Federal Aviation Administration

Memorandum

Date: September 6, 2007

From: Manager, Engine and Propeller Directorate, Aircraft Certification Service

To: SEE DISTRIBUTION

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Subject: **ACTION**: Policy for Diesel (Compression Ignition) Engine Certification, 33.7 [ANE-2006-33.7-4-1]

1. Purpose.

The purpose of this memorandum is to clarify the certification requirements for 14 CFR part 33, type certification of diesel reciprocating engines. This memorandum provides compliance interpretations necessary to accommodate the unique design features of a diesel reciprocating engine. It also identifies areas of regulatory compliance that may require equivalent level of safety findings (ELOS) or special conditions (SC) to address design features of diesel engines not envisioned when part 33 was created. However, an appropriate ELOS or special condition for each engine model must be determined on a case-by-case basis, in accordance with part 21, §§ 21.16, 21.17, and part 11.

2. Related Documents.

Final Policy Statement, Diesel Engine Installation, PS-ACE100-2002-004, dated May 15, 2003

3. Background.

Several diesel engine models were certified in the United States and Europe before World War II. However, the development of higher performance spark-ignition engines fueled by leaded aviation gasoline (AVGAS) during that conflict resulted in a suspension of further development of these engines. Interest in diesel aircraft engines has recently been renewed in response to the demand for engines that do not require leaded fuel for operation. Many new issues develop as modern diesel engine technology is integrated into these aircraft engines.

4. Policy.

All proposed diesel engine type certification projects must be coordinated with the Engine and Propeller Directorate, as directed in Order 8100.5A, Section 3-3, and Order 8110.4C, Change 1, section 2-4. These projects are categorized as significant by the EPD, and early program coordination between the Standards Staff Office and the Aircraft Certification Office (ACO) is necessary. The ACO is expected to notify the Standards Staff Office of these projects by promptly submitting the certification project notification (CPN) and associated certification plans as soon as practical after the project application is received. The ACO should identify technical areas of concern based on the guidance contained in this policy statement, as well as any other identified concerns. The ACO will then develop a G-1 issue paper to establish the certification basis, including any anticipated ELOS findings or special conditions.

a. Nomenclature. The following nomenclature will be used to distinguish the two different types of reciprocating engines:

(1) Compression-Ignition (CI): The combustion process is initiated solely by the injection of fuel into hot, compressed air, as in a diesel engine. Diesel engines will be referred to as CI engines in this memo.

(2) Spark-Ignition (SI): An electrical spark applied to a compressed fuel and air mixture begins the combustion process in most conventional reciprocating aircraft engines. Therefore, conventional engines are referred to as "spark ignition" (SI) engines.

b. Part 33 Compliance for CI Reciprocating Engines.

The regulations applicable to CI reciprocating engines include, but are not limited to, the following:

Table 1. Affected Regulations

PART 33 – AIRWORTHINESS STANDARDS: AIRCRAFT ENGINES: AFFECTED REGULATIONS			
SECTION	TITLE	APPLICABILITY	DIESEL ENGINE COMPLIANCE ISSUE/COMMENTS
SUBPART A – GENERAL			
33.1	APPLICABILITY	YES	NONE
33.3	GENERAL	YES	NONE
33.4	INSTRUCTIONS FOR CONTINUED AIRWORTHINESS	YES	NONE
33.5	INSTRUCTION MANUAL FOR INSTALLING AND OPERATING THE ENGINE	YES	NONE
33.7	ENGINE RATINGS AND OPERATING LIMITATIONS	YES	ELOS FOR FUEL FLOW/POWER LEVER ANGLE USED AS ENGINE OPERATING LIMITATION IN LIEU OF MAP*. FUEL SPECIFICATION OVERSIGHT. CETANE NUMBER ANALYSIS.
33.8	SELECTION OF ENGINE POWER AND THRUST RATINGS	YES	NONE
SUBPART B – DESIGN AND CONSTRUCTION; GENERAL			
33.11	APPLICABILITY	YES	NONE
33.14	START-STOP CYCLIC STRESS	YES	NONE
33.15	MATERIALS	YES	NONE
33.17	FIRE PREVENTION	YES	EVALUATION OF HIGH PRESSURE FUEL SYSTEM
33.19	DURABILITY	YES	CONTAINMENT SAFETY ANALYSIS
33.21	ENGINE COOLING	YES	NONE
33.23	ENGINE MOUN TING ATTACHMENTS AND STRUCTURE	YES	NONE
33.25	ACCESSORY ATTACHMENTS	YES	NONE
33.27	TURBINE, COMPRESSOR, FAN AND TURBO SUPERCHARGER ROTORS	YES	NONE
33.28	ELECTRICAL AND ELECTRONIC ENGINE CONTROL SYSTEMS	YES	SEE AC 33.28-2
33.29	INSTRUMENT CONNECTION	YES	NONE
SUBPART C – DEISIGN AND CONSTRUCTION; RECIPROCATING AIRCRAFT ENGINES			
33.31	APPLICABILITY	YES	NONE
33.33	VIBRATION	YES	EVALUATION OF HIGH PRESSURE FUEL LINE INTEGRITY
33.35	FUEL AND INDUCTION SYSTEM	YES	ELOS TO USE TURBINE FUEL SYSTEM ICING REGULATION § 33.67
33.37	IGNITION SYSTEM	NO	
33.39	LUBRICATION SYSTEM	YES	NONE

*MANIFOLD AIR PRESSURE

Table 1. Affected Regulations (continued)

PART 33 – AIRWORTHINESS STANDARDS: AIRCRAFT ENGINES: AFFECTED REGULATIONS			
SECTION	TITLE	APPLICABILITY	DIESEL ENGINE COMPLIANCE ISSUE/COMMENTS
SUBPART D – BLOCK TESTS; RECIPROCATING AIRCRAFT ENGINES			
33.41	APPLICABILITY	YES	NONE
33.42	GENERAL	YES	NONE
33.43	VIBRATION TEST	YES	SINGLE CYLINDER INOPERATIVE TEST APPLIES
33.45	CALIBRATION TEST	YES	NONE
33.47	DETONATION TEST	YES	NOT APPLICABLE
33.49	ENDURANCE TEST	YES	NONE
33.51	OPERATION TEST	YES	EVALUATION OF OVERSPEED
33.53	ENGINE COMPONENT TESTS	YES	NONE
33.55	TEARDOWN INSPECTION	YES	NONE
33.57	GENERAL CONDUCT OF BLOCK TESTS	YES	NONE
	ENGINE CONTAINMENT	YES	SC FOR CONTAINMENT SAFETY ANALYSIS
SUBPART E - DEISIGN AND CONSTRUCTION; TURBINE AIRCRAFT ENGINES – NOT APPLICABLE			
SUBPART D – BLOCK TESTS; TURBINE AIRCRAFT ENGINES – NOT APPLICABLE			
APPENDIX A TO PART 33 – INSTRUCTIONS FOR CONTINUED AIRWORTHINESS			
A33.1	GENERAL.	YES	NONE
A33.2	FORMAT	YES	NONE
A33.3	CONTENT	YES	NONE
A33.4	AIRWORTHINESS LIMITATIONS	YES	NONE
APPENDIX B TO PART 33 – CERTIFICATION STANDARD ATMOSPHERIC CONCENTRATIONS OF RAIN AND HAIL – NOT APPLICABLE			

c. Manifold Air Pressure Indicator: (§ 33.7(b)(1)).

(1) Section 33.7(b)(1) requires that ratings and operating limitations be established for "manifold air pressure", but this may not be a relevant engine parameter for CI engines.

(2) For an SI engine, engine power output is typically represented by manifold air pressure and engine RPM. Manifold air pressure is also used to control turbocharger speed and boost. These two parameters allow the pilot to control the engine within the approved operating limits. However, CI engines typically do not throttle airflow into the engine inlet, but rather allow the engine to pump as much air as it demands. The airflow and manifold air pressure are simply a function of the engine RPM and ambient conditions, and the engine power is modulated by

controlling fuel flow. At a given RPM and ambient condition, the engine power varies as fuel flow is increased from the lean limit, where combustion cannot be supported, to a “rich limit” where power begins to drop off because of excess fuel. Between these lean and rich limits, fuel flow is the only indicator of engine power output at a given RPM. Fuel flow is typically controlled by a power lever angle input into the high-pressure fuel pump. Therefore, the power level is best represented by a power lever angle and its association to the fuel flow.

(3) For turbocharged engines, other means such as a turbocharger pressure ratio or speed indication can be used to control turbocharger speed.

(4) Therefore, the engine parameter specified in § 33.7(b)(1) is not appropriate for CI engines, and a method of compliance based on an ELOS to §33.7(b)(1) should be established for approval of fuel flow or power-lever angle as indicators of power level in place of manifold air pressure.

d. Fuels Approval: (§ 33.7(b)(2)).

(1) Fuel Specification Oversight:

(a) Section 33.7 requires that the engine operating limitation be established for “fuel grade or specification”. This limitation is usually specified on the type certificate data sheet (TCDS). The specific limitations have varied over the years, from only octane grade (for example, 80/87 AVGAS), to identifying the industry or company specification numbers (for example, 80/87 AVGAS per ASTM D910, JET-A per ASTM D1655). The specific details are dependent on the operating requirements of the engine. For example, more modern engines may require tightly controlled fuel properties that are defined in the ASTM specifications, other industry specifications, or company specifications. However, industry specifications are typically revised on an annual basis, causing the specification number to change with each revision (for example, ASTM D1655-05 to D1655-06). The FAA acceptance of these annual revisions without re-certification is based on oversight from a committee of industry expert’s knowledgeable in fuel, and the products the fuel is intended for. The primary purpose of this oversight is to ensure the fuel remains "fit for purpose" for the type of engines referenced in the specification. As a result, this committee consensus process negates the need for re-certification of every engine and aircraft when a new revision is issued.

(b) It is anticipated that CI engines will use jet fuels, such as JET-A, which are produced in accordance with the ASTM International specification D1655, or automotive diesel fuels produced in accordance with automotive fuel specifications. In either case, the CI engine TC applicant should provide evidence that they are an active member of the ASTM or other industry committee responsible for oversight of the designated fuel specification. In addition, the TC applicant should evaluate specification revisions on an annual basis for their impact on “fit for purpose” relative to aviation CI engines.

(2) Cetane Number Analysis: Aviation jet fuel specifications such as ASTM International D1655 do not include criteria for control of cetane number because this is not a critical performance parameter for turbine engines. The cetane number characterizes the ignition capability of a diesel fuel, and is a critical parameter for assessing the acceptability of a fuel for a particular engine design. Using the appropriate cetane rated fuel in a diesel engine is critical to developing the appropriate power. Therefore, the CI engine applicant will be required to provide an analysis that substantiates operation with jet fuel with an inadequate cetane number will not create an unsafe condition. The applicant's analysis should consider the minimum cetane requirement of their CI engine design, the probability that commercially available fuel may have a cetane number below that minimum, and the consequences of operating with a fuel with a cetane number that is below that minimum.

(3) Additives: Additives needed for turbine fuels that will also be required by an aircraft CI engine (such as anti-icing and biocide additives) should be specified on the engine TCDS and in the fuel specification listed in the TCDS.

(4) Automotive Diesel Fuel: If automotive diesel fuel is to be approved, appropriate specifications will need to be identified. Approval of fuels that do not have a specification (such as protein or plant-based (bio-diesel) fuels) should be handled on a case-by-case basis.

(5) Materials Compatibility: In addition to engine performance requirements, compatibility of the fuel system materials (for example: elastomers, sealants, seals, liners, hoses, composite parts) with the approved fuels for an aircraft CI engine has to be established.

e. High Pressure Fuel Lines: (§§ 33.17 and 33.33).

Using high-pressure fuel lines is common in the automotive industry, but it is limited in the aircraft piston engine environment. However, aircraft CI engines typically require fuel under high pressure to support the combustion process. Failure of an external fuel line that carries this high-pressure fuel may create a fire hazard and needs to be evaluated under § 33.17 (Fire Prevention) and § 33.33 (vibration). This should be accomplished as part of the basic compliance effort.

f. Engine Containment: (§ 33.19).

(1) The possibility that engine failures may lead to liberation of high-energy engine fragments must be evaluated because much higher cylinder pressures exist in CI engines. The applicant should perform a safety analysis that addresses the engine construction and possible failure modes.

(2) The engine manufacturer should perform the safety analysis and submit it to the FAA. If the safety analysis indicates a possible engine failure mode that will liberate engine parts, then the energy levels of the anticipated fragments should be characterized and noted in the Installation Manual. This information will then be used during the 14 CFR part 23 aircraft certification process. This should be accomplished as part of the basic compliance effort.

g. Electronic Engine Controls: (§ 33.28).

Many new technology aircraft CI engines use a Full Authority Digital Engine Control (FADEC) or Electronic Engine Control (EEC). Such systems are not unique to aircraft CI engines and are increasingly common on conventional reciprocating engines. FAA AC 33.28-2 addresses EECs in reciprocating engines, and most of the guidance in that document is applicable to CI engines as well as SI engines. Note that coordination with the aircraft manufacturer and the FAA ACO responsible for the aircraft certification is necessary to ensure the lightning, HIRF, and EMI testing levels used for the engine-level part 33 compliance meet the corresponding aircraft-level certification requirements of part 23.

h. Fuel System Icing: (§ 33.35(b) and § 33.67).

(1) JET-A fuel has the potential to absorb greater amounts of water into the solution than AVGAS, making it more susceptible for icing. In addition, the higher fuel system operating pressures of CI engines, relative to spark ignition engines, also increases the risk of fuel icing. Sustained operation of a CI engine using jet fuel at high pressure flows could result in supercooled water adhering to fuel system surfaces, freezing, and forming blockages in the fuel system. Therefore, CI reciprocating engines are very similar to turbine engines, relative to the fuel used and the potential of freezing occurring before mixing with air. The current reciprocating engine fuel carburetor icing regulation (§ 33.35(b)) is intended to address condensation of moisture-laden air occurring in the carburetor throat area and forming ice that blocks the airflow. Accordingly, CI engine manufacturers should apply the turbine engine fuel icing requirements of § 33.67 to CI engines instead of using § 33.35(b), which addresses the fuel system icing requirements of reciprocating engines. Because of this unique attribute of CI engines, the certification office must also ensure that it evaluates CI engine fuel system icing using the turbine engine fuel icing requirements of § 33.67, not the reciprocating engine fuel carburetor icing requirements of § 33.35(b).

(2) Jet fuel icing protection is addressed for turbine engine fuel systems in § 33.67(b)(4)(ii). That regulation requires the fuel system for a turbine engine to sustain operation throughout its flow and pressure range with fuel initially saturated with water at 80° F and having 0.025 fluid ounces of free water per gallon added and cooled to the most critical condition for icing likely to be encountered in operation. Some turbine engines have shown compliance with this requirement by mandating the use of fuel anti-icing additives. Mandating the use of approved anti-icing additives would be an acceptable method to show compliance; however, the use of these additives is generally being decreased in some countries for environmental reasons. As an alternative, the applicant may show compliance by incorporating a fuel heater which maintains the fuel temperature at the fuel strainer or fuel inlet above 32° F (0° C) under the most critical conditions. The requirements of § 33.67 should be applied as an ELOS to §33.35(b) for the CI engines.

i. Vibration: (§§ 33.33 and 33.43).

(1) Aircraft CI engines may yield a greater level of vibration than current SI engines. As part of the basic compliance for aircraft CI engine type certification, the effects of vibration levels higher than those typical for conventional reciprocating engine powered airplanes must be considered. In addition, the one-cylinder-inoperative vibration test of §33.43(d) is applicable to CI engines and should be conducted by deactivating a fuel injector.

(2) The vibratory loads imparted to the airframe by a CI engine may exceed those of a conventional SI engine, and therefore need to be defined during the engine certification process. This vibration data should be included in the engine instructions for installation in accordance with § 33.5 to establish it as required powerplant installation design data

j. Detonation Test: (§ 33.47).

Section 33.47 requires that applicants demonstrate that each engine is "tested to establish the engine can function without detonation throughout its range of intended conditions of operation." SI engines rely on spark-initiated combustion timed to occur at a precise moment in relation to piston travel. However, under excessive temperatures or pressures, the fuel-air mixture can self-detonate without the aid of the spark. This is an abnormal operating condition in SI engines. In CI engines, combustion is initiated by injecting fuel into a compressed, high-temperature chamber, without the aid of a spark. Therefore, uncontrolled detonation is very unlikely. Accordingly, § 33.47 is not applicable for CI engines.

k. Engine Overspeed: (§ 33.51).

CI engines have a greater potential for destructive overspeed due to an oversupply of fuel. The engine control system operation and the engine structural integrity should be evaluated relative to overspeed conditions. This should be accomplished as part of the basic compliance effort.

5. Effect of Policy.

a. The general policy stated in this document does not constitute a new regulation nor create a "binding norm". Offices should follow this policy when it is applicable to a specific project. Whenever an applicant's proposed method of compliance is outside this or any established policy, the proposed method must be coordinated with the policy issuing office (for example, through the issue paper process or equivalent).

b. Applicants should expect the FAA will consider this policy when making findings of compliance relevant to new certificate actions.

6. Conclusion.

All proposed CI engine type certification projects should be coordinated with the Engine and Propeller Directorate, as defined in Order 8100.5A, Section 3-3, and Order 8110.4C, Change 1, Section 2-4. The ACO is expected to notify the Standards Staff Office of such projects by promptly submitting the CPN and associated certification plans as soon as practical after project application. The ACO will identify the technological areas of concern identified in this policy paper, as well as any additional concerns and develop a G-1 issue paper to establish the certification basis. Signature authority for certificate issuance on these projects are retained by the Standards Staff Office, and will be redelegated on a case-by-case basis as this new technology is understood and integrated into aerospace products.

/signed by Peter A White – for Francis Favara/
Francis Favara

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