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Standard Test Method for Evaluation of Diesel Engine Oils in T-10 Exhaust Gas Recirculation Diesel Engine¹

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1. Scope

1.1 This test method is commonly referred to as the Mack T-10.² This test method covers an engine test procedure for evaluating diesel engine oils for performance characteristics, including lead corrosion and wear of piston rings and cylinder liners.

1.2 This test method also provides the procedure for running an abbreviated length test, which is commonly referred to as the T-10A. The procedures for the T-10 and T-10A are identical with the exception of the items specifically listed in Annex A8. Additionally, the procedure modifications listed in Annex A8 refer to the corresponding section of the T-10 procedure.

1.3 The values stated in either SI units or inch-pound units are to be regarded separately as standard. The values stated in each system may not be exact equivalents; therefore, each system shall be used independently of the other. Combining values from the two systems may result in non-conformance with the standard.

1.4 *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. See Annex A7 for specific Safety Hazards.*

2. Referenced Documents

2.1 ASTM Standards:³

D86 Test Method for Distillation of Petroleum Products at Atmospheric Pressure

D93 Test Methods for Flash Point by Pensky-Martens Closed Cup Tester

D97 Test Method for Pour Point of Petroleum Products

D129 Test Method for Sulfur in Petroleum Products (General High Pressure Decomposition Device Method)

D130 Test Method for Corrosiveness to Copper from Petroleum Products by Copper Strip Test

D235 Specification for Mineral Spirits (Petroleum Spirits) (Hydrocarbon Dry Cleaning Solvent)

D287 Test Method for API Gravity of Crude Petroleum and Petroleum Products (Hydrometer Method)

D445 Test Method for Kinematic Viscosity of Transparent and Opaque Liquids (and Calculation of Dynamic Viscosity)

D482 Test Method for Ash from Petroleum Products

D524 Test Method for Ramsbottom Carbon Residue of Petroleum Products

D613 Test Method for Cetane Number of Diesel Fuel Oil

D664 Test Method for Acid Number of Petroleum Products by Potentiometric Titration

D976 Test Method for Calculated Cetane Index of Distillate Fuels

D1319 Test Method for Hydrocarbon Types in Liquid Petroleum Products by Fluorescent Indicator Adsorption

D2274 Test Method for Oxidation Stability of Distillate Fuel Oil (Accelerated Method)

D2500 Test Method for Cloud Point of Petroleum Products

D2709 Test Method for Water and Sediment in Middle Distillate Fuels by Centrifuge

D2622 Test Method for Sulfur in Petroleum Products by Wavelength Dispersive X-ray Fluorescence Spectrometry

D3338 Test Method for Estimation of Net Heat of Combustion of Aviation Fuels

D4052 Test Method for Density, Relative Density, and API Gravity of Liquids by Digital Density Meter

D4485 Specification for Performance of Active API Service Category Engine Oils

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² The ASTM Test Monitoring Center (TMC) will update changes in this test method by means of Information Letters. This edition includes all Information Letters through 05-1-11-1. Information Letters may be obtained from the ASTM Test Monitoring Center, 6555 Penn Ave., Pittsburgh, PA 15206-4489, Attention: Administrator. www.astmtmc.cmu.edu

³ 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.

- D4739 Test Method for Base Number Determination by Potentiometric Hydrochloric Acid Titration
- D5185 Test Method for Determination of Additive Elements, Wear Metals, and Contaminants in Used Lubricating Oils and Determination of Selected Elements in Base Oils by Inductively Coupled Plasma Atomic Emission Spectrometry (ICP-AES)
- D5186 Test Method for Determination of the Aromatic Content and Polynuclear Aromatic Content of Diesel Fuels and Aviation Turbine Fuels By Supercritical Fluid Chromatography
- D5302 Test Method for Evaluation of Automotive Engine Oils for Inhibition of Deposit Formation and Wear in a Spark-Ignition Internal Combustion Engine Fueled with Gasoline and Operated Under Low-Temperature, Light-Duty Conditions
- D5844 Test Method for Evaluation of Automotive Engine Oils for Inhibition of Rusting (Sequence IID)
- D5967 Test Method for Evaluation of Diesel Engine Oils in T-8 Diesel Engine
- D6078 Test Method for Evaluating Lubricity of Diesel Fuels by the Scuffing Load Ball-on-Cylinder Lubricity Evaluator (SLBOCLE)
- D6483 Test Method for Evaluation of Diesel Engine Oils in T-9 Diesel Engine
- D6681 Test Method for Evaluation of Engine Oils in a High Speed, Single-Cylinder Diesel Engine Caterpillar 1P Test Procedure
- E29 Practice for Using Significant Digits in Test Data to Determine Conformance with Specifications
- E178 Practice for Dealing With Outlying Observations
- E344 Terminology Relating to Thermometry and Hydrometry

3. Terminology

3.1 Definitions:

- 3.1.1 *blind reference oil, n*—a reference oil, the identity of which is unknown by the test facility. **D5844**
- 3.1.1.1 *Discussion*—This is a coded reference oil that is submitted by a source independent from the test facility. **D5844**
- 3.1.2 *blowby, n*—in internal combustion engines, the combustion products and unburned air-and-fuel mixture that enter the crankcase. **D5302**
- 3.1.3 *calibrate, v*—to determine the indication or output of a measuring device with respect to that of a standard. **E344**
- 3.1.4 *candidate oil, n*—an oil that is intended to have the performance characteristics necessary to satisfy a specification and is intended to be tested against that specification. **D5844**
- 3.1.5 *exhaust gas recirculation (EGR), n*—the mixing of exhaust gas with intake air to reduce the formation of nitrogen oxides (NO_x). **Automotive Handbook**⁴

[ASTM D6987/D6987M-11](https://standards.iteh.ai/catalog/standards/sist/3e2459d0-c29b-40d5-a93c-d744de725bb9/astm-d6987-d6987m-11)

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⁴ Available from Robert Bosch GmbH, Postfach 50, D-7000 Stuttgart 1., Germany.

3.1.6 *heavy-duty, adj*—in internal combustion engine operation, characterized by average speeds, power output, and internal temperatures that are close to the potential maximums. **D4485**

3.1.7 *heavy-duty engine, n*—in internal combustion engines, one that is designed to allow operation continuously at or close to its peak output. **D4485**

3.1.8 *non-reference oil, n*—any oil other than a reference oil, such as a research formulation, commercial oil, or candidate oil. **D5844**

3.1.9 *non-standard test, n*—a test that is not conducted in conformance with the requirements in the standard test method, such as running on an uncalibrated test stand, using different test equipment, applying different equipment assembly procedures, or using modified operating conditions. **D5844**

3.1.10 *oxidation, n*—of engine oil, the reaction of the oil with an electron acceptor, generally oxygen, which can produce deleterious acidic or resinous materials often manifested as sludge formation, varnish formation, viscosity increase, or corrosion, or a combination thereof. **Sub. B Glossary⁵**

3.1.11 *reference oil, n*—an oil of known performance characteristics and used as a basis for comparison.

3.1.11.1 *Discussion*—Reference oils are used to calibrate testing facilities, to compare the performance of other oils, or to evaluate other materials (such as seals) that interact with oils. **D5844**

3.1.12 *sludge, n*—in internal combustion engines, a deposit, principally composed of insoluble resins and oxidation products from fuel combustion and the lubricant, that does not drain from engine parts but can be removed by wiping with a cloth. **D5302**

3.1.13 *standard test, n*—a test on a calibrated test stand using the prescribed equipment according to the requirements in the test method, and conducted according to the specified operating conditions.

3.1.13.1 *Discussion*—The specified operating conditions in some test methods include requirements for determining a test's operational validity. These requirements are applied after a test is completed and can include (1) mid-limit ranges for the average values of primary and secondary parameters that are narrower than the specified control ranges for the individual values, (2) allowable deviations for individual primary and secondary parameters for the specified control ranges, (3) downtime limitations, and (4) special parameter limitations. **D5844**

3.1.14 *varnish, n*—in internal combustion engines, a hard, dry, generally lustrous deposit that can be removed by solvents but not by wiping with a cloth. **D5302**

3.1.15 *wear, n*—the loss of material from, or relocation of material on, a surface.

3.1.15.1 *Discussion*—Wear generally occurs between two surfaces moving relative to each other, and is the result of mechanical or chemical action or by a combination of mechanical and chemical action. **D5302**

4. Summary of Test Method

4.1 The test operation involves use of a Mack E-TECH V-MAC III diesel engine with exhaust gas recirculation (EGR). A warm-up and a 1-h break-in are followed by a two-phase test consisting of 75 h at 1800 r/min and 225 h at 1200 r/min, both at constant speed and load.

4.2 Take oil samples periodically and analyze for viscosity increase and wear metals content.

4.3 Rebuild the engine prior to each test. Disassemble, solvent-clean (see 7.4), measure, and rebuild the engine power section using all new pistons, rings, cylinder liners, and connecting rod bearings in strict accordance with furnished specifications.

4.4 Solvent-clean (see 7.4) the engine crankcase and replace worn or defective parts.

4.5 Equip the test stand with appropriate accessories for controlling speed, load, and various engine operating conditions.

5. Significance and Use

5.1 This test method was developed to evaluate the wear performance of engine oils in turbocharged and intercooled four-cycle diesel engines equipped with EGR. Obtain results from used oil analysis and component measurements before and after the test.

5.2 The test method may be used for engine oil specification acceptance when all details of the procedure are followed.

6. Apparatus

6.1 General Description:

6.1.1 The test engine is a Mack E-TECH V-MAC III, electronically controlled fuel injection with six electronic unit pumps, P/N 11GBA81025 (Annex A2). It is an open-chamber, in-line, six-cylinder, four-stroke, turbocharged, charge air-cooled, and compression ignition engine. The bore and stroke are 124 by 165 mm [4⁷/₈ by 6¹/₂ in.], and the displacement is 12 L [728 in³].

6.1.2 The ambient laboratory atmosphere shall be relatively free of dirt and other contaminants as required by good laboratory standards. Filtering air, controlling temperature, and controlling humidity in the engine buildup area helps prevent accumulation of dirt and other contaminants on engine parts and aids in measuring and selecting parts for assembly.

6.2 The Test Engine:

6.2.1 *Mack T-10 Test Engine*—The engine is available from Mack Trucks, Inc. A complete parts list is shown in Table A2.1. Use test parts on a first-in/first-out basis.

⁵ Available from the ASTM Test Monitoring Center (TMC), 6555 Penn Avenue, Pittsburgh, PA 15206-4489, Attention: Administrator.

6.2.2 Engine Cooling System:

6.2.2.1 Use a new Mack coolant conditioner shown in Table A2.1, for every test to limit scaling in the cooling system. Pressurize the system to 103 kPa [15 psi] at the expansion tank. Use the coolant shown in 7.3.1.

6.2.2.2 Use a closed-loop, pressurized external engine cooling system composed of a nonferrous core heat exchanger, reservoir, and water-out temperature control valve. The system shall prevent air entrainment and control jacket temperatures within the specified limit. Install a sight glass between the engine and the cooling tower to check for air entrainment and uniform flow in an effort to prevent localized boiling. Block the thermostat wide open.

6.2.2.3 Flow the coolant from the engine block fitting to the EGR coolers (see Fig. A1.3). Return the EGR coolant flow to the engine coolant-in line near the coolant pump inlet (see Fig. A1.7).

6.2.3 Auxiliary Oil System—To maintain a constant oil level in the pan, provide an additional 9.5 L [10 qt] sump by using a separate closed tank connected to the sump. Circulate oil through the tank at a rate of 5.7 ± 1.9 L/min [1.5 ± 0.5 gal/min] with an auxiliary pump. The system schematic is shown in Fig. A1.1. The No. 6 and No. 8 lines are to have inside diameters of 10 mm [$\frac{3}{8}$ in.] and 13 mm [$\frac{1}{2}$ in.], respectively. Use a minimum No. 8 size vent line. Equivalent lines may be substituted for Aeroquip⁶ lines provided they have the proper inside diameters.

6.2.3.1 Locate the auxiliary oil system suction line on the exhaust side of the oil pan, 127 mm [5.00 in.] down from the oil pan rail and 178 mm [7.00 in.] back from the front of the pan. This location is directly above the oil sump temperature thermocouple. Refer to Fig. A1.4. Connect the auxiliary oil system return line to the power steering pump cover on the front timing gear cover. Refer to Fig. A1.5. Connect the auxiliary oil scale vent line to the top of the auxiliary oil sump bucket and the dipstick tube opening.

6.2.3.2 Use a Viking pump Model No. SG053514 as the auxiliary oil pumps. Pump speed is specified as 1725 r/min.⁷

6.2.4 Oil Cooling System:

6.2.4.1 Use the oil cooler adapter blocks to mount the oil cooler to the engine. The adapter blocks are available from the supplier list in A2.7, Annex A2.

6.2.4.2 Use the oil filter housing (part no. 27GB525M) shown in Fig. A1.8.

6.2.5 Blowby Meter—Use a meter capable of providing data at a minimum frequency of 6 min. To prevent blowby condensate from draining back into the engine, the blowby line shall have a downward slope to a collection bucket. The collection bucket shall have a minimum volume of 18.9 L [5 gal]. Locate the blowby meter downstream of the collection bucket. The slope of the blowby line downstream of the collection bucket is unspecified.

6.2.6 Air Supply and Filtration—Use the Mack air filter element and the Mack filter housing shown in A2.3, Annex A2. Replace filter cartridge when 2.5 kPa [10 in. H₂O] ΔP is reached. Install an adjustable valve (flapper) in the inlet air system at least two pipe diameters before any temperature, pressure, and humidity measurement devices. Use the valve to maintain inlet air restriction within required specifications.

6.2.7 Fuel Supply—Heating or cooling, or both, of the fuel supply may be required, and a recommended system is shown in Fig. A1.2.

6.2.8 Intake Manifold Temperature Control—Use a Modine intercooler to control intake manifold temperature (refer to A2.4).

6.2.9 Injection Timing Control—Remove the engine intake manifold temperature sensor. Use the intake manifold temperature to control injection timing according to the temperature to injection timing correlation shown in Annex A5.

6.2.10 Oil Pump—Use a Mack P/N 315GC465BM oil pump. The oil pump is available from Mack Trucks, Inc. (see A2.2).

7. Engine Fluids

7.1 Test Oil:

7.1.1 Approximately 151 L [40 gal] of test oil is required for the test.

7.2 Test Fuel:

7.2.1 Obtain test fuel from the supplier shown in A2.6, Annex A2. The required fuel properties and tolerances are available from the TMC.⁵

7.3 Engine Coolant:

7.3.1 Use demineralized water with less than 0.03 g/L [2 grains/gal] of salts or distilled water (do not use antifreeze solutions). Use Pencoool 3000 coolant additive at the manufacturer's recommended rate. Pencoool 3000 may be obtained from the supplier shown in A2.8, Annex A2.

7.4 Solvent—Use only mineral spirits meeting the requirements of Specification D235, Type II, Class C for Aromatic Content (0-2% vol), Flash Point (142°F/61°C, min) and Color (not darker than +25 on Saybolt Scale or 25 on Pt-Co Scale). (**Warning**—Combustible. Health hazard.) Obtain a Certificate of Analysis for each batch of solvent from the supplier.

8. Preparation of Apparatus at Rebuild

8.1 Cleaning of Parts:

⁶ Aeroquip lines are available at local industrial hose suppliers.

⁷ The sole source of supply of the apparatus known to the committee at this time is Viking Pump, Inc., A Unit of IDEX Corp., 406 State St., P.O. Box 8, Cedar Falls, IA 50613-0008. If you are aware of alternative suppliers, please provide this information to ASTM International Headquarters. Your comments will receive careful consideration at a meeting of the responsible technical committee, which you may attend.

8.1.1 *Engine Block*—Thoroughly spray the engine with solvent (see 7.4) to remove any oil remaining from the previous test and air-dry. Additionally, use of an engine parts washer shall be followed by a solvent wash.

8.1.2 *Rocker Covers and Oil Pan*—Remove all sludge, varnish, and oil deposits. Rinse with solvent (see 7.4) and air-dry. Additionally, use of an engine parts washer shall be followed by a solvent wash.

8.1.3 *Auxiliary Oil System*—Flush all oil lines, galleries, and external oil reservoirs first with a solvent (see 7.4) to remove any previous test oil and then air-dry.

8.1.4 *Oil Cooler and Oil Filter*—Flush the oil cooler and filter lines first with a solvent (see 7.4) to remove any previous test oil and then air-dry. Additionally, use of an engine parts washer shall be followed by a solvent wash.

8.1.5 *Cylinder Head*—Clean the cylinder heads using a wire brush to remove deposits and rinse with a solvent (see 7.4) to remove any sludge and oil and then air-dry. Additionally, use of an engine parts washer shall be followed by a solvent wash.

8.1.6 *Intake Manifold*—Clean the intake manifold before each test. Scrub the manifold using a nylon brush and a solvent, and then wash the manifold using an engine parts cleaner.

8.1.7 *EGR Coolers*—Clean the EGR coolers before each test by flushing with a solvent and then air-drying (see 7.4).

8.1.8 *EGR Venturi Unit*—Clean the venturi before each test. Spray with a solvent and scrub with a nylon brush.

8.2 *Valves, Seats, Guides, and Springs*—Visually inspect valves, seats, and springs for defects or heavy wear and replace if necessary. Replacement of the valves, guides, and seat inserts for each test is recommended, but not required.

8.2.1 Replace and ream guides to 0.9525 ± 0.0013 cm [0.3750 ± 0.0005 in.].

8.3 *Cylinder Liner, Piston, and Piston Ring Assembly:*

8.3.1 *Cylinder Liner Fitting*—For proper heat transfer, fit cylinder liners to the block according to the procedure outlined in the Mack Service Manual.⁸

8.3.2 *Piston and Rings*—Cylinder liners, pistons, and rings are provided as a set and should be used as a set. Examine piston rings for any handling damage. Record pre-test measurements as detailed in 11.1.

8.4 *Injectors and Injection Pumps:*

8.4.1 *Injectors*—Check the injector opening pressure at the start of each calibration period. Reset the injector opening pressure if it is outside the specification of 36 900 to 37 900 kPa [5350 to 5500 psi].

8.4.2 *Injection Pumps*—The electronic unit pumps (EUP) may be changed at any time using the procedure specified in the Mack Service Manual. Be sure to enter the EUP's four digit calibration code into the engine control unit (ECU). The calibration code can be found on the EUP label.

8.5 *Assembly Instructions:*

8.5.1 *General*—The test parts specified for this test are intended to be used without material or dimensional modification. Exceptions, for example, a temporary parts supply problem, shall be approved by the Test Monitoring Center (TMC), and noted in the test report. All replacement test engine parts shall be genuine Mack Truck Inc. parts. Assemble all parts as illustrated in the Mack Service Manual except where otherwise noted. Target all dimensions for the means of the specifications. Use Bulldog Premium EO-M+ Oil for lubricating parts during assembly; see A2.10, Annex A2.

8.5.1.1 *Thermostat*—Block the thermostat wide open.

8.5.1.2 *Rod Bearings*—Install new rod bearings for each test. See 10.1 for pre-test measurements to be recorded.

8.5.1.3 *Main Bearings*—Install new main bearings for each test.

8.5.1.4 *Piston Under Crown Cooling Nozzles*—Take particular care in assembling the piston under crown cooling nozzles to ensure proper piston cooling (as outlined in the Mack Service Manual).

NOTE 1—Proper oil pressure is also important to ensure sufficient oil volume for proper cooling.

8.5.1.5 *Thrust Washers*—Install new thrust washers for each test.

8.5.2 *New Parts*—Use test parts on a first-in/first-out basis. Install the following new parts for each rebuild, see Table A2.1 for part numbers:

8.5.2.1 Cylinder liners.

8.5.2.2 Pistons.

8.5.2.3 Piston rings.

8.5.2.4 Overhaul gasket set.

8.5.2.5 Oil filters.

8.5.2.6 Engine coolant conditioner.

8.5.2.7 Primary fuel filter.

8.5.2.8 Secondary fuel filter.

8.5.2.9 Valve stem seals.

8.5.2.10 Valve guides.

8.5.2.11 Connecting rod bearings.

8.5.2.12 Main bearings.

⁸ Mack Service Manuals are available from local Mack Trucks, Inc. distributors.

8.5.2.13 Thrust washers.

8.6 Measurements:

8.6.1 Calibrations:

8.6.1.1 Calibrate thermocouples, pressure gages, speed, and fuel flow measuring equipment prior to each reference oil test or at any time readout data indicates a need. Conduct calibrations with at least two points that bracket the normal operating range. Make these calibrations part of the laboratory record. During calibration, connect leads, hoses, and read-out systems in the normally used manner and calibrate with necessary standards. For controlled temperatures, immerse thermocouples in calibration baths. Calibrate standards with instruments traceable to the National Institute of Standards and Technology on a yearly basis.

8.6.1.2 *Oxygen Sensor*—Calibrate the oxygen sensor prior to every test in accordance with Annex A4.

8.6.2 Temperatures:

8.6.2.1 *General*—Measure temperatures with thermocouples and conventional readout equipment or their equivalent. For temperatures in the 0 to 150°C [32 to 300°F] range, calibrate temperature-measuring systems to $\pm 0.5^\circ\text{C}$ for at least two temperatures that bracket the normal operating range. Insert all thermocouples so that the tips are located midstream of the flow unless otherwise indicated.

8.6.2.2 *Ambient Air*—Locate thermocouple in a convenient, well-ventilated position between 2 and 3 m [approximately 6 and 10 ft] from the engine and hot accessories.

8.6.2.3 *Coolant*—Locate the coolant-out thermocouple in the water manifold prior to the thermostat housing. Locate in center of water stream. Refer to Fig. A1.6. Locate the coolant-in thermocouple anywhere between the heat exchanger and the coolant pump inlet (upstream of the junction with the EGR coolant return). Refer to Fig. A1.7.

8.6.2.4 *Oil Gallery*—Locate thermocouple at the center port on the filter housing. Insertion depth shall be 98 mm [3.875 in.] Refer to Fig. A1.8.

8.6.2.5 *Oil Sump Temperature*—Using a front sump oil pan configuration, locate thermocouple on the exhaust side of the oil pan, 178 mm [7 in.] from the front and 178 mm [7 in.] from the top of the pan. Thermocouple length shall be 4 in. Refer to Fig. A1.4.

8.6.2.6 *Intake Air Temperature*—Locate the intake air thermocouple in center of air stream at the turbocharger inlet as shown in Fig. A1.9. The temperature thermocouple is to be approximately 102 mm [4 in.] upstream of the compressor inlet connection. It is not necessary to control intake air humidity, but measurements are required.

8.6.2.7 *Fuel In*—Locate thermocouple at the fitting on the outlet side of the fuel transfer pump as shown in Fig. A1.10.

8.6.2.8 *Pre-Turbine Exhaust*—Locate one thermocouple in each side of exhaust manifold section; see Fig. A1.11. The thermocouple shall be downstream of the pre-turbine exhaust pressure sensor.

8.6.2.9 *Exhaust Tailpipe*—Locate thermocouple in exhaust pipe downstream of turbine in accordance with Fig. A1.12.

8.6.2.10 *Intake Manifold*—Locate thermocouple at tapped fitting on intake air manifold as shown in Fig. A1.13.

8.6.2.11 *EGR Cooler Inlet*—Distinct EGR cooler inlet temperature measurements are not necessary. Use the pre-turbine exhaust temperatures instead (see 8.6.2.8).

8.6.2.12 *EGR Cooler Outlet*—Locate thermocouple as shown in Fig. A1.14.

8.6.2.13 *EGR Pre-Venturi*—Locate thermocouple as shown in Fig. A1.15. Be aware that the EGR pre-venturi thermocouple shall be downstream of the pressure sensor.

8.6.2.14 *Additional*—Monitor any additional temperatures that the test laboratory regards as helpful in providing a consistent test procedure.

8.6.3 Pressures:

8.6.3.1 *Before Oil Filter*—Locate pickup at tapped hole on oil cooler fitting; see Fig. A1.16.

8.6.3.2 *After Oil Filter (Main Oil Gallery)*—Locate pickup at the left port of the filter housing; see Fig. A1.8.

NOTE 2—The E7 engine has only one oil gallery, and it serves as both a main gallery and piston-cooling gallery.

8.6.3.3 *Pre-Turbine Exhaust*—Locate pickup in each side of exhaust manifold section (tap shall be upstream of the pre-turbine temperature thermocouple); see Fig. A1.11. This measurement is not mandatory but is recommended for diagnostic and safety purposes.

8.6.3.4 *Intake Manifold (Air Boost)*—Take measurement at tapped fitting provided on intake manifold as illustrated in Fig. A1.17.

8.6.3.5 *Intake Air Pressure (Intake Air Restriction)*—Measure with a Keil probe (p/n KDF-8-W required) located approximately 203 mm [8 in.] upstream of the compressor inlet (see Fig. A1.9). The probes may be obtained from the supplier shown in A2.9.

8.6.3.6 *Exhaust Back*—Locate pickup in exhaust pipe after turbocharger in center of exhaust stream. Measure exhaust backpressure in a straight section of pipe, 30.5 to 40.6 cm [12 to 16 in.] downstream of the turbo with a pressure tap hole as shown in Fig. A1.12.

8.6.3.7 *Crankcase Pressure*—Locate pickup at any location in the auxiliary oil system vent line, such as between the dipstick tube fitting and the top of the auxiliary oil sump bucket.

8.6.3.8 *Compressor Discharge*—Locate pickup within 15.2 cm [6 in.] of the second compressor.

8.6.3.9 *Coolant System*—Locate pickup at the top of the coolant system expansion tank.

8.6.3.10 *Barometric Pressure*—Locate barometer approximately 1.2 m [4 ft] above ground level in convenient location in the laboratory.

8.6.4 *Exhaust Oxygen Sensor*—Locate the oxygen sensor at the 12 o'clock position, 35.6 to 43.2 cm [14 to 17 in.] downstream of the turbine. Countersink the sensor coupling and install the sensor so that the sensor threads are flush with the inside diameter of the exhaust pipe. Do not expose threads to the flow stream. Refer to Fig. A1.12.

8.6.5 *Intake Carbon Dioxide Sensor*—Measure intake CO₂. Locate the probe as shown in Fig. A1.8.

8.6.6 *Engine Blowby*—Connect the metering instrument to the filter element canister on the engine front cover.

8.6.7 *Fuel Consumption Measurements*—Place the measuring equipment in the fuel line before the primary fuel filter. Install the primary fuel filter before the fuel transfer pump and install the secondary filter before the unit injection pumps. Never plug fuel return lines. Accurate fuel consumption measurements require proper accounting of return fuel.

8.6.8 *Humidity*—Place the measurement equipment between the inlet air filter and compressor in such a manner as not to affect temperature and pressure measurements. Do not condition the intake air downstream of the humidity sensor. Report humidity on the appropriate form.

8.6.9 *System Time Responses*—The maximum allowable system time responses are shown in Table 1. Determine system time responses in accordance with the Data Acquisition and Control Automation II (DACA II) task force report.⁵

9. Procedure

9.1 Pretest Procedure:

9.1.1 Initial Oil Fill for Pretest Break-In:

9.1.1.1 The initial oil fill is 32.7 kg [72.0 lb)] of test oil: 16.4 kg [36.0 lb] for the pan, 3.3 kg [7.2 lb] for the filters, 1.6 kg [3.6 lb] for the engine oil cooler, and 11.4 kg [25.2 lb] for the auxiliary oil reservoir and lines. Add the first 3.3 kg [7.2 lb] of fresh test oil to the oil filters (half in each filter), then turn on the auxiliary oil pumps and add an additional 29.4 kg [64.8 lb] of test oil to the engine. This oil may be added directly through the engine oil fill tube.

9.1.2 Pretest Break-In:

9.1.2.1 Run the break-in sequence described in Annex A6.

9.1.2.2 Drain the oil within 1 h after the break-in is completed. Replace all oil filters. Refill the engine with test oil and conduct the test in accordance with 9.4. When performing the pre-test oil charge, do not account for any hang up oil left in the oil system.

9.2 Engine Start-Up:

9.2.1 Perform all engine start-ups in accordance with Annex A6. Start-ups are not included as test time. Test time starts as soon as the engine returns to the test cycle. The start date and time of a test is defined as when the engine first reaches test conditions as shown in Table 2. (**Warning**—Crank the engine prior to start-up to fill the engine oil passages. This practice will enhance engine durability significantly.)

9.3 Engine Shutdown:

9.3.1 Perform all non-emergency shutdowns in accordance with Annex A6. The shutdown operation does not count as test time. Record the length and reason of each shutdown on the appropriate form.

9.3.2 All operationally valid tests should not exceed 10 shutdowns. Additionally, all operationally valid tests should not exceed 150 h of downtime. Conduct an engineering review if either condition is exceeded.

9.4 Test Cycle:

9.4.1 The test cycle includes a 1-h break-in followed by a 300-h test. Operating conditions are shown in Table 2. Conduct the break-in by operating at Phase II conditions for 30 min, followed by Phase I conditions for 30 min. Conduct the test by operating for 75 h at Phase I conditions, followed by 225 h at Phase II conditions. Conduct the transition from Phase I to Phase II in accordance with Annex A6.

9.4.1.1 Based upon oil analysis, injection timing may be changed within the first 75 h of the test (Phase I) to ensure meeting the 75-h soot window of 5.0 ± 0.3 % (see 11.7).

9.4.2 Operational Validity:

9.4.2.1 Determine operational validity in accordance with Annex A3.

9.5 Oil Samples:

9.5.1 Take 120-mL [4-oz] oil samples at every 25-h interval except the 75-h sample. At 75 h, take a 240-mL [8-oz] sample. Take the EOT oil sample within 30 min of test completion. Obtain oil samples through a drain petcock located in the oilrig return line (oil pan return pump); see Fig. A1.1. Always take oil samples before new oil is added.

9.6 Oil Addition/Drain:

TABLE 1 Maximum Allowable System Time Responses

Measurement Type	Time Response(s)
Speed	2.0
Temperature	3.0
Pressure	3.0
Flow	45.0

TABLE 2 Test Conditions

Parameters	Limits	
	Phase I	Phase II
Time, h	75	225 ^A
Injection timing, °BTDC	Variable	18
Controlled Parameters ^B		
Speed, r/min	1800	1200
Fuel flow, kg/h (lb/h)	59.2 (130.5)	63.5 (140.0)
Intake CO ₂ level, %	1.5 ± 0.05	0.2 ± 0.05
Inlet manifold temperature, °C (°F)	70 (158)	66 (150)
Coolant out temperature, °C (°F)	66 (150)	85 (185)
Fuel in temperature, °C (°F)	40 (104)	40 (104)
Oil gallery temperature, °C (°F)	88 (190)	113 (235)
Intake air temperature, °C (°F)	25 (77)	25 (77)
Ranged Parameters ^C		
Inlet air restriction, kPa (in. H ₂ O)	3.5-4.0 (14-16)	3.5-4.0 (14-16)
Inlet manifold pressure, kPa (in. Hg), min	160 (47.4)	210 (62.2)
Exhaust back pressure, kPa (in. H ₂ O)	2.7-3.5 (11-14)	2.7-3.5 (11-14)
Crankcase pressure, kPa (in. H ₂ O)	0.25-0.75 (1-3)	0.25-0.75 (1-3)
Uncontrolled Parameters		
Power, kW (bhp)	~257 (~345)	~324 (~434)
Torque, N·m (lbf·ft) ^C	record ^D	record ^D
Exhaust O ₂ level, %	record	record
Exhaust temperature, °C (°F)		
Pre-turbine	record	record
Tailpipe	record	record
Oil sump temperature, °C (°F)	record	record
Coolant in temperature, °C (°F)	record	record
EGR cooler inlet temperature front, °C (°F)	record	record
EGR cooler outlet temperature rear, °C (°F)	record	record
EGR pre-venturi temperature, °C (°F)	record	record
Inlet air dew point, °C (°F)	record	record
Inlet air humidity, g/kg (gr/lb)	record	record
Blowby, L/min (ft ³ /min)	record	record
Pre-turbine exhaust pressure, kPa (in. Hg)	record	record
Main gallery oil pressure, kPa (psi)	record	record
Oil filter DP, kPa (psi)	Not to exceed 138 (20) ^E	Not to exceed 138 (20) ^E

^A Check valve lash after break-in.

^B All control parameters shall be targeted at the mean indicated.

^C All ranged parameters shall fall within the specified ranges.

^D At 98.2 kPa (29 in. Hg) and 29.5°C (85°F) dry air.

^E If oil filter ΔP exceeds 138 kPa (20 psi), change the two full flow filters. If the filters are changed, attempt to recover as much oil as possible by draining the filters. No new oil is to be added. The test report shall indicate if the filters are changed.

9.6.1 Initially establish the full mark as the oil weight after 1 h of running at Phase II test conditions, but do not add any new oil until test hour 100 (25 h into Phase II). At 100-h test and each 50-h period thereafter, perform a forced drain. Drain a sufficient amount of oil to obtain an oil weight, which is 2.27 kg [5.0 lb] below the full mark, and add 2.27 kg [5.0 lb] of new oil to the engine. After a shutdown, use the drain level of the previous period to determine the forced drain quantity. For any period, if the oil weight is already more than 2.27 kg [5.0 lb] below the full mark, do not perform a forced drain.

9.6.2 If the auxiliary oil sump goes dry after 250 h, continue running the test to 300 h. Do not take a 275-h oil sample. Take the EOT oil sample from the engine sump within 30 min of test completion.

9.6.3 If the auxiliary oil sump goes dry at or before 250 h, declare the test non-interpretable.

9.7 Oil Weight Measurements:

9.7.1 Record the oil weight every 6 min and compute the oil consumption (see 10.5) from these readings.

9.8 Fuel Samples:

9.8.1 Take two 1-L [1-qt] fuel samples prior to the start of test and at EOT.

9.9 Periodic Measurements:

9.9.1 Make measurements at 6-min intervals on the parameters listed in 9.9.2 and record statistics on the appropriate form. Automatic data acquisition is required. Recorded values shall have minimum resolution as shown in Table 3. Characterize the procedure used to calculate the data averages on the appropriate form.

9.9.2 Parameters:

9.9.2.1 Speed, r/min,

9.9.2.2 Torque, N·m [lbf·ft],

9.9.2.3 Oil gallery temperature, °C [°F],

9.9.2.4 Oil sump temperature, °C [°F],

9.9.2.5 Coolant out temperature, °C [°F],



TABLE 3 Minimum Resolution of Recorded Measurements

Parameter	Record Data to Nearest	Parameter	Record Data to Nearest
Speed	1 r/min	Blowby	1 L/min
Fuel flow	0.1 kg/h	Inlet air dew point	1°C
Coolant temperatures	0.1°C	Oil temperatures	0.1°C
Fuel in temperature	0.1°C	Exhaust temperatures	1°C
Intake air temperature	0.1°C	EGR temperatures	1°C
Intake manifold temperature	0.1°C	Oil pressures	1 kPa
Exhaust back pressure	0.1 kPa	Crankcase pressure	0.1 kPa
Inlet air restriction	0.1 kPa	Intake manifold pressure	1 kPa
Torque	1 Nom	Oxygen	0.1 %
Power	1 kW	Oil weight	0.001 kg
Humidity	0.1 g/kg		

9.9.2.6 Coolant in temperature, °C [°F],

9.9.2.7 Intake air temperature, °C [°F],

9.9.2.8 Intake manifold temperature, °C [°F],

9.9.2.9 Intake manifold pressure, kPa [in. Hg],

9.9.2.10 Fuel flow, s/kg or kg/h [s/lb or lb/h],

9.9.2.11 Fuel inlet temperature, °C [°F],

9.9.2.12 Tailpipe exhaust back pressure, kPa [in. H₂O],

9.9.2.13 Before filter oil pressure, kPa [psi],

9.9.2.14 Main gallery oil pressure, kPa [psi],

9.9.2.15 Crankcase pressure, kPa [in. H₂O],

9.9.2.16 Pre-turbine exhaust temperature, front manifold, °C [°F],

9.9.2.17 Pre-turbine exhaust temperature, rear manifold, °C [°F],

9.9.2.18 Inlet air restriction, kPa [in. H₂O],

9.9.2.19 Tailpipe exhaust temperature, °C [°F],

9.9.2.20 Crankcase blowby, L/min [ft³/min] (see 9.10),

9.9.2.21 Pre-turbine exhaust pressure, front manifold, kPa [in. Hg],

9.9.2.22 Pre-turbine exhaust pressure, rear manifold, kPa [in. Hg],

9.9.2.23 Inlet air humidity, g/kg [grains/lb],

9.9.2.24 Tailpipe oxygen level, %,

9.9.2.25 EGR cooler outlet temperature, °C [°F],

9.9.2.26 EGR pre-venturi temperature, °C [°F],

9.9.2.27 Inlet air dew point, °C [°F], and

9.9.2.28 Oil weight, kg [lbf].

9.10 *Blowby:*

9.10.1 Record the crankcase blowby on the appropriate form. Exercise care to prevent oil traps from occurring in the blowby line at any time during operation.

9.11 *Centrifugal Oil Filter Mass Gain:*

9.11.1 Prior to the start of test, determine the mass of the centrifugal oil filter canister. At EOT, remove the centrifugal oil filter canister from the engine and drain upside down for 30 min. After draining, determine the mass of the canister and record on the appropriate form. Determine the centrifugal oil filter mass gain for each test.

9.12 *Oil Filter ΔP Calculation:*

9.12.1 The reported oil filter ΔP is the maximum oil filter ΔP that occurs as a result of the test. Calculate the oil filter ΔP as follows:

$$\Delta P = \Delta P_{max} - \Delta P_{initial} \quad (1)$$

where:

ΔP_{max} = the maximum ΔP across the oil filter, and

ΔP_{initial} = the ΔP across the oil filter at the start of test conditions.

If an oil filter change is made, add the oil filter ΔP value obtained after the filter change to the oil filter ΔP obtained prior to the filter change. If a shutdown occurs, add the oil filter ΔP value obtained after the shutdown to the oil filter ΔP obtained prior to the shutdown. Change the oil filter if the ΔP exceeds 138 kPa [20 psi]. Report oil filter ΔP on the appropriate form.

10. Inspection of Engine, Fuel, and Oil

10.1 *Pre-Test Measurements:*

10.1.1 *Pistons:*

10.1.1.1 No piston measurements are required.

10.1.2 *Cylinder Sleeves Inside Diameter Surface Finish*—Measure in accordance with 10.1.2 of Test Method D6483. Report results on the appropriate form.

10.1.3 *Piston Rings*—Clean and measure according to the Mack Test Ring Cleaning and Measuring Procedure, available from the TMC.⁵ Report results on the appropriate form.

10.1.4 *Connecting Rod Bearings*—Clean and measure in accordance with 10.1.4 of Test Method D6483. Report results on the appropriate form.

10.2 *Post Test Engine Measurements* :

10.2.1 *Pistons*—Before removing pistons, carefully remove carbon from top of cylinder sleeve. Do not remove any metal.

10.2.1.1 Rate all six pistons for deposits in accordance with Test Method D6681. Use the 1P piston rating method. Report the results on the appropriate forms.

10.2.2 *Cylinder Sleeves*—Measure in accordance with Instructions for Measuring Cylinder Sleeves, available from the TMC.⁵ Report the results on the appropriate form.

10.2.3 *Piston Rings*—Clean and measure in accordance with the Mack Test Ring Cleaning and Measuring Procedure, available from the TMC.⁵ Report results on the appropriate form.

10.2.4 *Connecting Rod Bearings*—Clean and measure in accordance with 10.2.4 of Test Method D6483. Report the results on the appropriate form.

10.3 *Oil Inspection*:

10.3.1 Analyze oil samples for viscosity at 100°C [212°F] in accordance with either Test Method D445 or Test Method D5967, Annex A3. Base viscosity increase on the minimum viscosity. In addition to the viscosity measurements, conduct soot analysis in accordance with Test Method D5967, Annex A4. Conduct the 75-h soot measurement twice and report the average (round the result in accordance with Practice E29). To maintain accuracy and precision, conduct all soot measurements at a TMC-calibrated laboratory. Determine wear metals content (iron, lead, copper, chromium, aluminum), additive metals content, silicon, and sodium levels in accordance with Test Method D5185 every 25 h from 0 h to EOT. Conduct EOT lead content measurements at least twice and report the average value. Conduct oil analysis as soon as possible after sampling. Determine base number every 25 h, including EOT, in accordance with Test Method D4739. Determine acid number every 25 h, including EOT, in accordance with Test Method D664. Determine oxidation using integrated IR every 25 h, including EOT. Report all results on the appropriate form.

10.4 *Fuel Inspections*:

10.4.1 Use fuel purchase inspection records to ensure conformance to the specifications (see 7.2.1) and to complete the appropriate form for the last batch of fuel used during the test. In addition, perform the following inspections on new (0 h) and EOT (300 h) fuel samples:

10.4.1.1 API gravity at 15.6°C [60°F], Test Method D287 or D4052.

10.4.1.2 Total Sulfur, % Weight, Test Method D129 or D2622.

10.4.1.3 Use one 1-L [1-qt] sample for inspections.

10.5 *Oil Consumption Calculation* :

10.5.1 Using the 6-min oil weight measurements (see 9.7), determine the oil consumption in g/h by performing linear regression on the data for each of the nine 25-h periods from 75 to 300 h. The oil consumption for a 25-h period is the slope of the regression line for that same period. The reported oil consumption is the average of the nine results.

10.5.1.1 Following any shutdowns, oil samples, oil additions, or phase transitions, exclude 1 h of oil weight data from the regression to account for the stabilizing of the oil scale.

10.5.1.2 If any shutdowns occur during a 25-h period, the result for that 25-h period shall be the weighted average of all the regression slope that apply to that period. The weighting of a regression slopes is the length of run time associated with it. An example with two shutdowns, one at 84 h and one at 93.5 h are shown in Table 4.

10.5.1.3 Report the average oil consumption for the test on the appropriate form.

11. Laboratory and Engine Test Stand Calibration/Non-Reference Oil Test Requirements

11.1 *Calibration Frequency*:

TABLE 4 25-h Period Oil Consumption Sample Calculation

Oil Scale Data	Time Start (hh:mm)	Time Stop (hh:mm)	Run Time	Regression Slope (g/h)
Stabilizing	75:00	76:00	1:00	n/a
Collecting	76:00	84:00	8:00	40.0
Stabilizing	84:00	85:00	1:00	n/a
Collecting	85:00	93:30	8:30	45.0
Stabilizing	93:30	94:30	1:00	n/a
Collecting	94:30	100:00	5:30	48.5
Oil consumption 75-100 h = [(8 x 40.0) + (8.5 x 45.0) + (5.5 x 48.5)] / 22 = 44.1 g/h				

11.1.1 To maintain test consistency and severity levels, calibrate the engine and test stand at regular intervals.

11.2 *Calibration Reference Oils:*

11.2.1 The reference oils used to calibrate T-10 test stands have been formulated or selected to represent specific chemical types or performance levels, or both. They can be obtained from the TMC. The TMC will assign reference oils for calibration tests. These oils are supplied under code numbers (blind reference oils).

11.2.2 *Reference Oils Analysis:*

11.2.2.1 Do not submit reference oils to physical or chemical analyses for identification purposes. Identifying the oils by analyses could undermine the confidentiality required to operate an effective blind reference oil system. Therefore, reference oils are supplied with the explicit understanding that they will not be subjected to analyses other than those specified within this procedure unless specifically authorized by the TMC. In such cases where analyses are authorized, supply written confirmation of the circumstances involved, the data obtained, and the name of the person authorizing the analysis to the TMC.

11.3 *Test Numbering:*

11.3.1 Number each T-10 test to identify the test stand number, the test stand run number, engine serial number, and engine hours at the start of the test. The sequential stand run number remains unchanged for reruns of aborted, invalid, or unacceptable calibration tests. However, follow the sequential stand run number by the letter A for the first rerun, B for the second, and so forth. For calibration tests, engine hours shall be zero. For non-reference oil tests, engine hours are the test hours accumulated since last calibration. For example, 58-12A-2H0380-0 defines a test on stand 58 and stand run 12 as a calibration test that was run twice on engine 2H0380 (serial number). A test number of 58-14-2H0380-300 defines a test on stand 58 and stand run 14 as a non-reference oil test on engine 2H0380, which has run 300 hours since the last reference.

11.4 *New Laboratories and New Test Stands:*

11.4.1 A new laboratory is any laboratory that has never previously calibrated a test stand under this test method, or has not calibrated a test stand within one year from the end of the last successful calibration test. All stands at a new laboratory are considered new stands.

11.4.2 A new stand is a test cell and support hardware, which has never previously been calibrated under this test method, or has not been calibrated within a year from the end of the last successful calibration test on that stand.

11.4.2.1 A new complete engine with EGR kit requires a successful calibration test.

11.4.3 Calibrate a new test stand in accordance with the Lubricant Test Monitoring System (LTMS).⁵

11.5 *Test Stand Calibration:*

11.5.1 *Test Stand Calibration*—Perform a calibration test on a reference oil assigned by the TMC after six months have elapsed since the completion of the last successful calibration test. A non-reference test may be started provided at least 1 h remains in the calibration period. An unsuccessful calibration test voids any current calibration on the test stand.

11.5.2 *Test Stand/Engine Combination*—For reference and non-reference tests, any engine may be used in any stand. However, the engines shall be used in the test stands on a first available engine basis (FIFO). In other words, there shall be no attempt on the part of the test laboratory to match a particular test stand and engine combination for any given test.

11.5.2.1 A new complete engine setup with EGR kit requires a calibration test.

11.5.3 If non-standard tests are conducted on a calibrated test stand, the TMC may require the test stand to be recalibrated prior to running standard tests.

11.6 *Test Results*—The reference oil test specified test results are average top ring weight loss [mg], average cylinder liner wear [µm], Δlead [mass ppm] at EOT, Δlead [mass ppm] 250 to 300 h, and average oil consumption (g/h). The non-reference oil test specified test result is the Mack Merit Rating.

11.6.1 *Average Top Ring Weight Loss*—Screen the data for outliers in accordance with Annex A9. Calculate the average top ring weight loss, excluding any outliers, and report the data on the appropriate forms.

11.6.2 *Average Cylinder Liner Wear*—Screen the data for outliers in accordance with Annex A9. Calculate the average cylinder liner wear step, excluding any outliers, and report the data on the appropriate forms.

11.6.3 *ΔLead at EOT*—Δ Lead at EOT results are adjusted to account for any upper rod bearing weight loss outliers.

11.6.3.1 Calculate the measured average upper rod bearing weight loss and report the value on the appropriate form.

11.6.3.2 Use Practice E178, two-sided test at a 95 % significance level, to determine if any rod bearing weight loss values are outliers. Report the outlier screened average upper rod bearing weight loss on the appropriate form. If no outliers were identified, this value will be identical to the measured value calculated in 11.6.3.1.

11.6.3.3 For connecting rod bearing batch codes A through G, calculate Δlead according to the following:

$$\Delta lead = (lead_{300} - lead_{NEW}) \times (OABWLU / ABWLU) \quad (2)$$

where:

$lead_{300}$ = lead content of the 300 h oil sample, ppm,

$lead_{NEW}$ = lead content of the new oil sample, ppm,

$ABWLU$ = as measured upper rod bearing weight loss, mg, and

$OABWLU$ = outlier screened upper rod bearing weight loss, mg.

Report the calculated Δlead at EOT value on the appropriate forms.

11.6.3.4 For connecting rod bearing batch code J, calculate Δlead according to the following: