Designation: D 6812 – 03

An American National Standard

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

This standard is issued under the fixed designation D 6812; 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]

D 2700 Test Method for Motor Octane Number of Spark-Ignition Fuel

3. Terminology

3.1 *Definitions:*

3.1.1 *amine number of reference fuels above 100*—determined in terms of the weight percent of 3-methylphenylamine in reference grade *iso*octane. No attempt has been made to correlate performance number of leaded reference fuels to the amine number of unleaded 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 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. Alternate reference fuels may be used if appropriate, for example, MON in Test Method D 2700, Section 8, mixtures of tetraethyl lead and reference grade

[1] This practice is under the jurisdiction of ASTM Committee D02 on Petroleum Products and Lubricants and is the direct responsibility of Subcommittee D02.J0 on Aviation 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.

*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 which 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 D 2700. 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, and 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 D 2700 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.

8.4 The installation of the proper intercoolers or aftercoolers, if required, for the specific engine model and application shall be verified. The intercooler/aftercooler shall be supplied with proper cooling air pressure and any cabin bleed-air venturis shall be free to vent to the local environment.

8.5 The installation of the proper fuel control system, including the metering unit, pump, distribution manifold, nozzles, and fuel lines for the specific engine model and application shall be verified. This should also include ensuring equal fuel flow distribution through all nozzles and associated lines.

8.6 The exhaust system employed shall be free to discharge into the surrounding environment without extended plumbing, plenums, or mufflers which may induce an improper pressure balance across cylinders.

8.7 Proper spark plugs matching the required heat range and depth for the engine model to be tested shall be verified. The plugs should be cleaned and gapped prior to octane rating. The integrity of the spark plug ignition leads shall also be verified.

8.8 Crankcase vents shall be free to vent to the local environment.

8.9 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 or RFs.

8.10 The idle and full-rich mixture settings shall be set, and the resulting fuel flow rates verified to be within the engine manufacturer's specifications.

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

8.12 It shall be verified that the mass moment of inertia of the flywheel, couplers, driveshaft, and spacers and the driveshaft stiffness are sufficient to prevent operational resonance and possible engine failure.

8.13 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.

8.14 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.

8.15 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, turbocharger waste gate controller setting, proper overboost relief valve operation, fuel flows, and magneto timing.

8.16 A systems check shall be performed, in accordance with 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 and full-rich positions. This shall also include fuel and oil system leak inspections.

8.17 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 in accordance with the engine manufacturer's recommendations, instrumentation indications within normal ranges, and induction and exhaust system leak inspections.

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 the engine manufacturer's specified allowable range for that engine make and model.

9.2 The fuel flows shall be set within ±2 % of the recommended fuel flow (or ±5 % of the recommended pressure when appropriate).

9.3 Proper waste gate controller operation shall be verified which must include ensuring that maximum rated power is attained at full throttle and maximum rated speed without encroaching the limiting manifold pressure.

9.4 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, break it in prior to conducting initial octane ratings. Conduct the break-in in accordance with the engine manufacturer's recommendations. Conduct the break-in with a fuel that does not contain metallic additives.

10.1.2 Start the engine, and follow the engine manufacturer's warm-up procedures. Perform a magneto check in accordance with the engine manufacturer's recommendation.

10.1.3 Operate the engine at the manufacturer's recommended power settings, and record the oil consumption 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, maintain the engine operating temperatures and oil temperature in accordance with the manufacturer's recommendations.

10.2 *Power Baselines*:

10.2.1 After oil consumption is stabilized, perform three separate power baseline tests of the engine. Each test requires measuring the power developed at combinations of every hundred 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 1 full channel scan for every 10 s of engine operation, and attach the results to the octane rating data.

10.2.3 Perform the installation of the knock sensing equipment 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 perform the three power baselines again, after the knock sensor installation. Retest the same MAP and rpm settings tested in 10.2.1, and record the results. Record the engine parameter data again at a rate of at least 1 full channel scan for every 10 s of engine operation.

10.3 *Cylinder Compression Check*:

10.3.1 After power mapping the engine, perform cylinder compression checks, and record the results.

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

10.3.3 Perform cylinder compression tests using the proper tooling and methods specified by the engine manufacturers.

10.4 *Octane Rating*:

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

10.4.2 For this test, record the engine parameter data at a minimum rate of 1 full channel scan for every 10 s of engine operation. The knock data sample rate shall be equal to or greater than at least 1 pressure sample per cylinder for every 0.4° of crankshaft 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 the engine to warm up. Ensure all instrumentation indications are within proper range. Conduct ignition systems check.

10.4.4 Adjust the induction air temperature to maintain the engine manufacturer's limiting MAT within ±3°C (5°F) of the manufacturer's recommended maximum limit.

10.4.5 Adjust the cooling air pressure to maintain the maximum CHT within ±6°C (10°F) of the manufacturer's recommended maximum limit. Maintain all CHT within 28°C (50°F) of the maximum CHT. Maintain these settings throughout the octane rating.

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

10.4.7 Set maximum rated engine rpm, full throttle, and full rich mixture conditions on the house fuel. (**Warning—**Verify knock-free operation after each and every test point condition is adjusted on the house fuel. The engine shall be knock-free on the house fuel prior to switching to the PRF/RF fuels. Switching fuels during a knocking condition may result in inaccurate ratings.)

10.4.8 Select appropriate PRF or RF to be tested. Begin the test sequence with a PRF or RF of octane quality that is likely to result in no knock.

10.4.9 Each time a different PRF or RF is selected, or the engine power setting is changed, allow conditions to become stable. Allow time for the selected fuel to enter the engine and for the conditions to stabilize. (**Warning—**Under moderate to heavy knock conditions temperature stability may not be attainable. Do not allow the engine to operate under an unstable thermal condition for extended periods of time as this may cause severe and irreversible engine damage.)

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 10.4.7 with a higher octane quality PRF or RF.

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 or RF with the same octane quality 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 octane quality PRF or RF.

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

10.4.17 Select the PRF or RF with the same octane quality 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 octane quality PRF or RF.

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 or RF.

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 octane quality PRF or RF.

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, peak EGT in any cylinder is reached or limiting TIT 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 EGT's should be monitored so that the mixture is not leaned past peak EGT for any cylinder or past the limiting TIT. Rapid lean mixture adjustments may propagate heavy knock and may lead to engine damage.)

10.4.26 If peak EGT in any cylinder or the limiting TIT has been reached without experiencing a knock condition, enrich the mixture, and select a lower octane quality PRF or RF. If that lower octane quality PRF or RF has already been found to produce a knock condition, then the octane requirement is the last knock-free PRF or RF tested.

10.4.27 It is suggested, when choosing a lower octane quality PRF or RF, to choose a rating fuel of only one number (MON or AN) lower so as to minimize any potential engine damage. Continue testing with a lower octane quality PRF or RF until a knock condition is encountered. The octane requirement is defined as one number higher than the highest number 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 fuel selector valve does not leak. If the valve leaks, repair the valve and repeat the test to ensure the PRFs or RFs were not contaminated.

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

11. Report

11.1 Attach a description of the history of the aircraft engine to the results.

11.1.1 As a minimum, include information regarding whether or not the engine was recently remanufactured, overhauled, or new. Also include the number of hours since the last overhaul.

11.1.2 Include the type of wastegate controller employed.

11.2 Attach data recorded from the instrumentation listed in 6.1, recorded at a minimum rate of 1 sample of all parameters for every 10 s of engine testing, to the results.

11.3 Report the results from the cylinder compression checks. Report the data in terms of measured cylinder pressure when the applied pressure is equal to 552 kPa (80 psi).

11.4 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 octane number of the PRF or RF 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.

11.5 If utilizing a system other than the one described in Annex A1, provide a detailed description of that system.

11.5.1 Report the sample rate and length of sampling.

11.5.2 Report the number of knock events over the given sample period for each cylinder.

11.6 Report engine data, as listed in Section 6, for each engine power setting configuration tested. Report the data for the time during which the knock data was being collected. It may be advantageous to report averaged values over that same period.

11.6.1 Report both the observed engine power and the engine power corrected for standard day barometer. Report a description of the correction method used and the barometer.

11.6.2 Report the observed brake specific fuel consumption. Report the corrected specific fuel consumption using the corrected power values from 11.6.1.

11.7 Attach detailed descriptions of any engine difficulties or problems to the engine and knock data, including the time the problem occurred, the test fuels used, and any subsequent findings.

12. Keywords

12.1 aircraft engine; octane rating; octane requirement; spark ignition aircraft engine; turbocharged/supercharged

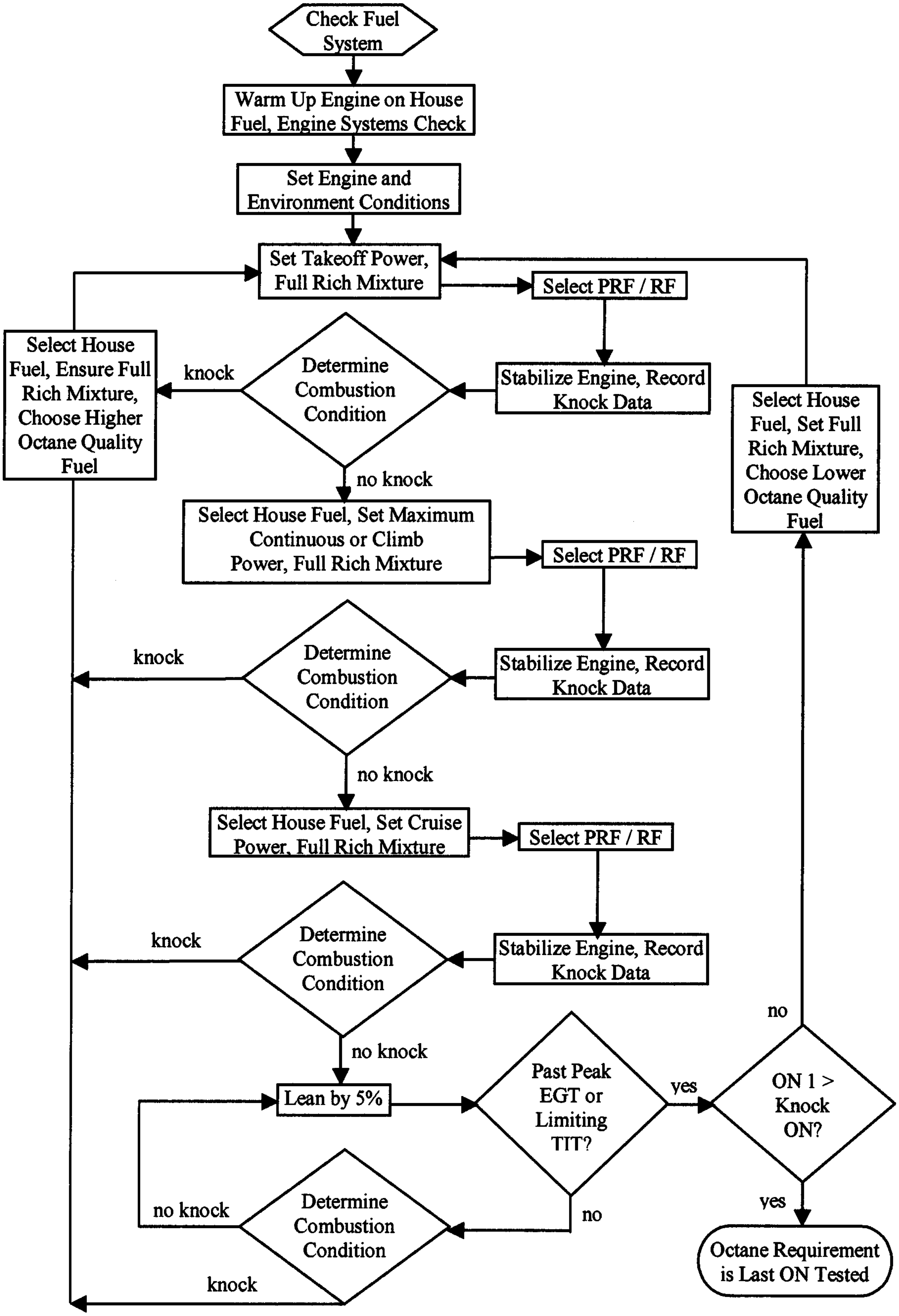


FIG. 1 Flow Chart Illustrating the Octane Rating Procedures

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. Take care 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. The angle of the transducer face with the cylinder head shall also be minimized as parallel mounting is ideal. 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 that are connected to the data acquisition interface. Data sampling rates must be shown to be at least the rate equivalent to one pressure reading per cylinder for each 0.4° of crankshaft travel.

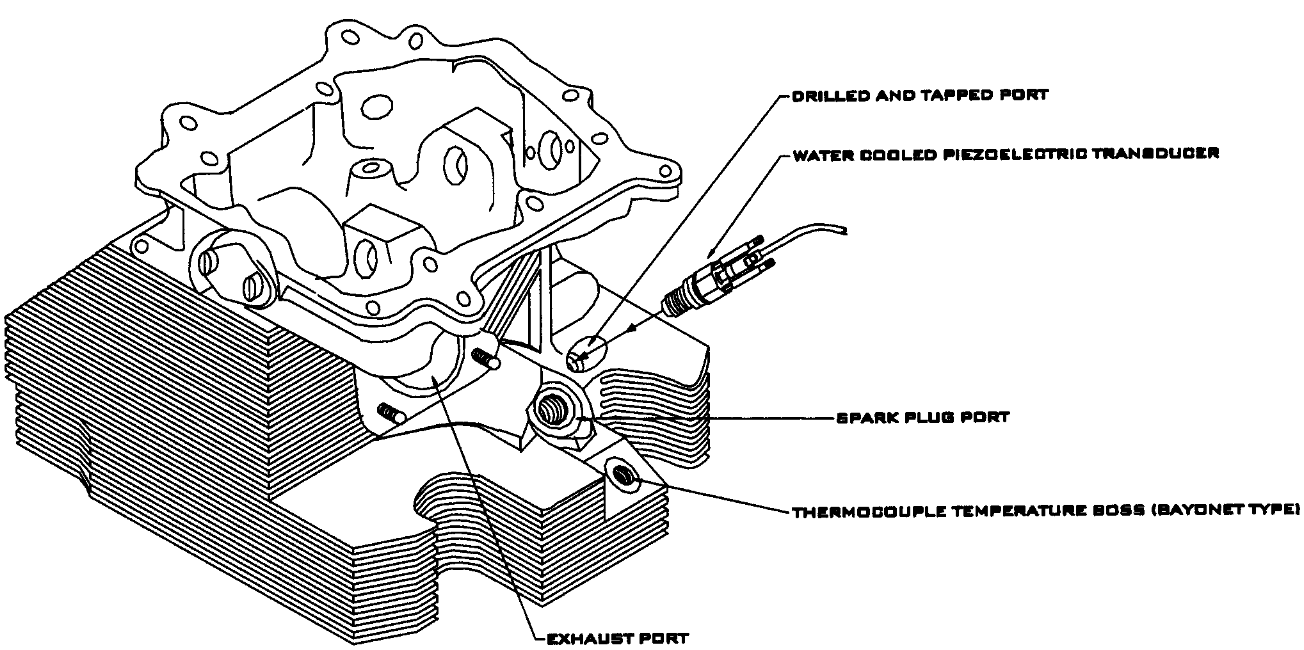
A1.2 Crank Angle Encoder

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 the TDC of cylinder No. 1 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, 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.



NOTE—Figure is not to scale.

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

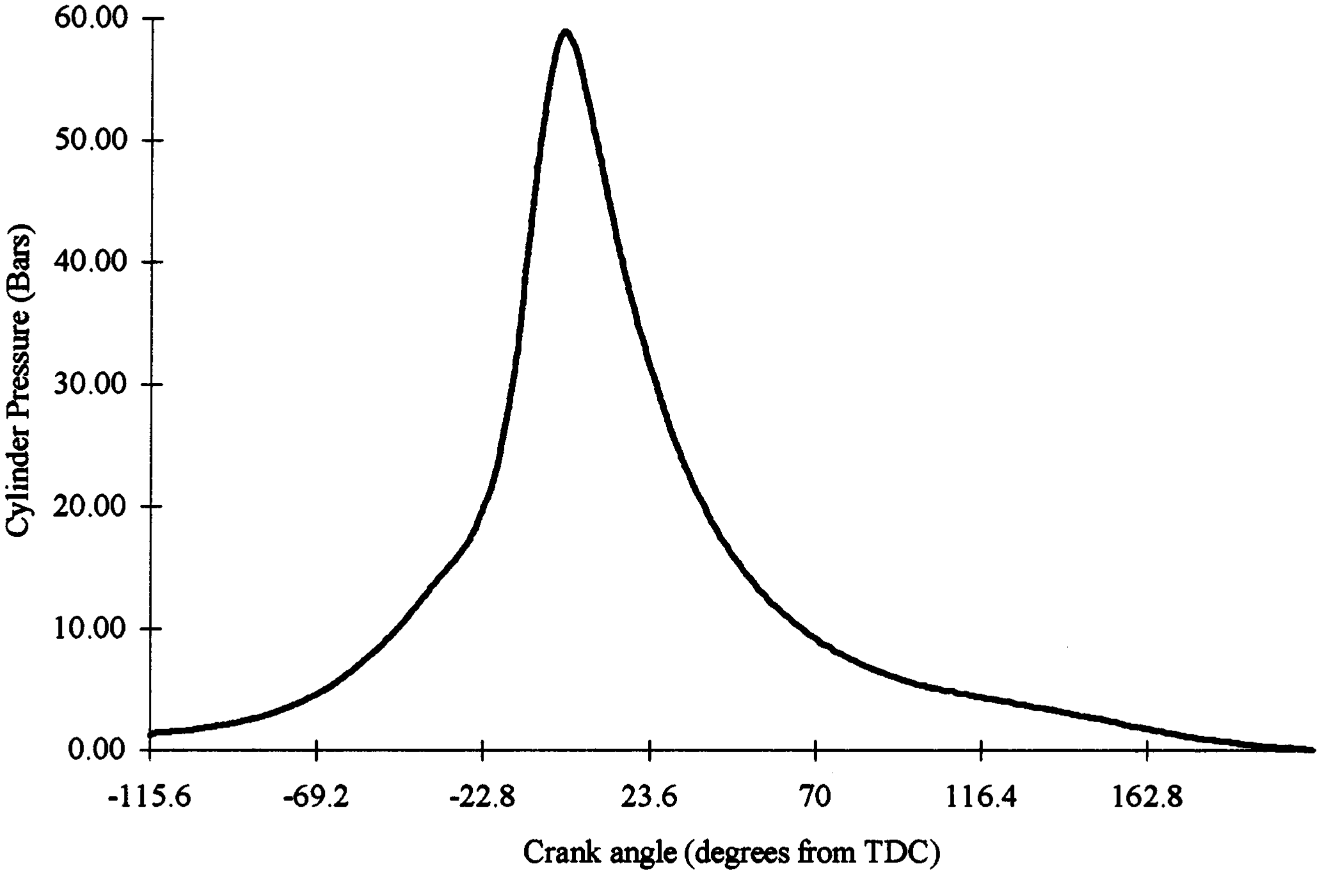


FIG. A1.2 Pressure Trace Showing Normal Combustion

A1.3.3 FAA Advisory Circular 33.47 describes a condition, which is not considered a knock condition, but where 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.

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 slope which accounts for peak pressure variation due to normal combustion variability and different power settings. The dividing point between the compression and expansion is not the same as the piston top-dead-center. At the top of the curve, prior to the sharp pressure rise due to knock, the slope of the pressure rise begins to approach zero. The point at this location where the slope is the least and approaching zero is the division between compression and expansion parts of the curve.

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 slope. Equal numbers of data points are chosen from both slopes. The sum of the absolute values of the consecutive pressure differences are summed for the compression. That sum is then subtracted from the sum of the absolute values of the consecutive pressure differences for the expansion. This difference in these two sums is known as the knock number. Take care not to include the intake or exhaust valve noise. The equation for the calculation of the knock number follows:

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

where:

P_0 = the pressure value as described in A1.4.1.
P_{-1} = the pressure value one point before this point.
P_{+1} = the pressure value one point after this point.
N = the number of points either before or after this point.

A1.4.3 Typically, a full range of 70° of crank shaft rotation is analyzed. A normal combustion cycle has a knock number which 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 in this annex, shall be shown to correlate with the results described in A1.4. The sample rate for such a system must eclipse the rate of 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 or RF tested.

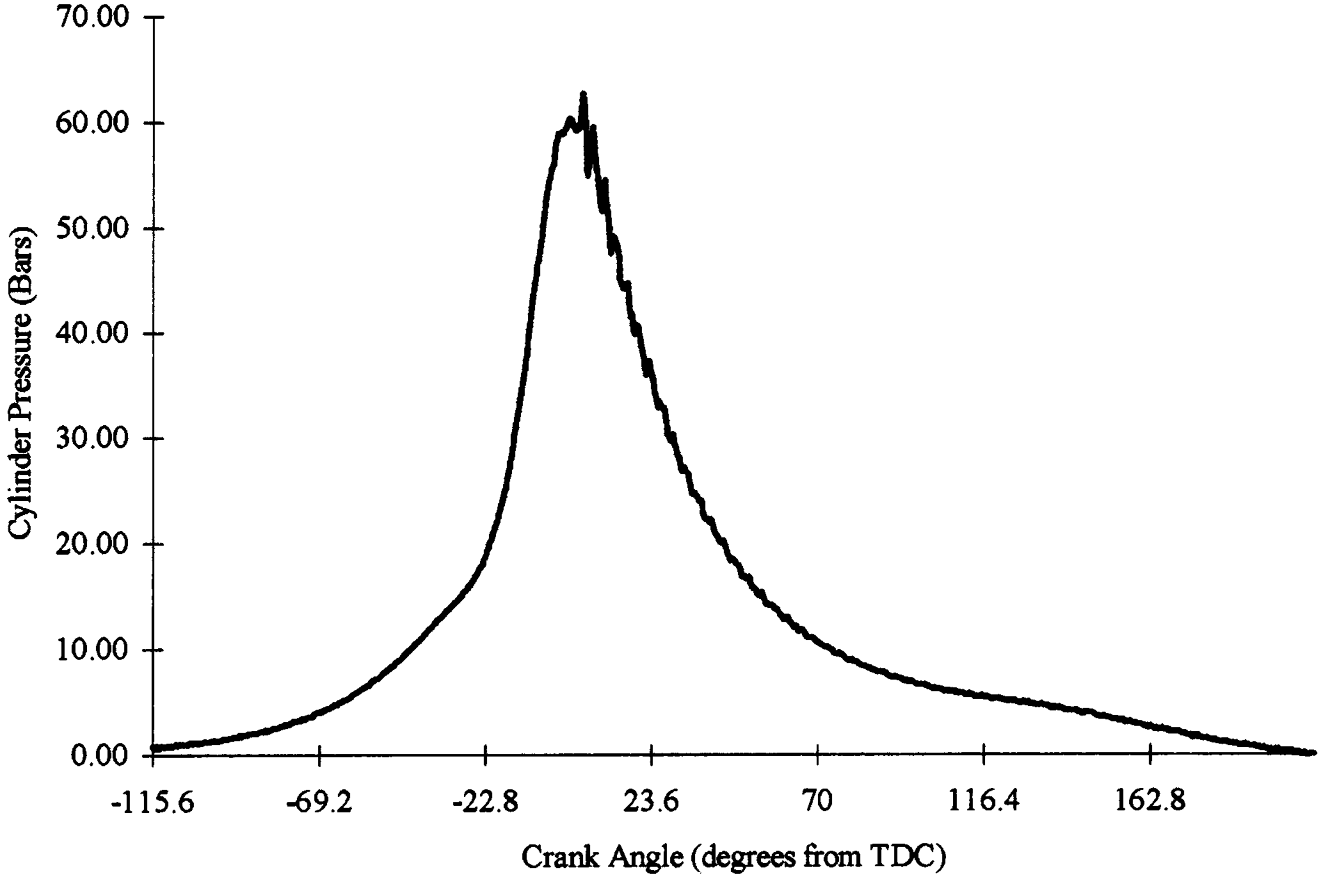


FIG. A1.3 Pressure Trace Showing Light Knock

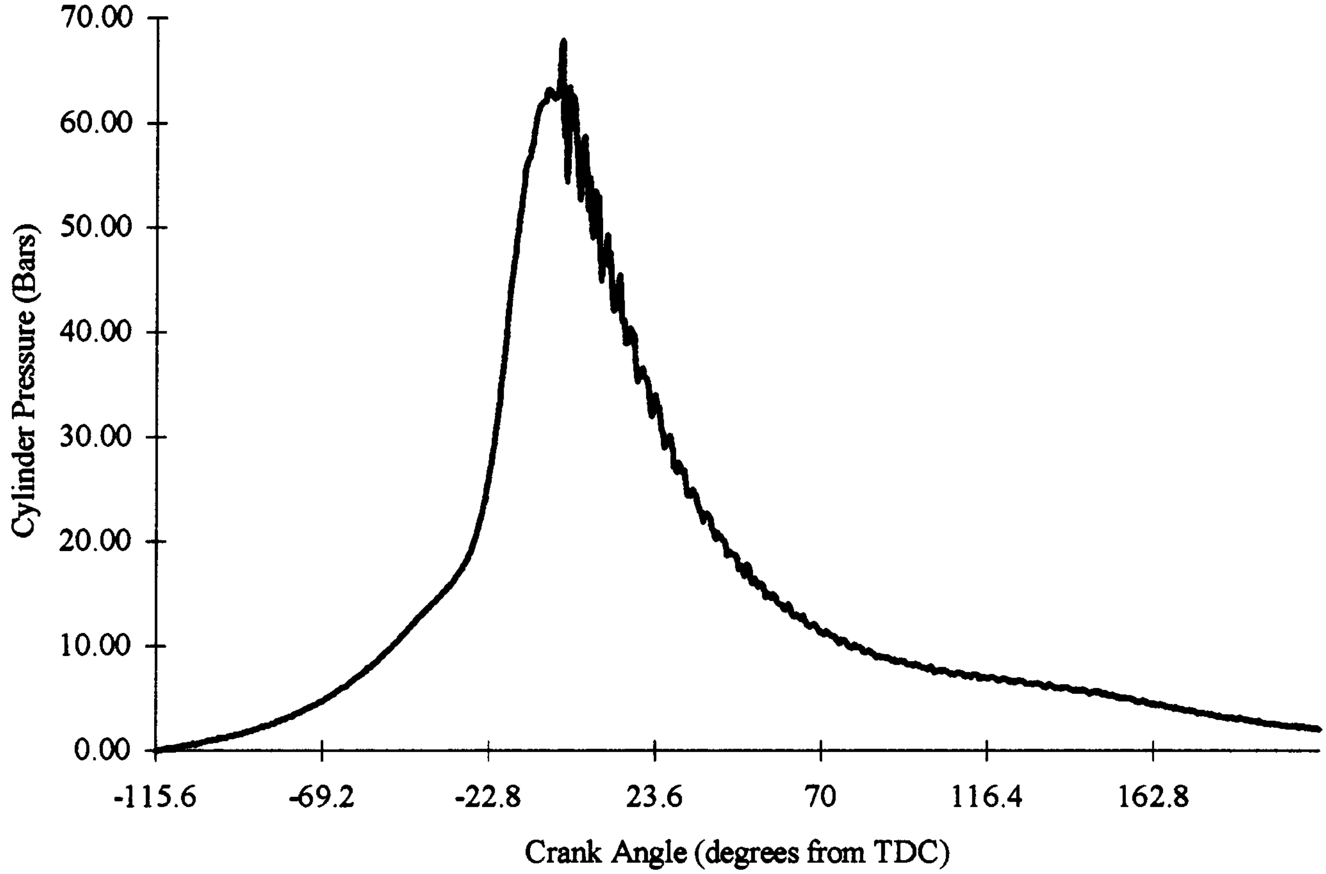


FIG. A1.4 Pressure Trace Showing Moderate Knock

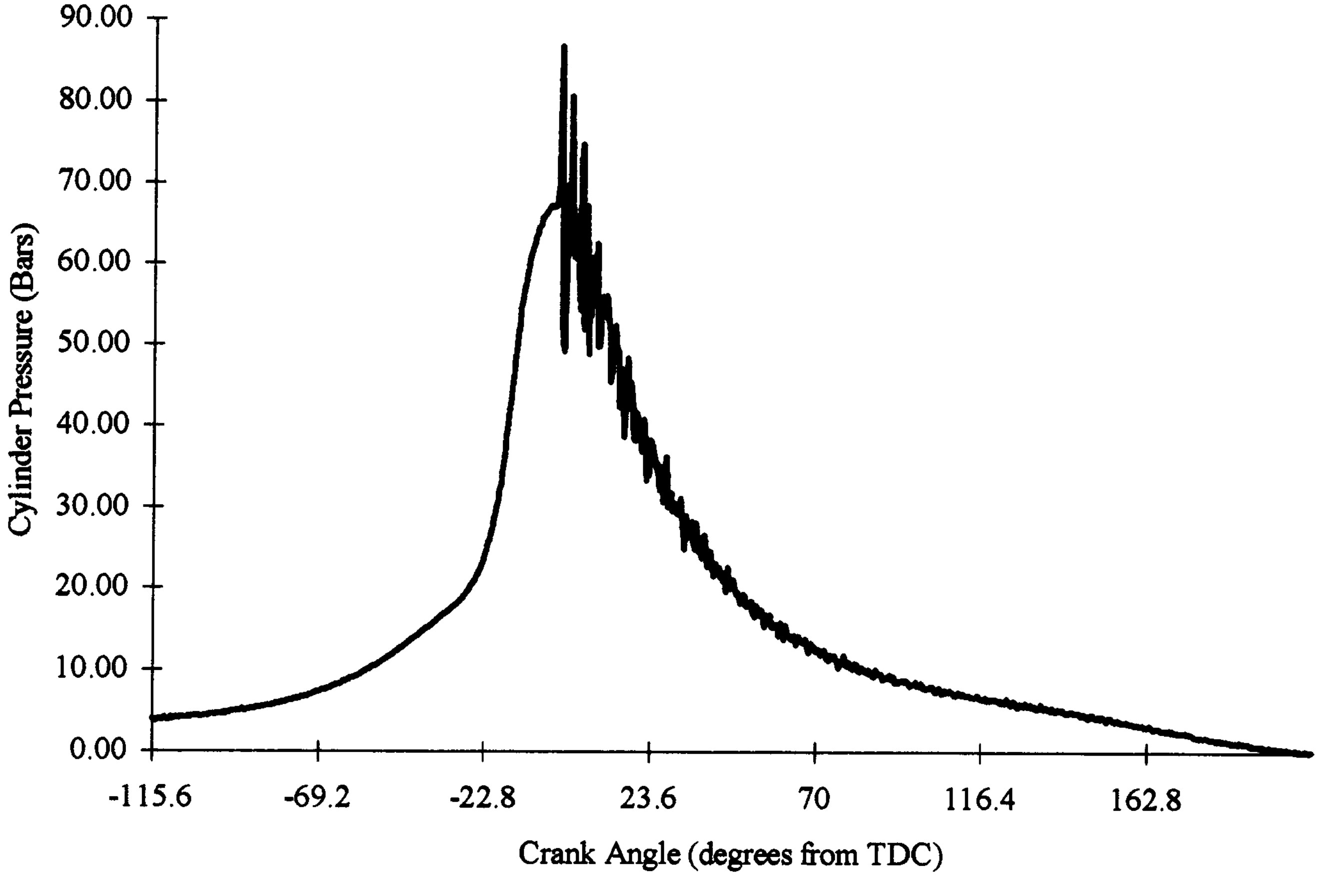


FIG. A1.5 Pressure Trace Showing Heavy Knock

APPENDIX

(Nonmandatory Information)

X1. SAMPLE DATA SHEETS

Fig. X1.1 depicts a sample engine parameter data sheet. Fig. X1.2 depicts a sample knock parameter data sheet.

DATE: ____________________

ENGINE MAKE / MODEL: ____________________

ENGINE SERIAL NUMBER: ____________________

TEST NUMBER: ____________________

AMBIENT AIR TEMPERATURE (C): ____________________

BAROMETER: ____________________

NOTES: ____________________

ENGINE PARAMETERS	DATA POINTS						
	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)							
#1 TURBINE INLET TEMPERATURE (C)							
#2 TURBINE INLET TEMPERATURE (C)							
MANIFOLD ABSOLUTE TEMPERATURE (C)							
OIL TEMPERATURE (C)							
OIL PRESSURE (kPa)							
COOLING AIR TEMPERATURE (C)							
INDUCTION AIR TEMPERATURE (C)							
FUEL MASS FLOW RATE (kg/h)							
MANIFOLD PRESSURE (mmHg)							
TORQUE (Nm)							
ENGINE SHAFT SPEED (rpm)							
OBSERVED BRAKE POWER (kW)							
CORRECTED POWER (kW)							
OBSERVED BRAKE SPECIFIC FUEL CONSUMPTION (kg/kW h)							
CORRECTED BRAKE SPECIFIC FUEL CONSUMPTION (kg/kW h)							
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	Usually Cruise power, 5 % lean mixture
E	Usually Cruise power, 10 % lean mixture
F	
G	

FIG. X1.1 Sample Engine Parameter Data Sheet

DATE: ______
ENGINE MAKE / MODEL: ______
ENGINE SERIAL NUMBER: ______
TEST NUMBER: ______
AMBIENT AIR TEMPERATURE (C): ______
BAROMETER: ______
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. X1.2 Sample Knock Parameter Data Sheet