U.S. Department of Transportation
Federal Aviation Administration

Advisory Circular

Subject: DETONATION TESTING IN RECIPROCATING AIRCRAFT ENGINES

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Initiated by: ANE-110

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Change:

1. PURPOSE. This advisory circular (AC) provides guidance material and information relating to detonation testing for reciprocating aircraft engines. The methods presented in this AC are not necessarily applicable to engines using alcohol or alcohol/gasoline type fuels. Guidance contained in this AC does not constitute a regulation and, therefore, is not mandatory. Additionally, it is not necessarily the only means of showing compliance with applicable airworthiness requirements.

2. RELATED FAR SECTIONS. FAR Part 33, Section 33.47, and CAR Part 13, Section 13.153.

3. BACKGROUND. This AC, relating to engine certification substantiation procedures, is intended to assist in establishing uniformity in the certification process and in the pre-certification test planning by defining certain terms and procedures which may be of assistance in meeting the related regulations. AC 23.909-1, Installation of Turbochargers in Small Airplanes with Reciprocating Engines, may be of further assistance.

4. DEFINITIONS.

a. Detonation. The spontaneous combustion of an unburned charge which occurs ahead of the flame front after normal ignition. Frequency and severity of detonation is defined as follows:

5-9 flashes/minute = incipient detonation; 10-20 flashes/minute = limiting detonation.

b. Preignition. The uncontrolled ignition of a charge prior to the occurrence of normal ignition.

c. Turbocharger. Any exhaust gas-driven device that is added to or part of a reciprocating engine. This definition applies to:

(1) Engines turbonormalized having a turbocharger that maintains approximately sea level manifold pressure to a critical altitude.

(2) Engines turbosupercharged having a turbocharger that provides a manifold pressure greater than that of a normally aspirated engine at sea level conditions and maintains this pressure to a critical altitude.

d. Supercharged Engine. An engine having a mechanical air-charging device (compressor) that provides a manifold pressure equal or greater than that of a normally aspirated engine at sea level conditions and maintains this manifold pressure to a critical altitude.

e. Intercooler. - Any device installed in the engine induction air system at the exit of turbocharger or supercharger compressor intended to reduce the temperature of air compressed by the turbocharger.

f. Fuel Mixture Runs. - A series of fuel mixture response curves run at various powers and speeds to determine an operating envelope free of detonation.

g. Rated Takeoff Power. The approved brake horsepower that is developed statically under standard sea level conditions within the engine operating limitations established under Part 33, and limited in use to periods of not over 5 minutes of operation.

h. Takeoff Power. - The brake horsepower that is developed under standard sea level conditions, and under the maximum conditions of crankshaft rotational speed and engine manifold pressure approved for the normal takeoff, and limited in continuous use to the period of time shown in the approved engine specification.

i. Critical Altitude. The maximum altitude at which, in standard atmosphere, it is possible to maintain at a specified rotational speed, a specified power, or a specified manifold pressure. Unless otherwise stated, the critical altitude is the maximum altitude at which it is possible to maintain, at the maximum continuous rotational speed, one of the following:

(1) The maximum continuous power, in the case of engines for which this power rating is the same at sea level and at the rated altitude.

(2) The maximum continuous rated manifold pressure, in the case of engines, the maximum continuous power of which is governed by a constant manifold pressure.

j. Standard Atmosphere. - A hypothetical vertical distribution of temperature, pressure, and density in the atmosphere used for instrument calibrations and aircraft performance calculations. The current standard was adopted, by international agreement, in 1962 by the U.S. Committee on Extension to the Standard Atmosphere. The U.S. standard has been adopted by the International Civil Aeronautical Organization (ICAO) up to 105,000 feet.

k. Standard Sea Level Conditions. - The value of temperature, pressure, and density at sea level in the standard atmosphere. (temperature = 59 $^{\circ}$F (15 $^{\circ}$C), pressure = 29.92 in. Hg, density = 0.0023769 slugs/ft^3).

l. Standard Hot Day. - The hypothetical vertical temperature variation in the atmosphere starting at a sea level temperature of 103°F (39.4°C) and having the same lapse rate (up to 36,089 ft) as the standard atmosphere. The specified sea level pressure for a hot day is the same as for a standard day.

5. RELATIONSHIP TO ENGINE CERTIFICATION PROCEDURES.

a. The detonation margin of reciprocating airplane engines at various power settings is related primarily to induction air inlet temperature and pressure, cylinder head temperature, engine exhaust back pressure, ignition timing, fuel grade, fuel flow, carburetor or injector metering characteristics, compression ratio, and cooling margins. Other features, such as cylinder combustion chamber design, induction system design and distribution, are also involved to a lesser degree. Changes to design features for purpose of meeting the detonation margin, such as compression ratio, ignition timing, and fuel metering and endurance characteristics may require re-certification of an engine.

b. The addition of a turbocharger to an engine not certified with it or a change in the engine turbocharger of a certified combination may affect detonation margin. If the original margin is small, unsatisfactory detonation characteristics may result. Turbocharging can also be expected to have an effect on induction system distribution.

c. For a turbocharged engine, induction air temperature may become critical at altitude because of the increased compression of air required. The turbocharger speed will also increase with altitude because increased turbine wheel speed is necessary to achieve the required pressure ratio to maintain manifold pressure. If detonation characteristics are unsatisfactory, changes of one or more of the other primary factors may be necessary to restore detonation margins. Refer to AC 23.909-1, Installation of Turbochargers in Small Airplanes with Reciprocating Engines, for additional guidance with turbocharged applications.

d. A detonation survey must be performed for the approval of a turbocharged engine installed in an airframe to verify that the detonation margins are still within acceptable limits and that the installation has not caused any detrimental effect related to detonation.

e. Whenever a power or performance increase is requested (i.e. turbocharged installation, higher manifold pressure, higher induction temperature, intercooler installation) a satisfactory detonation survey must be performed prior to approval.

6. DETONATION TEST

The detonation tests are intended to demonstrate that there is a satisfactory margin against the occurrence of detonation for the most critical operating conditions to be approved for the engine as installed in an aircraft.

The detonation test should be specified to cover power settings throughout the entire operating envelope using fuel of minimum specified octane. The usual method of doing this is to take successive power readings with the mixture leaned out progressively to the point of incipient detonation or where the engine cuts out. Intake air temperatures for detonation testing should account for the heat rise requirements for induction system icing protection. During the tests the engine should be operated with intake air at a temperature which complies with the intended class of aircraft preheated regulator requirements. For fuel injected engines, the intake air temperature should be commensurate with hot day condition. At least one cylinder should be within 10°F of the maximum permissible temperature value for cylinder head and cylinder barrel. (See also b., below)

Detonation testing should address the following considerations over the operating range for which engine approval is sought. In addition to sea level testing, sufficient altitude or simulated altitude testing should be conducted for turbocharged or supercharged engines to verify freedom from detonation with an appropriate margin for safety.

a. The detonation survey should consist of a series of fuel mixture runs and be made with oil inlet temperatures within plus or minus 10°F of limiting temperatures. The induction air temperature should be held to minus zero of that specified for a standard hot day at the particular altitude in question.

b. Cylinder head temperature should be maintained by regulating the cooling air differential pressure at the start of each fuel mixture control run in such a manner that the peak temperature reached by the hottest cylinder during leaning will be not more than 10° below the maximum specified engine limit. The temperature of all other cylinder heads should be maintained within 50°F of the hottest cylinder.

c. Detonation tests should define detonation characteristics throughout the operating envelope, including takeoff power and engine RPM (if applicable), rated power and engine RPM, and high and low cruise powers. It may be necessary to run tests at powers between high and low cruise to determine the maximum power setting at which detonation free operation exists during fuel mixture leaning. Care must be exercised to hold speed and power as close to the desired values as possible while leaning out the fuel mixture. Detonation testing based on evaluation of the maximum temperature cylinder only is not acceptable.

d. For naturally aspirated and single speed geared supercharged engines, the data should be taken at sea level pressure altitude. For turbocharged engines or engines using turbochargers and mechanical superchargers, the data should be obtained throughout the engine operating envelope. If an intercooler is used, then the induction air should be controlled to the maximum permissible temperature at each power setting and altitude.

e. The detonation tendencies should be observed by standard laboratory methods. The fuel mixture should be varied from full-rich to either limiting detonation, maximum allowable turbocharger temperature, best economy mixture, or power instability. Minimum fuel mixture margin should be 12 percent above limiting detonation. It is also necessary to show that the leanest fuel/air ratio allowable for the fuel metering device used is 12 percent richer than limiting detonation. The engine should not demonstrate any detonation characteristics at the minimum fuel flow specified for any operating condition. Engine power settings through the engine operating envelope should be tested to verify establishment of adequate detonation margins. The engine should not demonstrate limiting detonation at fuel flows down to 12 percent leaner than the minimum fuel flow recommended by the engine fuel flow chart.

f. In order to obtain certification to permit the use of a lower grade fuel, a satisfactory detonation test must be completed with the lower grade fuel.

7. TEST FUEL. A sample of fuel used during testing should be submitted to an approved or acceptable independent testing facility for analysis. The fuel should be analyzed in comparison with the properties specified for the fuel type approved for use with the engine. The specified properties will normally be detailed in either the American Society for Testing and Materials (ASTM) D910 for aviation fuel, or ASTM D439 for automotive fuel. The test fuel should be controlled to the low end of the octane rating.

8. TEST EQUIPMENT Test equipment should normally include the ability to measure the following parameters:

a. Temperatures
Cylinder Head (for each cylinder)
Induction Air
Turbocharger Compressor Inlet (if applicable)
Turbocharger Compressor Outlet (if applicable)
Intercooler Air Outlet (if applicable)
Engine Oil Temperature
Outside Air Temperature
Turbocharger Turbine Inlet

b. Pressures
Manifold (inlet and exhaust)
Engine Oil

c. Other Parameters
Engine Power (Torquemeter or calibrated engine)
Engine Speed (RPM)
Fuel Flow
Detonation -
(1) Pick-ups - Magnetostriction or piezoelectric type (one for each cylinder)
(2) Read out device - Oscilloscope or other read out with appropriate switching capability that has demonstrated satisfactory results in the past.

NOTES

- Prior to testing, all instrumentation must be calibrated and the engine magneto timing checked and reset if out of limits. Cylinder compression should also be checked and be within limits.

- Detonation pick ups must be matched as a set for sensitivity.

- Detonation equipment must be rechecked continually for proper timing, gain setting, and varying pick up sensitivity.