Designation: D6424 – 04a (Reapproved 2014)

An American National Standard

Standard Practice for
Octane Rating Naturally Aspirated Spark Ignition Aircraft Engines[1]

This standard is issued under the fixed designation D6424; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 This practice covers ground based octane rating procedures for naturally aspirated spark ignition aircraft engines using primary reference fuels.

1.2 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 *ASTM Standards:*[2]

D2700 Test Method for Motor Octane Number of Spark-Ignition Engine Fuel

3. Terminology

3.1 *Definitions:*

3.1.1 *amine number of reference fuels above 100, AN, n*—determined in terms of the weight percent of 3-methylphenylamine in reference grade *iso*octane (2,2,4–trimethylpentane). For example, 5 % of 3–methylphenylamine in reference grade *iso*octane has an amine number of 105 (AN 105). No attempt has been made to correlate performance number of leaded reference fuels to the amine number of unleaded reference fuels, and none is implied.

3.1.2 *engine motor octane requirement*—one full motor octane number greater than the maximum motor octane number that results in knock (graphic knock level descriptions can be seen in Annex A1). For example, a test engine knocks on primary reference fuels with 96 and 97 motor octane numbers. The test engine does not knock on a primary reference fuel with a 98 motor octane number. The maximum motor octane number that results in knock is 97, so the motor octane requirement is 98.

3.1.3 *full rich*—condition in which the mixture control is at the full stop position with the fuel flow within manufacturer's recommended settings.

3.1.4 *house fuel, n—for octane rating*, an unleaded, straight hydrocarbon fuel used for engine warm-up and all non-octane rating testing.

3.1.5 *knock, n—in an aircraft spark ignition engine*, abnormal combustion caused by autoignition of the air/fuel mixture.

3.1.6 *knock condition, n—for octane rating*, when the knock intensity in any cylinder is light knock or greater as described in Annex A1.

3.1.7 *knock number, n— for octane rating*, a numerical quantification of knock intensity.

3.1.8 *motor octane number of primary reference fuels above 100*—determined in terms of the number of millilitres of tetraethyl lead in *iso*octane.

3.1.9 *motor octane number of primary reference fuels from 0 to 100*—the volume % of *iso*octane (equals 100.0) in a blend with *n*-heptane (equals 0.0).

3.1.10 *naturally aspirated aircraft engine, n*—aircraft piston engine that breathes without forced means from either turbochargers or superchargers.

3.1.11 *no-knock condition, n—for octane rating*, when the combustion instability in all cylinders is less than light knock. Refer to Annex A1 for description of knock intensity.

3.1.12 *peak EGT, n—for octane rating*, as the mixture is manually leaned from a state rich of stoichiometric, the exhaust gas temperature will increase with the removal of excess fuel. As the mixture is continually leaned, a peak temperature will be attained, after which continued leaning will result in lower exhaust gas temperatures.

3.1.13 *primary reference fuels, n—for octane rating*, blended fuels of reference grade *iso*octane and *n*-heptane.

3.1.14 *stable engine conditions, n—for octane rating*, cylinder head temperatures change less than 5°C (9°F) during a 1-min period. Any changes or minor adjustments to throttle,

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[1] This practice is under the jurisdiction of ASTM Committee D02 on Petroleum Products, Liquid Fuels, and Lubricants and is the direct responsibility of Subcommittee D02.J0.02 on Spark and Compression Ignition Aviation Engine Fuels.

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[2] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

mixture, or engine conditions mandate restarting the clock for determining stable conditions.

3.2 *Acronyms:*

3.2.1 *CHT*—cylinder head temperature.

3.2.2 *EGT*—exhaust gas temperature.

3.2.3 *inHg*—inches of mercury.

3.2.4 *MAP*—manifold absolute pressure.

3.2.5 *mmHg*—millimetres of mercury.

3.2.6 *MON*—motor octane number.

3.2.7 *PRF*—primary reference fuel.

3.2.8 *psig*—pounds per square inch gauge.

3.2.9 *rpm*—revolutions per minute.

3.2.10 *TDC*—top dead center.

4. Summary of Practice

4.1 A recently overhauled, remanufactured, or new, naturally aspirated aircraft engine is octane rated, using PRFs, to determine the minimum motor octane requirement. Minimum motor octane requirement is defined as one number above the highest MON in which knock was detected. The engine is tested at three or more of the worst power points subject to detonation behavior. These points usually involve high manifold pressures. At the very least, takeoff power, a maximum continuous or climb power, and a cruise configuration shall be tested. Takeoff power and climb power are tested under full rich mixture conditions, and cruise power is tested under full rich and lean mixture configurations in 5 % increment reductions from full rich fuel flow. Engine operating temperatures and oil temperatures are kept at maximum allowable limits, while induction and cooling air temperatures are maintained at extreme hot day conditions for severe case testing.

4.2 Octane ratings are determined under stable engine conditions using PRFs of known MON.

4.3 Knock sensor installation and knock quantification are described in Annex A1.

5. Significance and Use

5.1 This practice is used as a basis for determining the minimum motor octane requirement of naturally aspirated aircraft engines by use of PRFs.

5.2 Results from standardized octane ratings will play an important role in defining the actual octane requirement of a given aircraft engine, which can be applied in an effort to determine a fleet requirement.

6. Apparatus

6.1 *Instrumentation:*

6.1.1 The engine shall be equipped with the following instrumentation, which shall be accurate within ±2 % of full scale unless noted otherwise.

6.1.1.1 *Absolute Manifold Pressure Transducer*—Location of MAP sensor shall conform to engine manufacturer's specified location. Manifold pressures shall be measured with an accuracy of less than 2.5 mmHg and recorded to ensure proper engine behavior and repeatability.

6.1.1.2 *Cooling Air Pressure Transducer,* located so as to determine the pressure within the cowling.

6.1.1.3 *Cooling Air Temperature Sensor,* located either within the cowling or at the entrance to the cowling. If a thermocouple is utilized, it should extend at least a third of the way across the measured area.

6.1.1.4 *Crankshaft Angle Encoder,* if required for knock detection. The encoder shall have a sample resolution of at least 0.4° of crank shaft rotation. The encoder TDC pulse shall be aligned with the TDC of cylinder number one prior to octane rating.

6.1.1.5 *Cylinder Head Temperature Sensors,* installed in each cylinder. The sensing locations and types of thermocouples shall conform to the engine manufacturer's recommendations. The CHT measurements shall be accurate to within 1 % of full scale.

6.1.1.6 *Exhaust Gas Temperature Sensors,* on all cylinders. Installation shall conform with manufacturer's recommended location and proper material selection. EGT probes are usually installed within 5 cm (2 in.) of the exhaust stack flange. The EGT probes shall be accurate to within 1 % of full scale.

6.1.1.7 *Engine Speed Sensor*—The dynamometer or propeller stand shall measure the engine shaft speed to determine power development. The engine speed sensor shall be accurate to within ±5 rpm.

6.1.1.8 *Fuel Flow Meter*—If the device is calibrated for a particular fuel, then the device shall be recalibrated for each different and subsequent fuel. Data should be reported in mass flow units.

6.1.1.9 *Fuel Pressure Transducers*—Locations of fuel pressure transducers shall conform with those recommended by the engine manufacturer. One transducer is required for the metered fuel pressure, if necessary, and another is required for the pump pressure. The fuel inlet pressure shall not fall below the minimum specified by the engine manufacturer during the rating process.

6.1.1.10 *Induction Air Pressure Transducer,* located so as to measure the pressure of the induction stream prior to the throttle plate.

6.1.1.11 *Induction Air Temperature Sensor,* located so as to measure the temperature of the induction stream prior to the throttle plate.

6.1.1.12 *Knock Sensors*—The referee method for knock detection is described in Annex A1. This method requires flush mounting piezoelectric transducers. At the very least, the four cylinders with the highest CHTs shall be monitored. These transducers are connected to charge amplifiers and shall be capable of measuring combustion pressures under a high temperature environment.

6.1.1.13 *Oil Pressure Transducer*—Location of pressure measurement shall conform to engine manufacturer's specified location.

6.1.1.14 *Oil Temperature Sensor*—Location of temperature measurement shall conform with manufacturer's specified location.

6.1.1.15 *Torque Meter*—The dynamometer or propeller stand shall measure the torque to determine power development. The torque measurement shall be accurate to within 1 % of full scale.

6.1.2 The engine should be equipped with the following instrumentation, which shall be accurate within ±2 % of full scale unless noted otherwise.

6.1.2.1 *Induction Air Flow Meter*—Data should be presented in mass flow units.

6.1.2.2 *Induction Air Humidity Sensor,* located in either the induction air plenum or induction air duct. Data should be presented in absolute, rather than relative, quantities.

6.1.2.3 *Outside Air Temperature Sensor,* capable of measuring both the ambient wet bulb and the dry bulb temperatures prior to any engine testing.

6.2 *Data Acquisition:*

6.2.1 The instrumentation listed in 6.1 shall be scanned and the data recorded at least once every 15 s by an automatic data acquisition system. The data shall be stored in a universal format (for example, comma separated values (CSV) for IBM compatible machines) that can be retrieved at a later date.

6.2.2 If in-cylinder pressures are recorded to determine knock intensity, the pressure data shall be sampled at a rate of at least 1800 samples per pressure cycle per cylinder.

6.3 *Power Absorption*—The testing is to be performed in a ground based test cell using either a dynamometer or propeller test stand that shall be capable of maintaining a constant speed to within ±10 rpm.

6.4 *Fuel System:*

6.4.1 The fuel supply shall have a disposable or cleanable filter. The filter shall allow the proper minimum fuel flow.

6.4.2 The fuel selection valve shall be capable of selecting at least two different fuel sources without the possibility of cross contamination of either source.

6.4.3 The fuel supply system must comply with federal, state, and local regulations related to fire, hazards, and health issues.

7. Reagents and Materials

7.1 The MON of PRFs is confirmed by using Test Method D2700. All fuels used for the initial engine octane ratings are PRFs that consist of blends of reference grade *iso*octane and *n*-heptane. The PRFs will be prepared in increments of one MON. (**Warning—**PRF is flammable, and its vapor is harmful. Vapors may cause flash fire.)

7.1.1 *Iso*octane (2,2,4-trimethylpentane) shall be no less than 99.75 % by volume pure, contain no more than 0.10 % by volume *n*-heptane, and contain no more than 0.5 mg/L (0.002 g/U.S. gal) of lead. (**Warning—***Iso*octane is flammable, and its vapor is harmful. Vapors may cause flash fire.)

7.1.2 *n*-Heptane shall be no less than 99.75 % by volume pure, contain no more than 0.10 % by volume *iso*octane, and contain no more than 0.5 mg/L (0.002 g/U.S. gal) of lead. (**Warning—***n*-Heptane is flammable, and its vapor is harmful. Vapors may cause flash fire.)

7.1.3 A sample shall be taken of each primary reference fuel and subjected to Test Method D2700 for motor octane verification.

7.2 Fuels used for operations other than octane rating (for example, warm-up) shall consist of unleaded hydrocarbons and should be capable of satisfying the test engine's octane requirement under the conditions for the fuel to be used. (**Warning—**These fuels are flammable, and their vapor is harmful. Vapors may cause flash fire.)

7.3 Engine break-in oil shall be one approved by the engine manufacturer.

7.4 All engine operations, other than during the break-in period, shall be performed with an oil approved by the engine manufacturer. (**Warning—**Lubricating oil is combustible, and its vapor is harmful.)

8. Preparation of Apparatus

8.1 The history and condition of each test engine should be known and documented by means of engine log books, test run sheets, and any other documentation issued by the original equipment manufacturers or repair overhaul shops before any octane rating tests are performed.

8.2 Only the engine accessories required to operate the engine shall be installed on the test engine when conducting the octane ratings.

8.3 The exhaust system employed shall not induce a back pressure greater than the back pressure called for in the engine manufacturer's specifications.

8.4 If the test engine's fuel system is designed to recirculate fuel to the tank, provisions shall be made to ensure that no fuel is recirculated to the containers with the PRFs.

8.5 The idle mixture setting and full rich fuel flow rate shall be set in accordance with the engine manufacturer's recommendations.

8.6 The idle stop and full throttle throw positions shall be set in accordance with the engine manufacturer's recommendations.

8.7 Before any octane rating, and after all break-in and power baseline runs have been performed, a cylinder compression test shall be performed on all cylinders and the results recorded.

8.8 Prior to testing, the integrity of the fuel selection system shall be confirmed and the system flushed. The engine fuel selector apparatus shall be checked to ensure no leakage.

8.9 All engine settings shall be checked after the break-in period and before any octane rating. As a minimum, this shall include fuel pressures, oil pressure, fuel flow, and magneto timing.

8.10 A systems check shall be performed, as per specific aircraft engine manufacturer's recommendations, prior to starting the test engine. As a minimum, this shall include the following: idle throttle stop, wide open throttle throw, mixture cut-off position, and mixture full rich position.

8.11 A systems check shall be performed after starting the test engine. This shall include as a minimum the following items: oil pressure, magneto ground check as per the engine manufacturer's recommendations, and instrumentation indications within normal ranges.

9. Calibration and Standardization

9.1 The engine shall be set up in accordance with the manufacturer's specifications. The ignition timing shall be set within ±1° of the recommended setting. The fuel flows shall be set within ±2 % of the recommended fuel flow (or ±5 % of the recommended pressure when appropriate).

9.2 Instrumentation shall be calibrated and checked to ensure accuracy to within ±2 % of full scale, unless noted otherwise.

10. Procedure

10.1 *Engine Break-In:*

10.1.1 If the test engine is new, remanufactured, or recently overhauled, it shall be broken in prior to conducting initial octane ratings. The break-in shall be conducted in accordance with the engine manufacturer's recommendations. Break-in shall be conducted with a non-metallic fuel.

10.1.2 The engine is started and the engine manufacturer's warm-up procedures are followed. A magneto check is performed as per the engine manufacturer's recommendation.

10.1.3 The engine is operated at the manufacturer's recommended power settings, and the oil consumption is recorded until either oil consumption is stabilized or 10 h of engine operation is attained. Oil consumption stabilization should conform to the engine manufacturer's recommendation.

10.1.4 During the engine break-in runs, the engine operating temperatures and oil temperature should be maintained in accordance with the manufacturer's recommendations.

10.2 *Power Baselines:*

10.2.1 After oil consumption is stabilized, three separate power baseline tests of the engine shall be performed. Each test requires measuring the power developed at combinations of every 100 rpm and 50 mmHg (2 inHg) MAP increments from takeoff power to low cruise power (that is, 55 % normal rated power). This ensures that proper power is being developed.

10.2.2 Record engine parameter data at a rate of at least one (1) full channel scan for every 15 s of engine operation, and attach the results to the octane rating data.

10.2.3 The installation of the knock sensing equipment is performed after the power baselines have been performed.

10.2.4 If this knock sensor installation alters the cylinder/ignition system in any way, such as drilling of cylinders, use of longer reach spark plugs, or use of modified spark plugs, then three power baselines shall be performed again, after the knock sensor installation. The same MAP and rpm settings tested in 10.2.1 shall be retested and the results recorded. Engine parameter data shall again be recorded at a rate of at least one (1) full channel scan for every 15 s of engine operation.

10.3 *Cylinder Compression Check:*

10.3.1 After power mapping the engine, cylinder compression checks shall be performed and the results recorded.

10.3.2 The engine shall be warm when the cylinder compression checks are performed.

10.4 *Octane Rating:*

10.4.1 After the cylinder compression checks have been performed, the octane rating shall be performed.

10.4.2 For this test, record the engine parameter data at a minimum rate of one (1) full channel scan for every 15 s of engine operation. The knock data sample rate shall be equal to or greater than at least one (1) pressure sample per cylinder for every 0.4° of crank shaft rotation. Knock data shall encompass at least 100 consecutive engine cycles per power setting for each cylinder monitored.

10.4.3 Start the engine on house fuel. Allow engine to warm up. Ensure all instrumentation indications are within proper range. Conduct ignition systems check.

10.4.4 The cooling and induction air temperatures shall be adjusted to 39 ± 2°C (103 ± 4°F). These settings shall be maintained throughout the octane rating.

10.4.5 The cooling air pressure shall be adjusted to maintain the maximum CHT within ±6°C (10°F) of manufacturer's recommended maximum limit. All CHTs shall be maintained within 28°C (50°F) of the maximum CHT. These settings shall be maintained throughout the octane rating.

10.4.6 The oil temperature shall be maintained within ±6°C (10°F) of the engine manufacturer's recommended maximum limit throughout the octane rating.

10.4.7 Set takeoff engine rpm, full throttle, and full rich mixture conditions on the house fuel.

10.4.8 Select the PRF to be tested. The test sequence should begin with a PRF of 100 MON or below that is likely to result in no knock.

10.4.9 Each time a different PRF is selected or the engine power setting is changed, conditions shall be allowed to become stable. Allow time for fuel to enter engine and for conditions to stabilize. The waiting period shall be a minimum of 2 min, the time required to consume three (3) times the volume of fuel contained in the fuel system upstream of the selector valve, or the time it takes for the conditions to stabilize, whichever is longer.

10.4.10 Record knock data, and determine the combustion condition (normal combustion, light knock, moderate knock, or heavy knock). See Annex A1 for more detail. Do not allow the test engine to operate under heavy knock for extended periods of time.

10.4.11 If knock occurs, select the house fuel, reduce the engine power, and return to step 10.4.7 with a higher MON PRF.

10.4.12 If no knock occurs, select the house fuel and set the power on the test engine to the recommended climb power setting or maximum continuous power setting, if appropriate. Leave the mixture at the full rich setting.

10.4.13 Select the PRF with the same MON as the fuel selected in 10.4.8.

10.4.14 Record knock data, and determine the combustion condition.

10.4.15 If knock occurs, select house fuel and return to 10.4.7 with a higher MON PRF.

10.4.16 If no knock occurs, select house fuel and set the test engine to the maximum recommended cruise setting at which the mixture can be leaned. Leave the mixture at the full rich position.

10.4.17 Select the PRF with the same MON as the fuel selected in 10.4.8.

10.4.18 Record knock data, and determine the combustion condition.

10.4.19 If knock occurs, select the house fuel and return to 10.4.7 with a higher MON PRF.

10.4.20 If no knock occurs, calculate a 5 % reduction in fuel flow from the reading obtained from the maximum recommended cruise full rich mixture setting.

10.4.21 Hold the throttle and engine speed fixed at the maximum recommended cruise settings. Starting with full rich mixture settings, lean until the fuel flow decreases by the 5 % increment just determined. The engine should still be operating on the PRF.

10.4.22 Allow conditions to stabilize after adjusting the mixture.

10.4.23 Record knock data, and determine the combustion condition.

10.4.24 If knock occurs, select house fuel and return to 10.4.7 with a higher MON PRF.

10.4.25 If no knock occurs, continue leaning by the 5 % increment determined in 10.4.20 at the maximum recommended cruise position until either knock occurs or peak EGT, in any cylinder, is attained. The engine shall be stabilized and knock data recorded after each 5 % increment change in fuel flow. (**Warning—**Excessive leaning may cause engine damage. All cylinder EGTs should be monitored so that the mixture is not leaned past peak EGT for any cylinder. Rapid lean mixture adjustments may propagate severe detonation and may lead to engine damage.)

10.4.26 If peak EGT in any cylinder has been reached without experiencing a knock condition, the mixture shall be enriched and a lower MON PRF shall be selected. If that lower MON PRF has already been found to produce a knock condition, then the motor octane requirement is the last knock-free PRF tested.

10.4.27 It is suggested when choosing a lower MON PRF to choose a rating fuel of only one MON lower so as to minimize any potential engine damage. Continue testing with a lower MON PRF until a knock condition is encountered. The motor octane requirement is defined as one MON higher than the highest MON PRF that produced a knock condition.

10.4.28 At the conclusion of the test, select the house fuel, gradually reduce the power setting to idle, and allow the engine to cool.

10.4.29 After shutdown, make sure the selector valve does not leak. If the valve leaks, repair the valve and repeat the test to ensure the PRFs were not contaminated.

10.4.30 Fig. 1 illustrates, in flowchart form, the octane rating test procedures.

11. Report

11.1 A description of the history of the aircraft engine shall be attached to the results.

11.1.1 As a minimum, this shall include information regarding whether or not the engine was recently remanufactured, overhauled, or new. The history shall also include the number of hours since last overhauled.

11.2 The results from the cylinder compression checks shall be reported. The data shall be reported in terms of measured cylinder pressure when the applied pressure is equal to 551.6 kPa (80 psi).

11.3 Annex A1 details the referee method for knock detection and the quantification of the combustion condition. If that method is utilized, the results shall include a description of the points tested, the MON of the PRF tested, the number of consecutive engine cycles collected, the maximum knock number over those cycles, and the number of those cycles that experienced a knock condition.

11.4 If a system other than the one described in Annex A1 is utilized, a detailed description of that system shall be provided.

11.4.1 The sample rate and length of sampling shall be reported.

11.4.2 The number of knock events over the given sample period, for each cylinder, shall be reported.

11.5 Engine data as listed in Section 7 shall be reported for each engine power setting configuration tested. The data shall be reported for the time during which the knock data was being collected. It may be advantageous to report averaged values over that same period.

11.5.1 Both the observed engine power and the engine power corrected for standard day barometer shall be reported. A description of the correction method used shall also be reported.

11.5.2 The observed brake specific fuel consumption shall be reported. The corrected specific fuel consumption using the corrected power values from 11.5.1 shall also be reported.

12. Keywords

12.1 aircraft engine; naturally aspirated ; octane rating; octane requirement; spark ignition aircraft engine

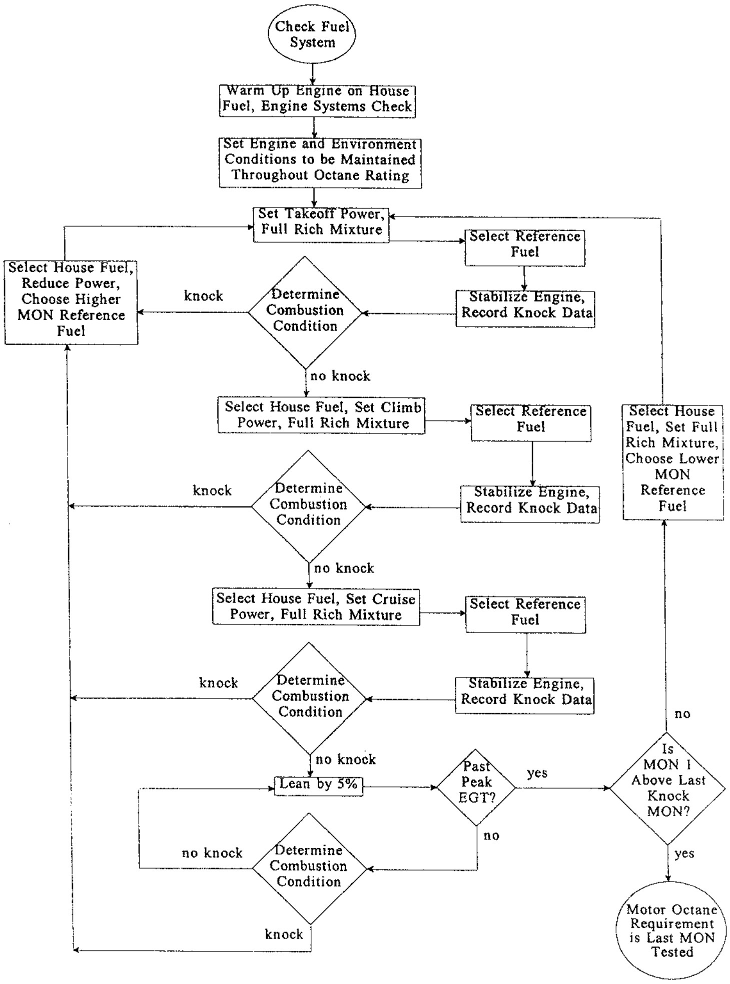


FIG. 1 Flow Chart Illustrating the Octane Rating Procedures

ANNEX

(Mandatory Information)

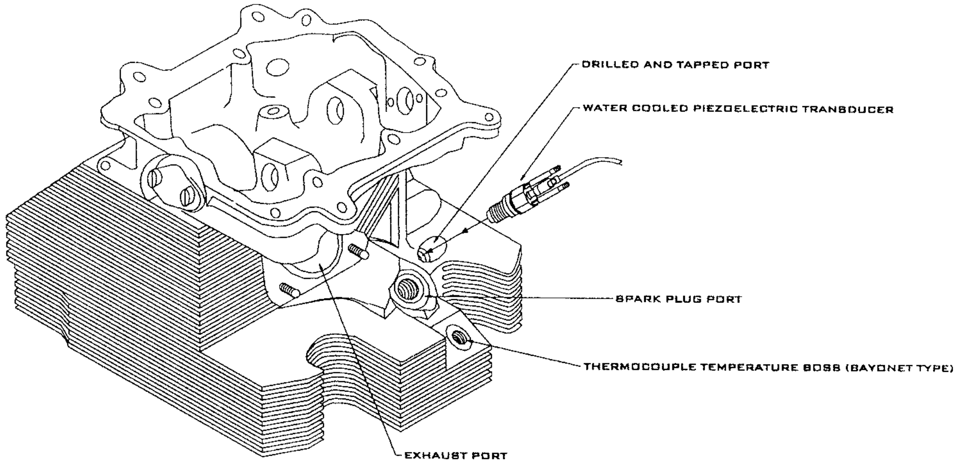
A1. REFEREE METHOD KNOCK RATING TECHNIQUE

A1.1 Pressure Sensor Installation

A1.1.1 A water cooled, high temperature, piezoelectric pressure transducer shall be flush mounted in each cylinder. Fig. A1.1 shows the typical installation of the transducer. Usually an area near the spark plug port is drilled and tapped. Care must be taken to minimize the loss of cooling fin surface area and to minimize material loss between the spark plug port and the transducer port to maintain cylinder structural integrity. The installation should be such that the recess of the transducer face from the combustion chamber is minimized. Any recess of the sensor face with the cylinder wall may result in the development of unwanted acoustic noise.

A1.1.2 After installation of the transducers and prior to octane rating, power baseline tests, as described in 10.2, shall again be performed to ensure the integrity of cylinder compression.

A1.1.3 The piezoelectric transducers are connected to charge amplifiers, which are connected to the data acquisition interface. Data sampling rates must be shown to be at least the



NOTE 1—Figure not drawn to scale.

FIG. A1.1 Typical Piezoelectric Pressure Transducer Installation in an Aircraft Cylinder Head

rate equivalent to one pressure reading per cylinder for each 0.4° of crankshaft travel.

A1.2 Crank Angle Encoder

A1.2.1 A position crank angle encoder is attached to the accessory tachometer drive on the engine. This allows for a pressure data scan to be taken once for every 0.4° of revolution of the crank shaft or the equivalent of 1800 points per pressure cycle for each cylinder. The encoder TDC pulse shall be aligned with TDC of cylinder number one prior to octane rating.

A1.3 Visual Description of Knock

A1.3.1 Cylinder pressure traces are displayed on a monitor by means of a data acquisition system. With the proper installation of the piezoelectric transducers, acoustic interference is negligible and the cylinder pressure traces display distinctive traits with increasing knock intensity. Under normal combustion, there is a steady increase in pressure until a peak is reached and then a steady expansion. For knock cycles, as the pressure on the compression stroke appears to be reaching a peak near TDC, autoignition of the end gas occurs, generating a pressure spike. This pressure spike resonates during the expansion stroke. In general, both the amplitude of the peak pressure spike and the subsequent pressure pulse amplitudes increase as knock intensity increases.

A1.3.2 Several pressure traces are shown in Figs. A1.2-A1.5, illustrating this effect. These traces demonstrate the typical changes in combustion characteristics and peak pressure that occur with an increase in knock intensity. Fig. A1.2 shows a normal combustion pressure curve versus crank angle rotation. Figs. A1.3-A1.5 show cylinder pressure traces of engine cycles with varying knock intensity levels.

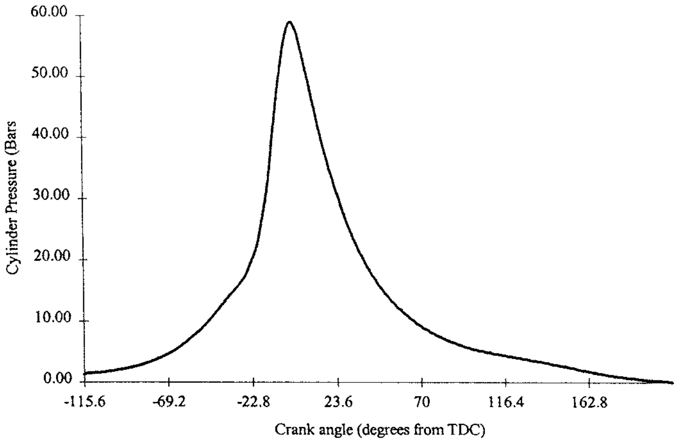


FIG. A1.2 Pressure Trace Showing Normal Combustion

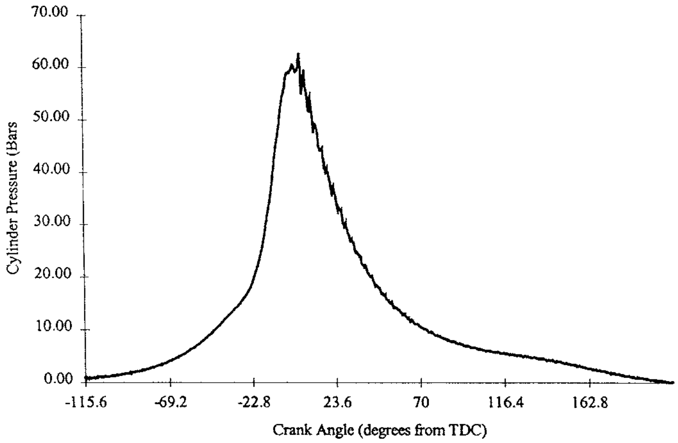


FIG. A1.3 Pressure Trace Showing Light Knock

A1.3.3 FAA Advisory Circular No. 33.47[3] describes a condition that is not considered a knock condition, but in which instability begins to become evident. Under this condition, peak pressures remain at the normal combustion level, pressure pulses are minimal, and cylinder head temperatures and oil temperature remain stable while the engine is left to operate for long periods of time. As such, the engine would not suffer damage if left to operate under this condition.

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[3] "Detonation Testing in Reciprocating Aircraft Engines," available from U.S. Government Printing Office, Superintendent of Documents, 732 N. Capitol St., NW, Mail Stop: SDE, Washington, DC 20401.

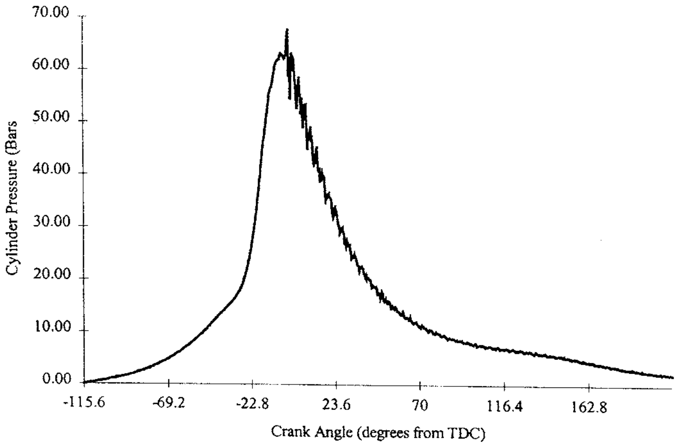

FIG. A1.4 Pressure Trace Showing Moderate Knock

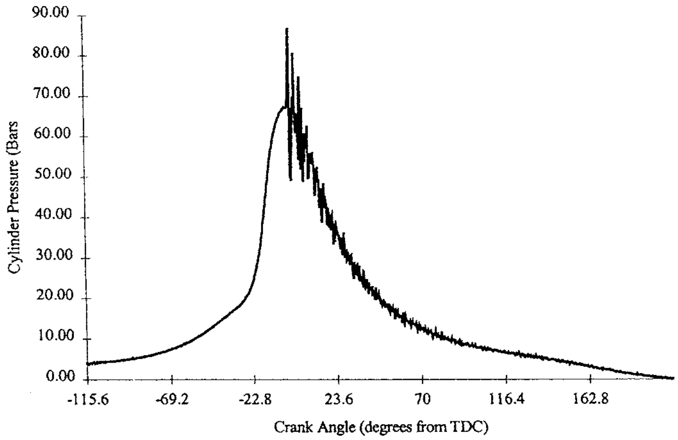

FIG. A1.5 Pressure Trace Showing Heavy Knock

A1.4 Quantitative Description of Knock Levels

A1.4.1 Numerical quantification of knock intensity utilizes the cylinder pressure versus crank angle data to calculate a value that measures the amplitudes of pressure pulses present in the pressure curve. This knock number is normalized by subtracting the cumulative effect of pressure increase on the compression stroke, which accounts for peak pressure variation due to normal combustion variability and different power settings.

A1.4.2 The knock quantification, or knock number, is determined by comparing the absolute values of the relative pressure changes on the expansion slope to those of the compression stroke. Equal numbers of data points are chosen from the compression stroke as from the expansion stroke. The sum of the absolute values of the consecutive pressure differences are summed for the compression stroke. That sum is then subtracted from the sum of the absolute values of the consecutive pressure differences for the expansion stroke. This difference in these two sums is known as the knock number. Care must be taken to include enough points to ensure enough of the knock is measured, but not to include either the intake or exhaust valve noise. Below is the equation for the calculation of the knock number.

$$\text{Knock Number} = \sum_{i=0}^{N-1} |P_i - P_{i+1}| - \sum_{i=0}^{N-1} |P_{-i} - P_{-i-1}| \tag{A1.1}$$

where:

P_0 = pressure value at the point separating the expansion and compression strokes,
P_{-1} = pressure value one point before P_0,
P_{+1} = pressure value one point after P_0, and
N = number of points either before or after P_0.

A1.4.3 Typically, a full range of 70° of crank shaft rotation is analyzed. A normal combustion cycle has a knock number that is negative, and knock cycles (light, moderate, and heavy) have knock numbers of ten or greater. Heavy knock cycles can have knock numbers as high as a few hundred.

A1.4.4 Use of any knock detection system, other than detailed here, shall be shown to correlate with the results described in A1.4. The sample rate for such a system must eclipse the rate of one (1) pressure data point per cylinder for each 0.4° of crank shaft revolution. Knock data for at least 100 consecutive pressure cycles per cylinder shall be recorded for each power setting and PRF tested.

APPENDIXES

(Nonmandatory Information)

X1. ENGINE PARAMETER SAMPLE DATA SHEET

X1.1 See Fig. X1.1.

DATE:
ENGINE MAKE / MODEL:
ENGINE SERIAL NUMBER:
TEST NUMBER:
AMBIENT AIR TEMPERATURE WET / DRY:
NOTES:

	DATA POINTS						
ENGINE PARAMETERS	*A*	*B*	*C*	*D*	*E*	*F*	*G*
REFERENCE FUEL MON							
#1 CYLINDER HEAD TEMPERATURE (C)							
#2 CYLINDER HEAD TEMPERATURE (C)							
#3 CYLINDER HEAD TEMPERATURE (C)							
#4 CYLINDER HEAD TEMPERATURE (C)							
#5 CYLINDER HEAD TEMPERATURE (C)							
#6 CYLINDER HEAD TEMPERATURE (C)							
#1 EXHAUST GAS TEMPERATURE (C)							
#2 EXHAUST GAS TEMPERATURE (C)							
#3 EXHAUST GAS TEMPERATURE (C)							
#4 EXHAUST GAS TEMPERATURE (C)							
#5 EXHAUST GAS TEMPERATURE (C)							
#6 EXHAUST GAS TEMPERATURE (C)							
OIL TEMPERATURE (C)							
OIL PRESSURE (kPa)							
COOLING AIR TEMPERATURE (C)							
INDUCTION AIR TEMPERATURE (C)							
FUEL MASS FLOW RATE (kg/hr)							
MANIFOLD PRESSURE (mmHg)							
TORQUE (Nm)							
ENGINE SHAFT SPEED (rpm)							
OBSERVED BRAKE POWER (kW)							
CORRECTED POWER (kW)							
OBSERVED BRAKE SPECIFIC FUEL CONSUMPTION (kg / kW hr)							
CORRECTED BRAKE SPECIFIC FUEL CONSUMPTION (kg / kW hr)							
INDUCTION AIR HUMIDITY RATIO (kg water / kg dry air)							
MIXTURE SETTING							
METERED FUEL PRESSURE (kPa)							
UNMETERED FUEL PRESSURE (kPa)							

POINT	*DESCRIPTION*
A	Usually Takeoff power, full rich mixture
B	Usually Climb or max continuous power, full rich mixture
C	Usually Cruise power, full rich mixture
D	
E	
F	

FIG. X1.1 Engine Parameter Sample Data Sheet

X2. KNOCK PARAMETER SAMPLE DATA SHEET

X2.1 See Fig. X2.1.

DATE: ____________________
ENGINE MAKE / MODEL: ____________________
ENGINE SERIAL NUMBER: ____________________
TEST NUMBER: ____________________
AMBIENT AIR TEMPERATURE WET / DRY: ____________________
NOTES: ____________________

		DATA POINTS						
		A	*B*	*C*	*D*	*E*	*F*	*G*
CYLINDER #1	MAXIMUM KNOCK #							
	# KNOCKING CYCLES / # OF CYCLES COLLECTED							
CYLINDER #2	MAXIMUM KNOCK #							
	# KNOCKING CYCLES / # OF CYCLES COLLECTED							
CYLINDER #3	MAXIMUM KNOCK #							
	# KNOCKING CYCLES / # OF CYCLES COLLECTED							
CYLINDER #4	MAXIMUM KNOCK #							
	# KNOCKING CYCLES / # OF CYCLES COLLECTED							
CYLINDER #5	MAXIMUM KNOCK #							
	# KNOCKING CYCLES / # OF CYCLES COLLECTED							
CYLINDER #6	MAXIMUM KNOCK #							
	# KNOCKING CYCLES / # OF CYCLES COLLECTED							

POINT	*DESCRIPTION*
A	Usually Takeoff power, full rich mixture
B	Usually Climb or max continuous power, full rich mixture
C	Usually Cruise power, full rich mixture
D	
E	
F	
G	

FIG. X2.1 Knock Parameter Sample Data Sheet

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