Standard Practice for Ground-Based Octane Rating Procedures for Turbocharged/Supercharged Spark Ignition Aircraft Engines[1]

This standard is issued under the fixed designation D6812; 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 turbocharged/supercharged spark ignition aircraft engines. This practice has been developed to allow the widest range of applicability possible but may not be appropriate for all engine types. This practice is specifically directed to ground-based testing and actual in-flight octane ratings may produce significantly different results.

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*—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 if 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 octane requirement*—one full number greater than the maximum 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 98 and 99 motor octane numbers. The test engine does not knock on a primary reference fuel with a 100 motor octane number. The maximum motor octane number that results in knock is 99 so the motor octane requirement is 100. If a test engine knocks on a reference fuel with a 3-amine number and does not knock on a fuel with a 4-amine number, then the engine requirement is a 4-amine number.

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

3.1.4 *house fuel, n—for engine operation*, a fuel that does not contain metallic additives used for engine warm-up and all non-octane rating engine operation.

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*, where 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 from 0 to 100*—the volume % of *iso*octane (equals 100.0) in a blend with *n*-heptane (equals 0.0).

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

3.1.10 *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.

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

3.1.12 *reference fuels above 100, n—for octane rating*, blended fuels of reference grade *iso*octane and 3-methylphenylamine.

3.1.12.1 *Discussion*—This practice describes reference fuels above 100 MON in terms of *iso*octane/3-methylphenylamine.

[1] This practice is under the jurisdiction of ASTM Committee D02 on Petroleum Products, Liquid Fuels, and Lubricantsand 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.

Alternate reference fuels may be used if appropriate, for example, MON in Test Method D2700, Section 8, mixtures of tetraethyl lead and reference grade *iso*octane. Care should be exercised to ensure the reference fuel does not adversely contaminate the engine and influence the results.

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

3.1.14 *takeoff power, n—for octane rating*, normal or maximum rated power with the engine speed at maximum rated.

3.1.15 *turbocharged/supercharged aircraft engine, n*—aircraft piston engine that breathes with forced means from either turbochargers or superchargers.

3.2 *Acronyms:*

3-MPA	=	3-methylphenylamine
AN	=	amine number
CHT	=	cylinder head temperature
EGT	=	exhaust gas temperature
inHg	=	inches of mercury
MAP	=	manifold absolute pressure
MAT	=	manifold absolute temperature
mmHg	=	millimetres of mercury
MON	=	motor octane number
PRF	=	primary reference fuel
psig	=	pounds per square inch gage
RF	=	reference fuel above 100
rpm	=	revolutions per minute
TDC	=	top dead center
TIT	=	turbine inlet temperature

4. Summary of Practice

4.1 A recently overhauled, remanufactured, or new, turbocharged/supercharged aircraft engine is octane rated to determine the minimum ground-based octane requirement. Minimum octane requirement is defined as one number above the highest MON or AN where knock was detected. The engine is tested at three or more of the worst power points subject to knock behavior while operating under harsh and repeatable environmental conditions. 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 to peak exhaust gas temperature. Engine operating temperatures and oil temperatures are kept at maximum allowable limits.

4.2 Octane ratings are determined under stable engine conditions using known PRFs and RFs.

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 ground-based octane requirement of turbocharged/supercharged aircraft engines by use of PRFs and RFs.

5.2 Results from standardized octane ratings will play an important role in defining the 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 to within ±2 % of full scale unless noted otherwise.

6.1.1.1 *Absolute Manifold Pressure Transducer*—The location of the 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 crankshaft 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 to the 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 *Turbine Inlet Temperature Sensors,* for each turbine. Installation shall conform to the manufacturer's recommended location and proper material selection. The TIT probes shall be accurate to within 1 % of full scale.

6.1.1.8 *Manifold Absolute Temperature Sensor*—Installation shall conform to the manufacturer's recommended location and proper material selection. The MAT probe shall be accurate to within 1 % of full scale.

6.1.1.9 *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.

6.1.1.10 *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. If applicable, vapor return flow rate shall also be measured to obtain the actual engine fuel consumption rate.

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

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

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

6.1.1.14 *Knock Sensors*—The referee method for knock detection is described in Annex A1. This method requires flush mounting piezoelectric transducers. All cylinders shall be monitored. These transducers are connected to charge amplifiers and shall be capable of measuring combustion pressures under a high temperature environment.

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

6.1.1.16 *Oil Temperature Sensor*—Location of temperature measurement shall conform to the manufacturer's specified location.

6.1.1.17 *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 to 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 the ambient dry bulb temperature.

6.2 *Data Acquisition:*

6.2.1 The instrumentation listed in 6.1 shall be scanned and the data recorded at least once every 10 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 for 100 consecutive engine cycles.

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 ±5 rpm.

6.3.1 The power absorber shall be capable of providing loads for given engine speeds covering the entire range of the engine's operating envelope.

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 shall comply with federal, state, and local regulations related with fire, hazards, and health issues.

7. Reagents and Materials

7.1 The MON of PRFs is confirmed by using Test Method D2700. All PRFs used for the engine octane ratings consist of blends of reference grade *iso*octane and *n*-heptane. The PRFs will be prepared in increments of one MON. All RFs used for engine octane rating consist of blends of reference grade *iso*octane and 3-MPA. The reference fuels will be prepared in increments of one weight % 3-MPA. (**Warning—**PRF and RF are flammable and the vapors are 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 MPA shall be no less than 99 % 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—**3-MPA is flammable and its vapor is harmful. 3-MPA is toxic by inhalation, in contact with skin, and if swallowed. Danger of cumulative effects. Vapors may cause flash fire.)

7.1.4 A sample shall be taken of each PRF and subjected to Test Method D2700 for motor octane verification.

7.1.5 A sample shall be taken of each RF and the amine content verified. Ensure reference fuel is a homogenous mixture under test conditions.

7.2 Fuels used for operations other than octane rating (for example, warm-up) shall not contain metallic additives 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 oils used for break-in and normal operation shall be oils approved by the engine manufacturer for their respective operation. (**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 installation of the proper turbocharger controller, wastegate actuator, wastegate valve, and overboost relief valve for the specific engine model and application shall be verified.