatigue life and overhaul periods. The durability requirement later became CAR § 13.104 and read: "all parts of the engine shall be designed and constructed to minimize the development of an unsafe condition of the engine between overhaul periods." Section 33.19 still reads substantially the same as § 13.104 regarding the durability of reciprocating engines, requiring the engine design to minimize the development of an unsafe condition between overhaul periods.

d. Over the life of an engine, redesigned parts are approved for incorporation into existing engine designs through type design changes, PMA, or STC and can involve material, material process, or geometry changes, or any combination of these three. What may initially appear to be a relatively benign design change, such as a material process change, can actually have a significant effect on material strength or stress and on the ability of the part to operate safely for the recommended engine TBO.

e. Replacement PMA parts approved under the identicality guidelines of § 21.303(c)(4) and FAA Order 811.42A, paragraphs 9a(3)(a) and (b) are not considered redesigned parts. The certification data submitted to the FAA for these replacement PMA parts should substantiate that the part does not incorporate any design changes relative to the corresponding engine type design part. If the engine designer cannot show this, then the part should be evaluated in accordance with the test and computation guidelines applicable to PMA parts.

f. The regulations governing these design changes require that engine parts be designed to operate safely for the duration of the applicable overhaul interval. The applicable overhaul interval is either the recommended TBO for the engine on which the part will be installed or a TBO established specifically for the redesigned part. When applicants recognized the effect of lengthy TBOs on durability, they have performed tests and analyses specifically to meet the durability requirement. These tests and analyses typically substantiate extremely lengthy or essentially infinite fatigue lives. In other cases the durability requirement was substantiated solely by performance of the endurance test required in § 33.49, despite lengthy TBOs. The FAA has developed this AC to describe acceptable methods, but not the only methods, for showing compliance with the durability regulations.

1-2. Definitions.

a. Essentially Infinite Fatigue or Service Life. Essentially infinite service or fatigue lives means the calculated fatigue life of the part is such a high number that it will not be reached during the typical operating life of the engine.

b. Fatigue Mechanism. Fatigue mechanism is how a crack starts and propagates from repeated loading.

c. Margin of Safety. The margin of safety is the ratio of excess strength to the nominal required strength in the design of a part.

d. Drive system Parts. Drive system parts are the parts that transmit the power produced in the combustion chamber to the propeller flange.

e. Redesigned Parts. Redesigned parts are parts for which material changes, material process changes, geometry changes, or any combination of changes have been incorporated into an existing approved design. FAA approval of these parts is accomplished through major type design changes, PMA, or STC. Replacement PMA parts approved under the identicality guidelines or parts with minor design changes are not considered redesigned parts.

f. Structural Parts. Structural parts are parts that hold drive system parts within the engine or otherwise hold the engine assembly together.

CHAPTER 2. GENERAL

2-1. Certification Procedures. The certification procedures in part 21 require redesigned parts to meet the applicable airworthiness standards of the following Sections:

a. Section 21.303(c)(4), airworthiness requirements for PMA parts substantiated by test and computation,

b. Section 21.115(a), airworthiness requirements for STC parts, and

c. Section 21.101(a), airworthiness requirements for type design changes.

2-2. Airworthiness Standards. For engine parts, Part 33 contains the applicable regulations or airworthiness standards. The applicant for major design change, PMA, or STC should review these regulations and determine which specific sections require re-evaluation based on the redesign of the part and the extent of that redesign. Drive system or structural parts, by their very nature, require re-evaluation of durability when redesigned.

2-3. Durability Compliance. For PMA (test and computation), STC, or major type design change certification projects involving drive system or structural parts in reciprocating engines, the following should be considered when substantiating compliance with § 33.19:

a. The extent of the redesign.

b. The TBO that applies to the engine on which the part will be installed, unless the applicant chooses to specify a separate inspection or replacement interval for the part. The applicant should perform testing and analysis sufficient to substantiate a fatigue life that is essentially infinite unless a fatigue life limit is defined for the part.

c. The substantiation may include material analyses and testing, finished part analysis and testing, and engine block testing.

d. For parts for which a fatigue life limit has not been defined, the substantiation test methods should be designed to accumulate a sufficient number of significant stress cycles for substantiation of an extremely lengthy (essentially infinite) fatigue life. The test methods should also consider the duty cycle per flight of the applicable engine, extrapolated to the recommended TBO. Engine parameters, such as manifold pressure, horsepower, cylinder head temperature (CHT), exhaust gas temperature (EGT), and revolutions per minute (RPM), should be selected to simulate the most adverse fatigue loading conditions expected in service.

2-4. Conformity. The certification procedures specified in part 21 require that parts undergoing certification testing be shown to conform to their type design. This conformity requirement encompasses all aspects of the type design, including manufacturing and assembly processes, material specifications, and finished part conformity. The specific regulations are:

a. Section 21.303(e), (e)(1), and §§ 21.303(f)(2) through (f)(4) specify conformity requirements for PMA parts. They require the applicant to demonstrate that the materials, part design, and processes, construction, and assembly conform to the design and authorize the Administrator to make any inspection necessary to determine compliance with these requirements.

b. Sections 21.33 and 21.53 specify conformity requirements for STC and type design change projects.

2-5. Model Eligibility. Engine designers occasionally use parts with common part numbers on several different engine models. For PMA applications for this type of common part, paragraph 9.g. (4) of FAA Order 8110.42A requires the Aircraft Certification Office (ACO) reviewing the application to separately evaluate the installation eligibility of the part for each engine model. FAA approval will be based upon a determination that each engine model will continue to comply with the applicable airworthiness regulations with the PMA replacement part installed. As discussed throughout this AC, the applicable airworthiness regulations include a requirement that the applicant demonstrate the durability of the part, which would require that the common part operate safely between overhaul intervals for each of the engine models on which it is proposed to be installed. Testing should be performed on each engine model, unless it can be shown that the installed environment (stress, temperature, etc.) of the engine model for which the applicant applies for eligibility is less severe than a model for which the part has previously been tested and approved. This can be done with an analysis that provides a quantitative comparison of the installed environments in terms of the relevant engine operating parameters.

2-6. Comparative Analysis for PMA Parts. FAA Order 8110.42A, paragraph 9.d.(2) provides for substantiation of PMA parts under test and computation by comparative or general analysis. However, comparative analyses that rely on dimensional and metallographic comparisons, but are not supported by testing, are not sufficient to substantiate the durability of the reciprocating engine drive system and structural parts. The criticality and complexity of these parts is such that testing in accordance with this AC should be performed to substantiate the fatigue strength and durability of the part. This testing can be accomplished as an element of either a general analysis or a comparative analysis substantiation program.

2-7. Substantiation Guidance. This AC provides the following information for defining substantiation plans to show compliance with § 33.19 for drive system or structural reciprocating engine parts.

a. Recommended substantiation methods, including conformity, test, and analyses.

b. An appendix that provides an overview of design issues to consider when changing a process used to manufacture a drive system or structural reciprocating engine part, including factors that may affect stress and strength.

c. An appendix that provides information regarding the assessment of the strength of materials used to manufacture drive system or structural parts.

CHAPTER 3. COMPLIANCE METHODS

3-1. General. Durability compliance methods for drive system and structural parts may encompass both analysis and testing of the uninstalled part, along with engine testing of the installed part. FAA conformity is required before component and engine testing.

3-2. Conformity.

a. The validity of the certification tests depends on adherence to the type design during the manufacture of the test hardware. The type design includes the material properties, manufacturing processes, assembly procedures, and physical part design characteristics. FAA conformity requirements are intended to address these issues. FAA conformity is especially important for drive system and structural parts which operate at high stress levels (and high temperatures for certain parts) and therefore may be sensitive to variations in material properties and manufacturing processes. Control of these properties and processes is necessary to ensure that the fatigue margin meets the intent of the design.

b. A conformity plan should be developed for the certification test hardware. The plan should provide for conformity of all phases of manufacture of the specific part(s) to undergo certification testing. The cognizant FAA ACO will establish FAA conformity requirements. This requires advance planning and coordinating by both the applicant and the FAA for conformity of the initial stages of test hardware fabrication, such as the forging or casting processes. Chapter 5-2 of Order 8110.4B contains an overview of the process the FAA uses to evaluate demonstrations of conformity. In general, a conformity plan should include the following elements:

(1) Evaluation of the process methods and controls (such as forging, casting, machining, and surface finishing processes) that were used during all phases of manufacturing the certification test article;

(2) Evaluation of in-process assembly procedures used to assemble the test article;

(3) Observation of in-process functional tests performed during all phases of manufacture of the test article;

(4) Verification of the design characteristics of the finished part;

(5) Verification of the certification test installation; and

(6) Observation of the certification tests.

3-3. Component Analysis and Test. Component analyses and testing may be used to establish baseline material strength and stress data for drive system and structural parts. This data can be useful for identifying any adverse impact on material strength or stress that the design change may have caused (see Appendix 1). The data can also be used for future redesigns, service problem resolution, and for the estimation of design safety margins. The applicant may validate the accuracy of the data obtained from the component tests and analyses by testing the part while it is installed in an engine.

a. Material Strength Evaluation. Testing and metallographic inspection of the finished part, or partially finished part (forging, casting, etc.) is more representative of the actual part characteristics than material strength data obtained from textbook material reference data or industry documents (see Appendix 2). The following part characteristics should be addressed in the design of the part and test articles should be inspected as noted to evaluate material strength (see Appendix 2 for notes relative to these items):

(1) Dimensional and surface finish.

(2) Crack and surface defects. Inspect using magnetic particle inspection (MPI), ultrasonic inspection (U/T) or fluorescent penetrant inspection (FPI), or other methods acceptable to the Administrator.

(3) Casting porosity. Inspect using radiography and applicable reference standards.

(4) Corrosion-resistant surface treatments, such as painting and plating.

(5) Surface cold working operations, such as shot-peening.

(6) Material chemistry (typically obtained from material supplier certificates).

(7) Material hardness, including surface and internal hardness and also the case/core hardness profile of nitrided, induction-hardened or carburized steel components for case depth determination.

(8) Material microstructure and macrostructure, including grain structure, grain boundary anomalies, porosity, and inclusions. Metallographic inspections should be used to evaluate these.

(9) Tensile, yield, and fatigue strength. Use experimental test methods such as rotating beam tests of material coupons or part specimens.

b. Stress Analysis. Knowledge of assembly and operating stress levels is a valuable asset regarding the structural aspects of component development, particularly during redesign or optimization of an existing design. Stress analysis procedures may be used to resolve service difficulties involving component cracking. Without reliable stress data, structural design evaluation may be extremely difficult. Depending on the part being evaluated, stress analysis may consist of theoretical or experimental methods, or a combination of these methods.

(1) Theoretical. Theoretical methods include basic calculations for components with relatively simple configuration and finite element modeling for more complex components. Finite element modeling should be correlated to actual test data to ensure accuracy.

(2) Experimental. These stress analysis techniques commonly include laboratory bench testing of components. They typically rely on the use of strain gauges, supplemented by brittle lacquers and photo-elastic coatings. The most useful data is obtained when strain gauges or coatings are placed in areas of known high stress, such as fillet radii or in locations where service cracking has occurred. However, strain gauges and surface coatings can only be used on surfaces that are directly accessible. Internal or hidden surfaces (in joints, for example) require

theoretical studies for stress evaluation. Dynamic measurements of the stress levels on parts may be obtained by using strain gauges installed on operating engines (usually in test cells).

3-4. Engine Testing.

a. General. An engine test intended to substantiate compliance with § 33.19 should consider the following factors:

(1) Fatigue Mechanism. Typically, reciprocating engine drive system or structural part failure can be attributed to fatigue overload resulting from a large number of stress cycles at a low level of overstress; this is referred to as "high cycle fatigue" (HCF). Depending on its design and function, the part may be most affected by either:

(a) A forced vibratory response;

(b) A forced vibratory response in combination with a resonant vibratory response; or

(c) A forced vibratory response at high structural temperatures.

(2) Test Duration. An engine test should expose the part to at least 10 million significant stress cycles under the loading conditions representative of the relevant fatigue mechanism. This criterion is based on the fatigue strength characteristics of steel and cast aluminum. For steel parts, if fatigue cracking has not initiated within 10 million stress cycles, then the parts will most likely last indefinitely. Cast aluminum parts also exhibit a reduction of fatigue strength above 10 million cycles. In addition, a safety margin beyond the 10 million stress cycles should be added to accommodate variations (or scatter) in the actual strengths of production components and differences between test and service operating conditions. The test duration should also be designed to represent the effect of the maximum stress cycles on the fatigue life of a part over a typical TBO range.

b. Durability Test Types.

(1) Type 1 Tests. These tests are designed for parts whose primary fatigue mechanism is a forced vibratory response that is proportional to combustion pressures and inertia loads. The operating condition most associated with this type of fatigue mechanism is maximum power operation. These tests are appropriate for parts in which high operating temperatures do not significantly affect the fatigue strength of the part.

(a) Applicable Parts. The reciprocating engine parts typically found to be most susceptible to this fatigue mechanism include such parts as connecting rods, connecting rod bolts, piston pins, rocker arms, rocker shaft attachment bolts/studs, intake valves, cylinder barrels, crankshaft counterweights, valve push rods, valve spring retainers and keepers, camshafts, crankcases, crankcase through bolts and cylinder deck studs, and engine mounts and mount leg brackets. The Type 1 tests may also be appropriate for other parts depending on the specific characteristics of the engine and part design.

(b) Test Elements. A Type 1 test should include both the 150-hour endurance test of § 33.49 and a unique durability test. The unique durability test should consist of operation for 100 hours at take-off power with normal CHT and EGT, plus operation for 50 hours at cruise power with normal temperatures.

(2) Type 2 Tests. These tests are designed for parts whose primary fatigue mechanism is a forced vibratory response in combination with a resonant vibratory response that occurs at any engine speed at which the natural frequency of the part (or assembly that includes the part) coincides with the frequency of a combustion or inertia harmonic. The engine speed at which a component experiences resonant vibration depends on its physical design and the imposed dynamic conditions resulting from engine operation. The part can be excited in a torsional mode (for example, crankshafts) or a bending mode (for example, brackets). These resonances should be addressed by endurance testing at the engine speed and power condition that produces the peak resultant resonant stress level as required by §33.43 (b) . These tests are appropriate for parts in which high operating temperatures do not significantly affect the fatigue strength of the part

(a) Applicable Parts. The reciprocating engine parts typically found to be most susceptible to this fatigue mechanism include such parts as crankshafts, propeller drive gears, main internal and magneto gears, and driveline quill shafts. The Type 2 tests may also be appropriate for other parts depending on the specific characteristics of the engine and part design.

(b) Test Elements. A Type 2 should include three tests: the 150-hour endurance test of § 33.49, the vibration test of § 33.43, and a unique durability test. The unique durability test should consist of operation for 100 hours at take-off power with normal CHT and EGT, plus operation for 50 hours at cruise power with normal temperatures. The vibration test should consist of operation for at least 10 million cycles at peak torsional resonance conditions (see § 33.43). A typical torsional resonant frequency for a straight drive six-cylinder engine is around 200 Hz, which translates into a durability test time of about 14 hours at the RPM at which this resonant frequency occurs.

(3) Type 3 Test. These tests are designed for parts whose primary fatigue mechanism is a forced vibratory response at any engine power level whose effect on fatigue strength is aggravated by high structural temperatures. The operating conditions most associated with this type of fatigue mechanism include both take-off and cruise power conditions. During take-off and climb, maximum CHT may be experienced because the cooling airflow through the cowling is reduced due to the “nose up” angle of attack and slower airspeed of the airplane. During cruise operation, maximum EGT and turbine inlet temperature (TIT) may occur because the fuel/air ratio mixture setting is leaned to improve fuel economy. For engine bearings, high oil temperatures may also be a concern, especially at high power.

(a) Applicable Parts. The reciprocating engine parts typically found to be most susceptible to this fatigue mechanism are pistons, exhaust valves, cylinder heads, connecting rod and crankshaft main bearing inserts, exhaust system tubes, and exhaust system band clamps and connectors. The Type 3 tests may also be appropriate for other parts depending on the specific characteristics of the engine and part design.

(b) Test Elements. A Type 3 test should include both the 150-hour endurance test of § 33.49 and a unique durability test. The unique durability test should consist of two segments. The first segment should include 100 hours at take-off power with fuel flow at the full rich limit specified by the engine manufacturer and with CHT and oil temperature controlled to the requirements of § 33.49(a). The second segment should include 150 hours at the maximum cruise power recommended by the engine manufacturer with fuel flow leaned to produce the maximum allowable EGT (or TIT for turbocharged engines).

c. Similarity Analyses. The material strength of drive system and structural reciprocating engine parts may be dependent on the manufacturing processes utilized in the production of that part. These processes are usually unique to a particular manufacturer. Similar manufacturing processes performed by different manufacturers should not be assumed to produce identical material strength characteristics or stress levels in finished parts. Therefore, the scope of similarity analyses used for compliance with § 33.19 should be based on the applicant's specific design and manufacturing experience.

3-5. Pass/Fail Inspection Criteria.

a. Pass/Fail. Following completion of a durability test, each component being evaluated should be subjected to crack inspections in addition to the normal wear/distortion measurements. The basic pass/fail criteria should be that each part is in good serviceable condition. Any abnormality such as cracking or unusual wear/distortion (significantly outside service limits) should generally result in a reevaluation of the design of the part. One possible exception is cracks that are classed as superficial, meet the engine manufacturer's service requirements for continued use, and have also been shown by service history not to result in flight safety issues. Cooling fins on cast aluminum cylinder heads (not barrels) are an example of an area in which cracking may be acceptable on some designs.

b. Inspections. The following inspections are commonly used for crack detection and should be standard practice. The actual technique used depends on the component being examined:

(1) Magnetic Particle Inspection (MPI) for magnetic components.

(2) Fluorescent Penetrant Inspection (FPI) for non-magnetic components.

(3) Ultrasonic Inspection (U/T) for crankshafts, as specified by the engine manufacturer.

(4) X-ray radiography.

c. Inspection of Interfacing Engine Parts. Other engine parts that are adjacent to, connected to, or functionally related to the redesigned part may be examined for any signs of structural failure or unusual wear. This ensures that the redesigned part does not have an adverse derivative affect on other engine parts.

d. Component Structural Complexity Issues. Cracking may not be readily detectable on parts with a complex assembly or shape. In such parts, a crack may only become apparent when it is well developed, potentially when developed to the point of total component failure.

(1) The following parts have complex shapes or assemblies:

(a) Piston pins. These components are considered complex due to the hidden inner surface in some designs.

(b) Cylinder assemblies. These assemblies are considered complex due to the various hidden surfaces and also due to the poor visibility in small radius fin roots on both head and barrel.

(2) These components may be sectioned before MPI or FPI as follows:

(a) Piston pins. Section piston pins lengthwise along a diameter to expose the inner surface.

(b) Cylinder assemblies.

1. Remove the cylinder fins and inspect the fin root areas for cracking.

2. Remove valve seats, valve guides, and rocker arm shaft bushings (if so-equipped) and inspect the surfaces behind these parts.

3. Section cylinder assemblies lengthwise by making two cuts along diameters at right angles to expose threaded joint surfaces, edges of fin roots, and port interiors.

3-6. Other Methods of Durability Substantiation. This AC provides methods, but not the only methods, of compliance with the durability requirement. Other methods that could be used in place of some or all of the testing described in this AC include the following:

a. Accelerated or "lead the fleet" flight-testing to rapidly accumulate operating hours in advance of introducing the part to service.

b. Extensive experimental bench testing of the part to evaluate the material strength.

c. Finite element analysis to evaluate applied loads on the part. This type of analysis should be correlated and validated with testing or service experience with a similar part.

//Original signed by FAF on 9/27/04//

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APPENDIX 1. MATERIAL AND PROCESS CHANGES ON REDESIGNED PARTS

A1-1. General.

a. Drive system and structural parts may have small margins of safety that result from operation at high stress levels relative to their material strength. Many redesigns include changes in materials or manufacturing processes relative to the original design part. The margin of safety may be eroded if careful attention isn't paid to the effects these changes may have on the material strength or stress levels. Consideration should be given to the following effects that material or process changes may have on the redesigned part:

(1) A local increase in stress caused by cracks, nicks, gouges, laps, rough surfaces, thin sections, undersize fillet radii, coarse porosity, or gross inclusions.

(2) Reductions in strength, wear resistance, or corrosion resistance caused by coarse microstructure, low hardness, inappropriate heat treatments or surface treatments.

b. The precise effects of these factors may be difficult to quantify in terms of stress or strength. In addition, many of these characteristics are difficult to detect or evaluate by analytical methods. For these and other reasons (related to dimensional and operational variables), substantial reliance should be placed on representative durability testing during certification of drive system and structural reciprocating engine parts.

c. These factors should also be considered when the extent of the redesign is limited to a change in material.

A1-2. Factors That Increase Stress. The following factors may affect mean (steady state) stresses and operational (dynamic) stresses:

a. Surface treatment processes (such as carburizing, nitriding, and shot peening) that introduce beneficial surface stresses may also cause increased residual tensile stresses in the core. This can be especially significant in thin sections of parts.

b. Prestress in bolted joints, which is generally beneficial if it is not excessive.

c. Straightening, which can result in residual stresses and risk of cracking.

d. Welding or brazing, which can cause residual stresses.

e. Dimensional changes.

f. Interference fits (assembly stresses).

g. Reduced cross-sectional areas, including wall thicknesses, which can cause increased operational stresses and mean stresses.

h. Manufacturing-related stress raisers, which can cause increased operational stresses. Manufacturing processes that produce surface stress raisers should normally be discovered during examination of test articles by visual observation and crack inspection procedures. Subsurface stress raisers resulting in material strength issues are largely controlled by process definition and control, and supported by destructive sampling procedures. Manufacturing related stress raisers include the following:

(1) Nicks, deep scratches, and gouges;

(2) Gross porosity, large inclusions, cold shuts, and hot tears (castings);

(3) Laps and inclusions (forgings);

(4) Sharp edges;

(5) Corrosion pits;

(6) Cracks;

(7) Overly rough surface finishes; and

(8) Undersize fillet radii.

A1-3. Factors That Reduce Strength. Most of the following factors are especially significant in their effect on fatigue strength, a major design consideration for reciprocating engine parts.

a. Low hardness (specifically true for steels; less significant for cast aluminum alloys). Low hardness is commonly associated with the of heat treatment processes.

b. Coarse microstructure/grain size, adversely affecting static strength, fatigue strength, and toughness. Coarse microstructure/grain size is commonly associated with the temperatures levels during casting and forging operations, during normalizing (for steels), or during the heat treatment processes.

c. Levels of impurities, inclusions, or porosity (castings).

d. Decarburization of steel surfaces, causing a soft, low-strength surface layer. Decarburization of steel surfaces is typically associated with the temperature levels during forging operations; some decarburization may be acceptable.

e. Inappropriately specified surface treatments such as carburizing, nitriding, and shot peening.

f. Inappropriately specified plating treatments of high strength steels, resulting in hydrogen embrittlement.

g. Inappropriately specified joining processes such as welding or brazing, which exhibit incomplete fill or, in the case of welding, local section reduction.

APPENDIX 2. NOTES ON MATERIAL STRENGTH EVALUATION

A2-1. Metallographic Analysis. In combination with chemistry and hardness data, metallographic analysis is a fundamental tool for assessing material properties. The metallographic inspection may be expected to provide information of a basic microstructural nature, including grain structure, the presence or absence of unusual intergranular conditions, porosity, and inclusions in the area sectioned. However, there are limits to the amount of information that can be obtained during a general metallographic evaluation. The information gathered depends on the scope of the evaluation. Component idiosyncrasies may go undetected without a thorough understanding of the manufacturing processes. Changes in microstructure between "good" and "bad" material performance are sometimes so subtle as to be indistinguishable.

A2-2. Microstructural Analysis. There are several important characteristics that a general microstructural evaluation may miss or, if detected, may not thoroughly assess in terms of component strength. The following list represents examples of several areas of analytical difficulties:

a. Detection of hydrogen embrittlement.

b. Detection of non-homogeneous microstructure.

c. Evaluation of directional properties.

d. Effects of section thickness on the properties of low alloy, high hardenability steels.

e. Detection of local nitrided surface case depth reduction (resulting from grinding/overpolishing).

f. Evaluation of decarburized layer thickness in terms of its effect on the fatigue strength of forged steel components.

g. Evaluation of cast aluminum microstructural and macrostructural variations and their effects on component fatigue strength.

A2-3. Material Strength Reference Data.

a. A large amount of basic material strength data is available in reference books. Although very valuable, the data, especially that on fatigue strength, should be used cautiously. Reports published in the handbooks of the American Society for Metals (ASM) indicate that there are significant problems in establishing or confirming fatigue strengths by relying on reference data. "The Selection of Steel for Fatigue Resistance" reports that although the fatigue strength of steel is usually in proportion to the tensile strength, this generalization does not hold in many instances and is not true over wide ranges of tensile strength. "Aluminum Alloy Castings: Mechanical Properties" states that the fatigue strength of cast aluminum is markedly dependent on the casting process. It further states that actual fatigue testing of fully machined cast aluminum parts is the only method of alloy or process selection. "Fatigue Resistance of Steels" states that: "Fatigue tests performed on small specimens are not sufficient for precisely establishing the fatigue life of a part." "Fatigue Failures" discusses fatigue failures and prediction of fatigue life and includes many of the variables affecting fatigue life. It also identifies that standard fatigue life data (as normally presented in reference books) is usually based on the median life of the specimens tested. In addition, it refers to the significant scatter associated with such fatigue life values.

b. Nevertheless, estimates of basic material fatigue strength should be an essential part of the design or redesign processes; laboratory-derived fatigue data should be used to support this evaluation. When calculating safety factors, avoid overestimating fatigue strengths. The values used should reflect the lower limits of data scatter, rather than median values, when possible. The fatigue test data presented in curves in the *ASM Metals Handbook* reports is valuable for assessing alloy steel and cast aluminum fatigue strength scatter. Fatigue strength estimates should also include the effects of such parameters as mean stresses, stress concentrations, surface finishes, and structural temperatures.

c. Complex components, such as cylinder assemblies, that depend significantly on assembly procedures for their strength present an additional difficulty in estimating fatigue strengths (or lives). The durability of such assemblies cannot be fully evaluated based only on their individual component material properties. Due to uncertainties and operational variables that may affect stress and strength, component analysis should be supported by durability testing.