Designation: D7422 – 17a

Standard Test Method for Evaluation of Diesel Engine Oils in T-12 Exhaust Gas Recirculation Diesel Engine[1]

This standard is issued under the fixed designation D7422; 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 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 in an engine equipped with exhaust gas recirculation and running on ultra-low sulfur diesel fuel.[2] This test method is commonly referred to as the Mack T-12.

1.1.1 This test method also provides the procedure for running an abbreviated length test, which is commonly referred to as the T-12A. The procedures for the T-12 and T-12A are identical with the exception of the items specifically listed in Annex A9. Additionally, the procedure modifications listed in Annex A9 refer to the corresponding section of the T-12 procedure.

1.2 The values stated in SI units are to be regarded as standard. No other units of measurement are included in this standard.

1.2.1 *Exception*—Where there is no direct SI equivalent, such as the units for screw threads, National Pipe Threads/diameters, tubing size, and single source supply equipment specifications.

1.3 *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, health, and environmental practices and determine the applicability of regulatory limitations prior to use.* See Annex A6 for specific safety precautions.

1.4 *This international standard was developed in accordance with internationally recognized principles on standardization established in the Decision on Principles for the Development of International Standards, Guides and Recommendations issued by the World Trade Organization Technical Barriers to Trade (TBT) Committee.*

2. Referenced Documents

2.1 *ASTM Standards:*[3]

D86 Test Method for Distillation of Petroleum Products and Liquid Fuels at Atmospheric Pressure
D93 Test Methods for Flash Point by Pensky-Martens Closed Cup Tester
D97 Test Method for Pour Point of Petroleum Products
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 and Liquid Fuels
D2622 Test Method for Sulfur in Petroleum Products by Wavelength Dispersive X-ray Fluorescence Spectrometry
D2709 Test Method for Water and Sediment in Middle Distillate Fuels by Centrifuge

[1] This test method is under the jurisdiction of ASTM Committee D02 on Petroleum Products, Liquid Fuels, and Lubricants and is the direct responsibility of Subcommittee D02.B0 on Automotive Lubricants.

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[2] The ASTM Test Monitoring Center will update changes in this test method by means of Information Letters. Information letters may be obtained from the ASTM Test Monitoring Center, 6555 Penn Avenue, Pittsburgh, PA 15206-4489, Attention: Administrator. This edition incorporates revisions in all Information Letters through No. 17-1.

[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.

***A Summary of Changes section appears at the end of this standard**

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
D4175 Terminology Relating to Petroleum Products, Liquid Fuels, and Lubricants
D4294 Test Method for Sulfur in Petroleum and Petroleum Products by Energy Dispersive X-ray Fluorescence Spectrometry
D4485 Specification for Performance of Active API Service Category Engine Oils
D4739 Test Method for Base Number Determination by Potentiometric Hydrochloric Acid Titration
D5185 Test Method for Multielement Determination of Used and Unused Lubricating Oils and 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
D5453 Test Method for Determination of Total Sulfur in Light Hydrocarbons, Spark Ignition Engine Fuel, Diesel Engine Fuel, and Engine Oil by Ultraviolet Fluorescence
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)
D6896 Test Method for Determination of Yield Stress and Apparent Viscosity of Used Engine Oils at Low Temperature
E29 Practice for Using Significant Digits in Test Data to Determine Conformance with Specifications
E178 Practice for Dealing With Outlying Observations

2.2 *National Archives and Records Administration:*[4]
Code of Federal Regulations Title 40 Part 86.310-79

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.

3.1.1.1 *Discussion*—This is a coded reference oil that is submitted by a source independent from the test facility. **D4175**

3.1.2 *blowby, n—in internal combustion engines*, that portion of the combustion products and unburned air/fuel mixture that leaks past piston rings into the engine crankcase during operation.

3.1.3 *calibrate, v*—to determine the indication or output of a device (for example, thermometer, manometer, engine) with respect to that of a standard.

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. **D4175**

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). **D4175**

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. **D4175**

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

3.1.8 *non-reference oil, n*—any oil other than a reference oil; such as a research formulation, commercial oil or candidate oil. **D4175**

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. **D4175**

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

3.1.11 *reference oil, n*—an oil of known performance characteristics, 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. **D4175**

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. **D4175**

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

3.1.14 *test parameter, n*—a specified component, property, or condition of a test procedure.

3.1.14.1 *Discussion*—Examples of *components* are fuel, lubricant, reagent, cleaner, and sealer; of *properties* are density, temperature, humidity, pressure, and viscosity; and of *conditions* are flow rate, time, speed, volume, length, and power. **D4175**

3.1.15 *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. **D4175**

3.1.16 *wear, n*—the loss of material from a surface, generally occurring between two surfaces in relative motion, and resulting from mechanical or chemical action or a combination of both. **D4175**

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

[4] Available from U.S. Government Printing Office Superintendent of Documents, 732 N. Capitol St., NW, Mail Stop: SDE, Washington, DC 20401, http://www.access.gpo.gov.

(EGR). A warm-up and a 1 h break-in are followed by a two-phase test consisting of 100 h at 1800 r/min and 200 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, 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 the engine crankcase and replace worn or defective parts.

4.5 Equip the test stand with appropriate accessories for controlling speed, torque, 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 and running on ultra-low sulfur diesel fuel. Obtain results from used oil analysis and component measurements before and after 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, using 2002 cylinder heads, 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 mm by 165 mm, and the displacement is 12 L.

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 *Test Engine:*

6.2.1 *Mack T-12 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.

6.2.2 *Engine Cooling System:*

6.2.2.1 Use a new Mack coolant conditioner shown in Table A2.1, every test, to limit scaling in the cooling system. Pressurize the system at the expansion tank to 103 kPa. Use the coolant described 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 observe and prevent localized boiling. Block the thermostat wide open.

6.2.2.3 Use a closed-loop, pressurized external EGR cooling system composed of a nonferrous core heat exchanger, reservoir, and coolant-out temperature control valve. The system shall prevent air entrainment and control jacket temperatures within the specified limit. Install a sight glass between the EGR coolers and the cooling tower to check for air entrainment and uniform flow in an effort to observe and prevent localized boiling. The coolant flow direction is to be parallel (concurrent) with the EGR gas flow. Every reasonable attempt should be made to ensure that the EGR temperatures leaving the coolers are very similar. Fig. A1.3 shows the coolant flow to and from the EGR coolers, respectively.

6.2.3 *Auxiliary Oil System:*

6.2.3.1 To maintain a constant oil level in the pan, provide an additional 9.5 L sump by using a separate closed tank connected to the sump. Circulate oil through the tank with an auxiliary pump. The system schematic is shown in Fig. A1.1. The supply line to the tank from the sump is to have an inside diameter of 13 mm. The return line from the tank to the sump is to have an inside diameter of 10 mm. Use a vent line with a minimum inside diameter of 13 mm.

6.2.3.2 Locate the auxiliary oil system suction line on the exhaust side of the oil pan, down from the oil pan rail 127 mm, and back from the front of the pan 178 mm. 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.

6.2.3.3 Use Viking Pump Model SG053514 as the auxiliary oil pumps. Pump speed is specified as 1725 r/min.[5]

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 A2.6.

6.2.4.2 Use the oil filter housing (part number 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, ensure the blowby line has a downward slope to a collection bucket. Ensure the collection bucket has a minimum volume of 18.9 L. 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. Replace filter cartridge when ΔP of 2.5 kPa is reached. Install an adjustable valve (flapper) in the inlet air system at least two pipe diameters before any temperature, pressure and humidity

[5] The sole source of supply of the apparatus known to the committee at this time is Viking Pump, Inc., a unit of IDEX Corporation, 406 State Street, 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,[1] which you may attend.

measurement devices. Use the valve to maintain inlet air restriction within required specifications.

6.2.7 *Fuel Supply*—Heating, 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 stainless steel intake manifolds (P/N M10105GCX4332RSS for front manifold, M10105GCX5212RSS for rear manifold) available from the supplier listed in A2.2. Use an intercooler suited to control intake manifold temperature to the setpoint specified in Table 1. To minimize potential intake air condensation keep the intercooler out temperature above 30 °C at all times of engine operation.

6.2.9 *Injection Timing Control*—Remove the engine intake manifold temperature sensor. Use the intake manifold temperature to control injection timing in accordance with the Temperature to Injection Timing Correlation shown in Annex A4.

6.2.10 *Oil Pump*—Use a Mack P/N 315GC465BM oil pump. The oil pump is available from the supplier listed in A2.2.

6.2.11 *EGR Venturi Unit*—Use a stainless steel EGR venturi unit, P/N 762GBX433SS, available from the supplier listed in A2.2.

6.2.12 *Fuel Pressure Regulator*—Use a P/N 691GC227M2 fuel pressure regulator.

6.2.13 *Engine Control Module (ECM)*—To avoid an ECM fault code, it may be necessary to replace the engine ECM sensors for Coolant Out and Fuel In temperatures with fixed resistances that are equivalent to the Phase I set points (refer to Table 1).

7. Engine Fluids

7.1 *Test Oil*—Approximately 151 L of test oil are required for the test.

7.2 *Test Fuel*—Obtain the ultra-low sulfur diesel (ULSD) test fuel from Chevron Phillips Chemical Company LP.[6] The required fuel properties and tolerances are shown in Table 2.

7.3 *Coolant:*

7.3.1 For the engine coolant, use demineralized water with salt content less than 0.03 g/L or distilled water (do not use antifreeze solutions). Use Pencool 3000 coolant additive at the

[6] The sole source of supply for test fuel known to the committee at this time is Ultra-Low Sulfur Diesel Fuel from Chevron Phillips Chemical Company LP, 10001 Six Pines Dr., Suit 4036B, The Woodlands, TX 77387–4910, Ph. 832–813–4859, Fax: 832–813–4907, Email: fuels@cpchem.com. 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,[1] which you may attend.

TABLE 1 Test Conditions

Parameters	Limits	
	Phase I	Phase II
Time, h	100	200
Injection Timing, °BTDC	Variable	21
Controlled Parameters^A		
Speed, r/min	1800	1200
Fuel Flow, kg/h	59.2	63.5
Intake CO_2 Level, %	3.09 ± 0.05	1.42 ± 0.05
Exhaust CO_2 Level, %	9.10–9.40	9.78–10.08 typical
Inlet Manifold Temp., °C	90	80
Coolant Out Temp., °C	66	108
Fuel In Temp., °C	40	40
Oil Gallery Temp., °C	88	116
Intake Air Temp., °C	25	25
Ranged Parameters^B		
Inlet Air Restriction, kPa	3.5–4.0	3.5 - 4.0
Inlet Manifold Pressure, kPa	266 nominal	302–312
Exhaust Back Pressure, kPa	2.7–3.5	2.7–3.5
Crankcase Pressure, kPa	0.25–0.75	0.25–0.75
Uncontrolled Parameters		
Torque, N·m^C	Record	Record
Exhaust Temp., °C		
Pre-turbine	Record	Record
Tailpipe	Record	Record
Oil Sump Temp., °C	Record	Record
Coolant In Temp., °C	Record	Record
EGR Pre-Venturi Temp., °C	Minimum 104	Minimum 104
Intercooler Out Temp., °C	Minimum 30	Minimum 30
Inlet Air Dew Point, °C	Record	Record
Inlet Air Humidity, g/kg	Record	Record
Blowby, L/min	Record	Record
EGR Pre-Venturi Pressure, kPa	Record	Record
Pre-turbine Exhaust Pressure, kPa	Record	Record
Main Gallery Oil Pressure, kPa	Record	Record
Oil Filter ΔP, kPa	Not to exceed 138^D	Not to exceed 138^D

^{A} All control parameters shall be targeted at the mean indicated.
^{B} All ranged parameters shall fall within the specified ranges.
^{C} At 98.2 kPa and 29.5 °C dry air.
^{D} If oil filter ΔP exceeds 138 kPa, 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.

TABLE 2 ULSD Fuel Specification

Property	Specification	Test Method
Additives	Lubricity additive only	...
Distillation Range, °C, 90 %	293–332	ASTM D86
Specific Gravity	0.840–0.855	ASTM D4052
API Gravity	34–37	ASTM D4052
Corrosion, 3 h at 50 °C	1 max	ASTM D130
Sulfur, g/kg	7–15	ASTM D5453 or equivalent
Flash Point, °C	54 min	ASTM D93
Pour Point, °C	–18 max	ASTM D97
Cloud Point, °C	Report	ASTM D2500
Viscosity at 40 °C, mm^2/s	2.0–2.6	ASTM D445
Ash, mass fraction %	0.005 max	ASTM D482
Carbon Residue on 10 % Bottoms	0.35 max	ASTM D524
Net Heat of Combustion	Report	ASTM D3338
Water and Sediment, volume %	0.05 max	ASTM D2709
Total Acid Number	0.05 max	ASTM D664
Strong Acid Number	0 max	ASTM D664
Cetane Index	Report	ASTM D976
Cetane Number	43–47	ASTM D613
Accelerated Stability, mg/100 mL	1.5 max	ASTM D2274
Composition		
Aromatics, mass fraction %	26–31.5	ASTM D5186
Olefins, vol %	Report	ASTM D1319
Saturates, vol %	Report	ASTM D1319
Lubricity, g	3100 min[A]	ASTM D6078[A]

[A] May be altered to be consistent with California Air Resources Board (CARB) or ASTM diesel fuel specifications.

manufacturer's recommended rate. Pencool 3000 may be obtained from the supplier shown in A2.7.

7.3.2 The EGR coolant is not specified and is at the discretion of the lab.

7.4 *Cleaning Materials:*

7.4.1 For cleaning engine parts, use only mineral spirits (solvent) meeting the requirements in Specification D235, Type II, Class C for Aromatic Content (0 to 2 vol %), Flash Point (142 °C, min) and Color (not darker that +25 on Saybolt Scale or 25 on Pt-Co Scale), refer to A2.5. (**Warning—**Combustible. Health hazard.) Obtain a Certificate of Analysis for each batch of solvent from the supplier.

7.4.2 Pentane. (**Warning—**Flammable. Health hazard.)

8. Preparation of Apparatus at Rebuild

8.1 *Cleaning of Parts:*

8.1.1 *Engine Block*—Thoroughly spray the engine with solvent to remove any oil remaining from the previous test and air-dry. Follow the optional use of an engine parts washer by a solvent wash.

8.1.2 *Rocker Covers and Oil Pan*—Remove all sludge, varnish and oil deposits. Rinse with solvent and air-dry. Follow the optional use of an engine parts washer by a solvent wash.

8.1.3 *Auxiliary Oil System*—Flush all oil lines, galleries and external oil reservoirs with solvent 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 with solvent to remove any previous test oil and then air-dry. Follow the optional use of an engine parts washer by a solvent wash.

8.1.5 *Cylinder Head*—Clean the cylinder heads using a wire brush to remove deposits and rinse with solvent to remove any sludge and oil and then air-dry. Follow the optional use of an engine parts washer by a solvent wash.

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

8.1.7 *EGR Coolers*—Replacing or cleaning of the EGR coolers is at the test laboratory's discretion. An example of a successful cleaning method is available from the Test Monitoring Center (TMC).

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

8.2 *Valves, Seats, Guides, and Springs:*

8.2.1 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.

8.2.2 Use honing and cutting oil when reaming the valve guides. Hone finish if desired. Valve stem-to-guide clearance shall be 0.038 mm to 0.089 mm for intake valves and 0.064 mm to 0.114 mm for exhaust valves.

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 using the procedure outlined in the Mack Service Manual.[7]

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

8.4 *Injectors and Injection Pumps:*

8.4.1 *Injectors*—Injector nozzles are available from the supplier shown in A2.2. Check the injector opening pressure at

[7] Mack Service Manuals are available from local Mack Trucks, Inc. distributors.

the start of each calibration period. Reset the injector opening pressure if it is outside the specification of 24 000 kPa ± 2000 kPa.

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. An exception, for example, is approval of a temporary parts supply problem by the TMC, and noting this approval 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 Oil for lubricating parts during assembly; see A2.9.

8.5.1.1 *Thermostat*—Block the thermostat wide open.

8.5.1.2 *Connecting Rod Bearings*—Install new connecting rod bearings for each test. See 10.1 for recording pre-test measurements.

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

8.5.1.4 *Piston Undercrown Cooling Nozzles*—Particular care shall be taken in assembling the piston undercrown cooling nozzles to insure proper piston cooling (as outlined in the Mack Service Manual).

NOTE 1—Proper oil pressure is also important to assure 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 re-build, 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.

8.5.2.13 Thrust washers.

8.6 *Measurements:*

8.6.1 *Calibrations*—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 readout 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.

8.6.2 *Temperatures:*

8.6.2.1 *General*—Measure temperatures with thermocouples and conventional readout equipment or equivalent. For temperatures in the 0 °C to 150 °C range, calibrate temperature measuring systems to ±0.5 °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 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 it in the center of the water stream. Refer to Fig. A1.6. Locate the coolant-in thermocouple anywhere between the heat exchanger and the coolant pump inlet, as shown in 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. Refer to Fig. A1.8.

8.6.2.5 *Oil Sump Temperature*—Using a front sump oil pan configuration, locate a thermocouple on the exhaust side of the oil pan, from the front of the pan 178 mm and from the top of the pan 178 mm. Thermocouple length shall be 102 mm. Refer to Fig. A1.4.

8.6.2.6 *Intake Air Temperature*—Locate the intake air thermocouple in the center of the air stream at the turbocharger inlet as shown in Fig. A1.9. The temperature thermocouple is to be upstream of the compressor inlet connection approximately 102 mm. 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 the exhaust manifold section, see Fig. A1.11.

8.6.2.9 *Exhaust Tailpipe*—Locate a thermocouple in the exhaust pipe downstream of the turbocharger 305 mm to 406 mm. Locate the thermocouple downstream of the exhaust back pressure tap, and upstream of the CO_2 probe. Refer to Fig. A1.12.

8.6.2.10 *Intake Manifold*—Locate a thermocouple at the tapped fitting on the 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. The pre-turbine exhaust temperatures may be used instead (refer to 8.6.2.8).

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

8.6.2.13 *EGR Pre-Venturi*—Locate thermocouple as shown in Fig. A1.15. The sensors may be located at a tee fitting. If they are not located at the same tee fitting then locate the EGR Pre-Venturi thermocouple downstream of the pressure sensor.

8.6.2.14 *Intercooler Outlet*—Locate the thermocouple downstream of the cooler outlet and prior to the flow stream split at the intake air bypass.

8.6.2.15 *Additional Temperature Measurements*—Monitor any additional temperatures that the test lab regards as helpful in providing a consistent test procedure.

8.6.3 *Pressures:*

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

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

8.6.3.3 *Pre-Turbine Exhaust*—Locate the pickup in each side of the exhaust manifold section, see Fig. A1.11. This measurement is not mandatory, but it is recommended for diagnostic and safety purposes.

8.6.3.4 *Intake Manifold (Air Boost)*—Take the measurement at the tapped fitting provided on the 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 upstream of the compressor inlet approximately 203 mm (see Fig. A1.9). The probes can be obtained from the supplier shown in A2.10.

8.6.3.6 *Exhaust Back*—Measure exhaust back pressure in a straight section of pipe, downstream of the turbocharger 305 mm to 406 mm, with a pressure tap hole as shown in Fig. A1.12. Do not locate the tap downstream of either the temperature thermocouple or the CO_2 probe.

8.6.3.7 *Crankcase Pressure*—Locate the 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 the pickup within 152 mm of the second compressor.

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

8.6.3.10 *Barometric Pressure*—Locate a barometer in a convenient location in the lab.

8.6.4 *Carbon Dioxide Measurements:*

8.6.4.1 *General*—Calibrate the sensors prior to each measurement taken during the course of the test. The CO_2 levels for the calibration span gases are specified. The Phase I intake span gas shall be 3 % to 4 % CO_2 and the Phase II intake span gas shall be 1.5 % to 2 % CO_2. The exhaust span gas for both phases shall be 10 % to 15 % CO_2. The blend quality for all span gases shall be Primary Standard ±1 %. Saturate the intake and exhaust CO_2 samples at 4 °C to 5 °C.

8.6.4.2 *Intake Carbon Dioxide Probe*—Measure intake CO_2. Locate the probe as shown in Fig. A1.8. Use a 6.4 mm probe that meets the Code of Federal Regulations, Title 40 Part 86.310-79. The probe diameter is not to exceed the sample line diameter.

8.6.4.3 *Exhaust Carbon Dioxide Probe*—Measure the exhaust CO_2. Locate the probe 355 mm to 432 mm downstream of the turbocharger. Locate the probe downstream of both the temperature thermocouple and exhaust back pressure tap. Use a 6.4 mm probe that meets the Code of Federal Regulations, Title 40 Part 86.310-79. The probe diameter is not to exceed the sample line diameter. Refer to Fig. A1.12.

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

8.6.6 *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.*

8.6.7 *Humidity*—Place the measurement equipment downstream of any air conditioning and in such a manner as not to affect intake air temperature and pressure measurements.

8.6.8 *System Time Responses*—The maximum allowable system time responses are shown in Table 3. Determine system time responses in accordance with the Data Acquisition and Control Automation II (DACA II) Task Force Report.[8]

9. Procedure

9.1 *Pretest Procedure:*

9.1.1 *Initial Oil Fill for Pretest Break-In*—The initial oil fill is 32.7 kg of test oil. Add the first 3.3 kg 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 of test oil to the engine. This oil can 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 A5.

9.1.2.2 Drain the oil after the break-in is completed within 1 h. 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*—Perform all engine start-ups in accordance with Annex A5. 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 1. 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 A5. 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 ten shutdowns. Additionally, all operationally valid tests should not exceed downtime of 150 h. Conduct an engineering review if either condition is exceeded.

9.4 *Test Cycle:*

[8] The Data Acquisition and Control Automation II Task Force Report may be obtained from the ASTM Test Monitoring Center, 6555 Penn Avenue, Pittsburgh, PA 15206-4489, Attention: Administrator.

TABLE 3 Maximum Allowable System Time Responses

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

9.4.1 The test cycle includes a 1 h break-in followed by a 300 h test. Operating conditions are shown in Table 1. 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 100 h at Phase I conditions, followed by 200 h at Phase II conditions. Conduct the transition from Phase I to Phase II in accordance with Annex A5.

9.4.1.1 Based upon oil analysis, injection timing may be changed within the first 100 h of the test (Phase I) to ensure meeting the soot window of 4.30 % ± 0.30 % at 100 h, refer to 11.7.

9.4.2 *Operational Validity*—Determine operational validity in accordance with Annex A3.

9.5 *Oil Samples*—Take 120 mL oil samples at every 25 h interval. Take the EOT oil sample within 30 min of test completion. Always take oil samples before new oil is added. Obtain oil samples from the pre-filter pressure port, refer to Fig. A1.16. This can be done by installing a tee fitting, a small petcock valve and No. 4 Aeroquip line of length 254 mm to 305 mm, from which the sample is taken. Prior to each sample, take a 240 mL purge. After sample completion, be sure to return the purge to the engine.

9.6 *Oil Addition and Drain:*

9.6.1 Initially establish the Phase I full mark as the oil mass after running at Phase I test conditions for 4 h, but *do not* add any new oil until 100 test hours (Phase II). Before transitioning to Phase II record the oil mass. Drain a sufficient amount of oil to obtain an oil mass which is below the Phase I full mark by 2.27 kg, and add 2.27 kg of new oil to the engine. If the oil mass is already more than 2.27 kg below the full mark, do not perform a forced drain.

9.6.1.1 Establish the Phase II full mark at 104 h. Starting at 150 h and each 50 h period thereafter, drain a sufficient amount of oil to obtain an oil mass which is below the full mark by 2.27 kg, and add 2.27 kg of new oil to the engine. For any 50 h period, if the oil mass is already below the full mark by more than 2.27 kg, do not perform a forced drain.

9.7 *Oil Mass Measurements*—Record the oil mass every 6 min and compute the oil consumption (refer to 10.5) from these readings.

NOTE 2—Experience has shown that a sudden and sharp increase in oil consumption may indicate an oil leak in the turbochargers and may necessitate a change of turbochargers.

9.8 *Fuel Samples*—Take one 120 mL fuel sample at SOT 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 4. 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.

9.9.2.3 Oil Gallery Temperature, °C.

9.9.2.4 Oil Sump Temperature, °C.

9.9.2.5 Coolant Out Temperature, °C.

9.9.2.6 Coolant In Temperature, °C.

9.9.2.7 Intake Air Temperature, °C.

9.9.2.8 Intake Manifold Temperature, °C.

9.9.2.9 Intake Manifold Pressure, kPa.

9.9.2.10 Fuel Flow, kg/h.

9.9.2.11 Fuel Inlet Temperature, °C.

9.9.2.12 Tailpipe Exhaust Back Pressure, kPa.

9.9.2.13 Before Filter Oil Pressure, kPa.

9.9.2.14 Main Gallery Oil Pressure, kPa.

9.9.2.15 Crankcase Pressure, kPa.

9.9.2.16 Pre-Turbine Exhaust Temperature, Front Manifold, °C.

9.9.2.17 Pre-Turbine Exhaust Temperature, Rear Manifold, °C.

9.9.2.18 Inlet Air Restriction, kPa.

9.9.2.19 Tailpipe Exhaust Temperature, °C.

9.9.2.20 Crankcase Blowby, L/min (see 9.10).

9.9.2.21 Pre-Turbine Exhaust Pressure, Front Manifold, kPa.

9.9.2.22 Pre-Turbine Exhaust Pressure, Rear Manifold, kPa.

9.9.2.23 Inlet Air Humidity, g/kg.

9.9.2.24 EGR Cooler Outlet Temperature, °C.

9.9.2.25 EGR Pre-Venturi Temperature, °C.

9.9.2.26 Inlet Air Dew Point, °C.

9.9.2.27 Oil Mass, kg.

9.9.2.28 Intercooler Outlet Temperature, °C.

9.10 *Blowby*—Record the crankcase blowby on the appropriate form. Take care to prevent oil traps from occurring in the blowby line at any time during operation.

9.11 *Centrifugal Oil Filter Mass Gain*—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

TABLE 4 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 N•m	Intake and Exhaust CO_2	0.01 %
Power	1 kW	Oil Mass	0.001 kg
Humidity	0.1 g/kg	...	...

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:

$$\Delta P = \Delta Pmax - \Delta Pinitial \quad (1)$$

where:

ΔPmax	=	maximum ΔP across the oil filter, and
ΔPinitial	=	ΔP across the oil filter at the start of test conditions.

9.12.2 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. Report oil filter ΔP on the appropriate form.

9.13 *Carbon Dioxide*—Measure and record intake and exhaust CO_2 levels every 4 h.

10. Inspection of Engine, Fuel, and Oil

10.1 *Pre-Test Measurements:*

10.1.1 *Pistons*—No piston measurements are required.

10.1.2 *Cylinder Sleeves Inside Diameter Surface Finish*—Measurement is to be an average of four readings, taken at 90° intervals over an axial trace length of 12.7 mm, beginning from the top of the sleeve at 6.35 mm, and extending from the top of the sleeve to 19.1 mm. Identify these trace locations as 12 o'clock (12:00), 3 o'clock (3:00), 6 o'clock (6:00), and 9 o'clock (9:00). For reference, locate 12:00 towards the front of engine. Designate the cylinder number equivalent permanent mark on the water jacket portion of the sleeve's outside diameter.

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

10.1.4 *Connecting Rod Bearings:*

10.1.4.1 Prior to measuring, mark bearings with a single digit on the locating tang to identify cylinder location.

10.1.4.2 Clean the bearings with solvent (see 7.4.1). Use a soft brush if necessary. Air-dry the bearings. Rinse in pentane. Do not handle bearings with bare hands. Use gloves or plastic covered tongs.

10.1.4.3 Weigh bearings on a scale capable of a resolution of 1 mg.

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*.

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

10.2.4 *Connecting Rod Bearings:*

10.2.4.1 Clean the bearings with solvent (see 7.4.1). Use a soft brush if necessary. Air-dry the bearings. Rinse in pentane. Do not handle bearings with bare hands. Use gloves or plastic covered tongs.

10.2.4.2 Weigh bearings on a scale capable of a resolution of 1 mg.

10.3 *Oil Inspection*—Perform all oil analyses listed in 10.3.1 – 10.3.7. Report all results.

10.3.1 *Viscosity*—Analyze oil samples for viscosity at 100 °C in accordance with Test Method D445 or Test Method D5967, Annex A3. Base viscosity increase on the minimum viscosity.

10.3.2 *Soot*—Conduct soot analysis in accordance with Test Method D5967, Annex A4. Conduct the 100 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.

10.3.3 *Metals*—Determine wear metals content (iron, lead, copper, chromium, aluminum, nickel), 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.

10.3.4 *Base Number*—Determine base number every 25 h, including EOT, in accordance with Test Method D4739.

10.3.5 *Acid Number*—Determine acid number every 25 h, including EOT, in accordance with Test Method D664.

10.3.6 *Oxidation*—Determine oxidation using both integrated IR (IR measurement techniques are available from the TMC) and peak height IR every 25 h, including EOT.

10.3.7 *MRV Viscosity*—For the 100 h oil sample, determine MRV viscosity at −20 °C in accordance with Test Method D6896. As part of the MRV measurement procedure, be sure to prepare the sample in accordance with A4.3, Annex A4 of Test Method D5967. The maximum reported result is 400 000 cP, and use this value if the results are too viscous to measure.

10.4 *Fuel Inspections:*

10.4.1 Use fuel purchase inspection records to ensure conformance to the specifications listed in Table 2 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, Test Method D287 or D4052.

10.4.1.2 Total Sulfur, mg/kg, Test Method D5453 (D2622 or D4294 can be substituted). Use one 120 mL sample for inspections.

10.5 *Oil Consumption Calculation:*

10.5.1 Using the 6 min oil mass measurements taken at 6 min intervals (see 9.7), determine the oil consumption in grams per hour by performing linear regression on the data for each of the eight 25 h periods from 100 h to 300 h, or when the auxiliary oil sump runs dry. The auxiliary oil sump is considered to have run dry when the oil mass curve shows a significant flattening which indicates that the oil mass is no longer decreasing. The oil consumption for a 25 h period is the slope of the regression line for that same period. Report the oil consumption as the average of the results for the periods before the auxiliary oil sump went dry.

10.5.1.1 Following any shutdowns, oil samples, oil additions, or phase transitions exclude from the regression 1 h of oil mass data 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 slopes 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 109 h and one at 118.5 h is shown in Table 5.

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

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

11.1 *Calibration Frequency*—To maintain test consistency and severity levels, calibrate the test stand at regular intervals.

11.2 *Calibration Reference Oils:*

11.2.1 The reference oils used to calibrate T-12 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 assigns reference oils for calibration tests. These oils are supplied under code numbers (blind reference oils).

11.2.2 *Reference Oils Analysis*—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*—Number each T-12 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 lab is any lab that has never previously calibrated a test stand under this test method.

11.4.2 A new stand is a test cell and support hardware which has never previously been calibrated under this test method.

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).[9]

11.5 *Test Stand Calibration:*

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

11.5.2 *Test Stand and Engine Combination*—For reference and non-reference tests, any engine may be used in any stand. However, use the engines 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.

11.5.3 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:*

11.6.1 The specified measurements for reference oil tests are average top ring weight loss in milligrams, average cylinder liner wear in micrometres, ΔLead at EOT in milligrams per kilogram, ΔLead in milligrams per kilogram 250 h to 300 h, and average oil consumption in grams per hour. The specified measurements for non-reference oil tests are included in the Mack Merit Rating system as shown in Annex A8.

11.6.2 *Average Top Ring Mass Loss*—Screen the data for outliers in accordance with Annex A7. Calculate the average top ring mass loss, excluding any outliers, and report the data on the appropriate forms.

11.6.2.1 *Correction Factor for Average Top Ring Mass Loss:*

(1) For all tests using the STWN hardware combination that completed on or before May 18, 2011, multiply the

TABLE 5 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	100:00	101:00	1:00	n/a
Collecting	101:00	109:00	8:00	40.0
Stabilizing	109:00	110:00	1:00	n/a
Collecting	110:00	118:30	8:30	45.0
Stabilizing	118:30	119:30	1:00	n/a
Collecting	119:30	125:00	5:30	48.5

Oil Consumption 100 h to 125 h = [(8 × 40.0) + (8.5 × 45.0) + (5.5 × 48.5)] / 22
= 44.1 g/h

[9] The Lubricant Test Monitoring System may be obtained from the ASTM Test Monitoring Center, 6555 Penn Avenue, Pittsburgh, PA 15206-4489, Attention: Administrator.

average top ring mass loss from 11.6.2 by 0.95 to get the final average top ring mass loss result.

(2) For all tests using the STWN hardware combination that completed on or after May 19, 2011 and started before June 5, 2012, multiply the average top ring mass loss from 11.6.2 by 0.92 to get the final average top ring mass loss result.

(3) For all tests using the STWN hardware combination that started on or after June 5, 2012, multiply the average top ring mass loss from 11.6.2 by 0.705 to get the final average top ring mass loss result.

(4) For all tests using the UUXO hardware combination, multiply the average top ring mass loss from 11.6.2 by 0.849 to get the final average top ring mass loss result.

(5) For all tests using the VUXO hardware combination that started on or after August 27, 2014, multiply the average top ring mass loss from 11.6.2 by 0.719 to get the final average top ring mass loss result.

(6) For all tests using the VUXO hardware combination with batch A or B pistons (VUXOA or VUXOB) that started on or after August 4, 2015, multiply the average top ring mass loss from 11.6.2 by 0.912 to get the final average top ring mass loss result.

(7) For all tests using the VUYP hardware combination with batch A, B, or C pistons (VUYPA, VUYPB, or VUYPC), multiply the average top ring mass loss from 11.6.2 by 0.912 to get the final average top ring mass loss result.

(8) For all tests using the VXYPD hardware combination, multiply the average top ring mass loss from 11.6.2 by 0.846 to get the final average top ring mass loss result

(9) Report the data on the appropriate form.

11.6.3 *Average Cylinder Liner Wear*—Screen the data for outliers in accordance with Annex A7. Calculate the average cylinder liner wear step, excluding any outliers, and report the data on the appropriate forms.

11.6.3.1 *Correction Factor for Average Cylinder Liner Wear:*

(1) For all test using Batch R piston ring and cylinder liner hardware, multiply the average cylinder liner wear from 11.6.3 by 0.58 to get the final average cylinder liner wear result.

(2) For all tests using the STWN hardware combination that completed on or before May 18, 2011, multiply the average cylinder liner wear from 11.6.3 by 0.86 to get the final average cylinder liner wear result.

(3) For all tests using the STWN hardware combination that completed on or after May 19, 2011 and started before June 5, 2012, multiply the average cylinder liner wear from 11.6.3 by 0.83 to get the final average cylinder liner wear result.

(4) For all tests using the SWTN hardware combination that started on or after June 5, 2012, multiply the average cylinder wear from 11.6.3 by 0.946 to get the final average cylinder wear result.

(5) For all tests using the UUXO hardware combination multiply the average cylinder liner wear from 11.6.3 by 0.566 to get the final average cylinder liner wear result.

(6) For all tests using the VUXO hardware combination that started on or after August 27, 2014, multiply the average cylinder liner wear from 11.6.3 by 0.818 to get the final average cylinder liner wear result.

(7) For all tests using the VUXO hardware combination with batch A or B pistons (VUXOA or VUXOB) that started on or after August 4, 2015, multiply the average cylinder liner wear from 11.6.3 by 0.953 to get the final average cylinder liner wear result.

(8) For all tests using the VUYP hardware combination with batch A, B, or C pistons (VUYPA, VUYPB, or VUYPC), multiply the average cylinder liner wear from 11.6.3 by 0.970 to get the final average cylinder liner wear result.

(9) For all tests using the VXYPD hardware combination, determine the final average liner wear result by applying the correction factor of 0.743 according to the following equation:

$$ALW_{Final} = \exp[(\ln \ (ALW) \times 0.743)] \quad (2)$$

where:

ALW_{Final} = final average liner wear, and
ALW = value calculated per 11.6.3.

(10) Report the data on the appropriate form.

11.6.4 *ΔLead at EOT*—ΔLead at EOT results are adjusted to account for any upper connecting rod bearing mass loss outliers.

11.6.4.1 Calculate the measured average upper connecting rod bearing mass loss and report the value on the appropriate form.

11.6.4.2 Use Practice E178, two-sided test at a 95 % significance level, to determine if any connecting rod bearing mass loss values are outliers. Report the outlier screened average upper connecting rod bearing mass loss on the appropriate form. If no outliers were identified, this value will be identical to the measured value calculated in 11.6.4.1.

11.6.4.3 Calculate ΔLead in accordance with the following:

$$\Delta lead = (lead_{300} - lead_{NEW}) \times (OABWLU/ABWLU) \quad (3)$$

where:

$lead_{300}$ = lead content of the 300 h oil sample, mg/kg,
$lead_{NEW}$ = lead content of the new oil sample, mg/kg,
$ABWLU$ = as measured upper connecting rod bearing mass loss, mg, and
$OABWLU$ = outlier screened upper connecting rod bearing mass loss, mg.

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

11.6.4.4 *Correction Factor for ΔLead at EOT:*

(1) For all tests using the STWN hardware combination that completed on or before May 18, 2011, determine the final ΔLead at EOT result by applying the correction factor of 0.95 according to the following equation:

$$\Delta Lead_{Final} = exp[\ (ln(\Delta Lead) \times 0.95)\ ] \quad (4)$$

where:

$\Delta Lead_{Final}$ = final ΔLead at EOT, and

ΔLead = value calculated per Eq 3 (11.6.4.3).

(2) For all tests using the STWN hardware combination that completed on or after May 19, 2011 and started before June 5, 2012, determine the final ΔLead at EOT result by applying the correction factor of 0.92 according to the following equation:

$$\Delta Lead_{Final} = exp[\ (ln(\Delta Lead) \times 0.92)\ ] \quad (5)$$

where:

$\Delta Lead_{Final}$ = final ΔLead at EOT, and
ΔLead = value calculated per Eq 3 (11.6.4.3).

(3) For all tests using the STWN hardware combination that started on or after June 5, 2012, determine the final ΔLead at EOT result by applying the correction factor of 0.923 according to the following equation:

$$\Delta Lead_{Final} = exp[\ (ln(\Delta Lead) \times 0.923)\ ] \quad (6)$$

where:

$\Delta Lead_{Final}$ = final ΔLead at EOT, and
ΔLead = value calculated per Eq 3 (11.6.4.3).

(4) For all tests using the UUXO hardware combination, determine the final ΔLead at EOT result by applying the correction factor of 0.797 according to the following equation:

$$\Delta Lead_{Final} = exp[\ (ln(\Delta Lead) \times 0.797)\ ] \quad (7)$$

where:

$\Delta Lead_{Final}$ = final ΔLead at EOT, and
ΔLead = value calculated per Eq 3 (11.6.4.3).

(5) For all tests using the VUXO hardware combination that started on or after August 27, 2014, determine the final ΔLead at EOT result by applying the correction factor of 0.813 according to the following equation:

$$\Delta Lead_{Final} = exp[\ (ln(\Delta Lead) \times 0.813)\ ] \quad (8)$$

where:

$\Delta Lead_{Final}$ = final ΔLead at EOT, and
ΔLead = value calculated per Eq 3 (11.6.4.3).

(6) For all tests using the VUXO hardware combination with batch A or B pistons (VUXOA or VUXOB) that started on or after August 4, 2015, determine the final ΔLead at EOT result by applying the correction factor of 0.954 according to the following equation:

$$\Delta Lead_{Final} = exp[\ (ln(\Delta Lead) \times 0.954)\ ] \quad (9)$$

where:

$\Delta Lead_{Final}$ = final ΔLead at EOT, and
ΔLead = value calculated per Eq 3 (11.6.4.3).

(7) For all tests starting on or after February 25, 2016 on hardware before batch VXYPD, determine the final ΔLead at EOT result by applying the correction factor calculated according to the following equations:
If $OC_{100\text{-}300}$ >65.0:

$$\Delta Lead_{Final} = exp[\ (ln(\Delta Lead) + (65.0\ -\ OC_{100\text{-}300}) \times 0.03088)\ ] \quad (10)$$

If $OC_{100\text{-}300}$ ≤65.0:

$$\Delta Lead_{Final} = \Delta Lead \quad (11)$$

where:

$\Delta Lead_{Final}$ = final ΔLead at EOT,
ΔLead = value calculated per Eq 3 (11.6.4.3), and
$OC_{100\text{-}300}$ = average oil consumption calculated in 11.6.6.

(8) For all tests run on VXYPD hardware, determine the final ΔLead at EOT result by applying the correction factor calculated according to the following equations:
If $OC_{100\text{-}300}$ >65.0:

$$\Delta Lead_{Final} = \exp[(\ln\ (\Delta Lead) + (65.0\ -\ OC_{100-300}) \times 0.03234)] \quad (12)$$

If $OC_{100\text{-}300}$ ≤65.0:

$$\Delta Lead_{Final} = \Delta Lead \quad (13)$$

where:

$\Delta Lead_{Final}$ = final ΔLead at EOT,
ΔLead = value calculated per Eq 3 (11.6.4.3), and
$OC_{100\text{-}300}$ = average oil consumption calculated in 11.6.6.

(9) Report the data on the appropriate form.

11.6.5 *ΔLead 250 h to 300 h*—Calculate the ΔLead 250 h to 300 h by subtracting the lead value at 250 h from the lead value at 300 h. Report the results on the appropriate forms. Do not adjust the results to account for outlier upper rod bearings.

11.6.5.1 *Correction Factor for ΔLead 250 h to 300 h:*

(1) For all tests using the STWN hardware combination that completed on or before May 18, 2011, determine the final ΔLead 250 h to 300 h result by applying the correction factor of 1.03 according to the following equation:

$$\Delta Lead\,(250\text{-}300)_{Final} = exp[\ (ln(\Delta Lead\ 250\text{-}300) \times 1.03)\ ] \quad (14)$$

where:

$\Delta Lead\ (250\text{-}300)_{Final}$ = final ΔLead 250 h to 300 h, and
ΔLead (250-300) = value calculated per 11.6.5.

(2) For all tests using the STWN hardware combination that completed on or after May 19, 2011 and started before June 5, 2012, determine the final ΔLead 250 h to 300 h result by applying the correction factor of 0.93 according to the following equation:

$$\Delta Lead\,(250\text{-}300)_{Final} = exp[\ (ln(\Delta Lead\ 250\text{-}300) \times 0.93)\ ] \quad (15)$$

where:

$\Delta Lead\ (250\text{-}300)_{Final}$ = final ΔLead 250 h to 300 h, and
ΔLead (250-300) = value calculated per 11.6.5.

(3) For all tests using the STWN hardware combination that started on or after June 5, 2012, determine the final ΔLead 250 h to 300 h result by applying the correction factor of 0.956 according to the following equation:

$$\Delta Lead\,(250\text{-}300)_{Final} = exp[\ (ln(\Delta Lead\ 250\text{-}300) \times 0.956)\ ] \quad (16)$$

where:

$\Delta Lead\ (250\text{-}300)_{Final}$ = final ΔLead 250 h to 300 h, and
ΔLead (250-300) = value calculated per 11.6.5.

(4) For all tests using the UUXO hardware combination, determine the final ΔLead 250 h to 300 h result by applying the correction factor of 0.700 according to the following equation: