



# Standard Test Method for Cummins M11 EGR Test<sup>1</sup>

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## 1. Scope

1.1 This test method is commonly referred to as the Cummins M11 Exhaust Gas Recirculation Test (EGR). The test method defines a heavy-duty diesel engine test procedure conducted under high soot conditions to evaluate oil performance with regard to valve train wear, sludge deposits, and oil filter plugging<sup>2</sup> in an EGR environment.

1.2 The values stated in SI units are to be regarded as the standard. The values given in parentheses are for information only.

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 and health practices and determine the applicability of regulatory limitations prior to use. See Annex A1 for general safety precautions.*

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<sup>1</sup> 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.B0.02 on Heavy Duty Engine Oils.

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<sup>2</sup> 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 contained in all information letters through 03-1.

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|  |           | <b>2. Referenced Documents</b>  |             |
|  |           | 2.1 <i>ASTM Standards</i> : <sup>3</sup>  |             |
|  |           | D86 Test Method for Distillation of Petroleum Products at Atmospheric Pressure  |             |
|  |           | D92 Test Method for Flash and Fire Points by Cleveland Open 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   |             |
|  |           | 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   |             |
|  |           | 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   |             |
|  |           | D2896 Test Method for Base Number of Petroleum Products by Potentiometric Perchloric Acid Titration   |             |
|  |           | 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  |             |
|  |           | D4737 Test Method for Calculated Cetane Index by Four Variable Equation   |             |
|  |           | 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) |             |
|  |           | D5302 Test Method for Evaluation of Automotive Engine Oils for Inhibition of Deposit Formation and Wear in a  |             |

<sup>3</sup> For referenced ASTM standards, visit the ASTM website, [www.astm.org](http://www.astm.org), or contact ASTM Customer Service at [service@astm.org](mailto:service@astm.org). For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

Spark-Ignition Internal Combustion Engine Fueled with Gasoline and Operated Under Low-Temperature, Light-Duty Conditions (Withdrawn 2003)<sup>4</sup>

**D5844** Test Method for Evaluation of Automotive Engine Oils for Inhibition of Rusting (Sequence IID) (Withdrawn 2003)<sup>4</sup>

**D5967** Test Method for Evaluation of Diesel Engine Oils in T-8 Diesel Engine

**D6483** Test Method for Evaluation of Diesel Engine Oils in T-9 Diesel Engine (Withdrawn 2009)<sup>4</sup>

**D6557** Test Method for Evaluation of Rust Preventive Characteristics of Automotive Engine Oils

**E29** Practice for Using Significant Digits in Test Data to Determine Conformance with Specifications

**E344** Terminology Relating to Thermometry and Hydrometry

2.2 *Coordinating Research Council (CRC):*<sup>5</sup>  
**CRC Manual No. 20**

2.3 *National Archives and Records Administration:*<sup>6</sup>  
**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. **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 *heavy-duty, adj*— in internal combustion engine operation, characterized by average speeds, power output, and internal temperatures that are close to the potential maximum. **D4485**

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

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

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

3.1.8 *reference oil, n*—an oil of known performance characteristics used as a basis for comparison. **D4485**

3.1.9 *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**

3.1.10 *test oil, n*—any oil subjected to evaluation in an established procedure. **D6557**

3.1.11 *wear, n*—the loss of material from, or relocation of material on, a surface. **D5302**

3.1.11.1 *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 actions.

#### 3.2 Definitions of Terms Specific to This Standard:

3.2.1 *crosshead, n*—an overhead component, located between the rocker arm and each intake valve and exhaust valve pair, that transfers rocker arm travel to the opening and closing of each valve pair.

3.2.1.1 *Discussion*—Each cylinder has two crossheads, one for each pair of intake valves and exhaust valves.

3.2.2 *de-rate protocols, n*—protocols in the engine control module that cause the engine to reduce power output when certain operating parameters are exceeded.

3.2.3 *exhaust gas recirculation (EGR), n*—a method by which a portion of the engine exhaust is returned to the combustion chambers through the intake system.

3.2.4 *overhead, n*—in internal combustion engines, the components of the valve train located in or above the cylinder head.

3.2.5 *overfuel, v*—to cause the fuel flow to exceed the standard production setting.

3.2.6 *valve train, n*— in internal combustion engines, the series of components, such as valves, crossheads, rocker arms, push rods, and camshaft, that open and close the intake and exhaust valves.

### 4. Summary of Test Method

4.1 This test method uses a Cummins M11 400 diesel engine with a specially modified engine block. Test operation includes a 25-min warm-up, a 2-h break-in, and 300 h in six 50-h stages. During stages A, C, and E, the engine is operated with retarded fuel injection timing and is overfueled to generate excess soot. During stages B, D, and F, the engine is operated at conditions to induce valve train wear.

4.2 Prior to each test, the engine is cleaned and assembled with new cylinder liners, pistons, piston rings, and overhead valve train components. All aspects of the assembly are specified.

4.3 A forced oil drain, an oil sample, and an oil addition, equivalent to an oil consumption of 0.23 g/kW-h, is performed at the end of each 25-h period.

4.4 The test stand is equipped with the appropriate instrumentation to control engine speed, fuel flow, and other operating parameters.

4.5 Oil performance is determined by assessing crosshead wear at 8.5 mass % soot, sludge deposits, and oil filter plugging.

<sup>4</sup> The last approved version of this historical standard is referenced on [www.astm.org](http://www.astm.org).

<sup>5</sup> Available from the Coordinating Research Council, Inc., 219 Perimeter Parkway, Atlanta, GA 30346.

<sup>6</sup> Available from Superintendent of Documents, Attn: New Orders, P.O. Box 371954, Pittsburgh, PA 15250-7954.

**TABLE 1 Maximum Allowable System Time Responses**

| Measurement | Time Response (s) |
|-------------|-------------------|
| Speed       | 2.0               |
| Temperature | 3.0               |
| Pressure    | 3.0               |
| Flow        | To be determined  |

## 5. Significance and Use

5.1 This test method was developed to assess the performance of an engine oil to control engine wear and deposits under heavy-duty operating conditions selected to accelerate soot generation, valve train wear, and deposit formation in a turbocharged, aftercooled four-stroke-cycle diesel engine equipped with exhaust gas recirculation hardware.

5.2 This test method may be used for engine oil specification acceptance when all details of this test method are in compliance. Applicable engine oil service categories are included in Specification **D4485**.

5.3 The design of the engine used in this test method is representative of many, but not all, modern diesel engines. This factor, along with the accelerated operating conditions, needs to be considered when extrapolating test results.

## 6. Apparatus

### 6.1 Test Engine Configuration:

6.1.1 *Test Engine*—The Cummins M11 400 is an in-line six-cylinder heavy-duty diesel engine with 11 L of displacement and is turbocharged and aftercooled. The engine has an overhead valve configuration and EGR hardware. It features a 1994 emissions configuration with electronic control of fuel metering and fuel injection timing. Obtain the test engine, the engine build parts kit, and non-kit parts from the central parts distributor (CPD).<sup>7,8</sup> The components of the engine build parts kit are shown in **Table A3.1**. Non-kit parts are shown in **Table A3.2**.

6.1.2 *Oil Heat Exchanger, Adapter Blocks, and Block-Off Plate*—The oil heat exchanger is relocated from the stock position with the use of adapter blocks as shown in **Fig. A4.1**.<sup>8,9</sup> Install an oil cooler block-off plate on the back of the coolant thermostat housing (**Fig. A4.1**). Control the oil temperature by directing engine coolant through the oil heat exchanger (**Fig. A4.2**).

6.1.3 *Oil Filter Head Modification*—Modify the oil filter head by plugging the filter bypass return to sump line and the engine oil thermostat (**Fig. A4.8**). Block the thermostat passage to route all of the engine oil into the oil cooler.

6.1.4 *Oil Pan Modification*—Modify the oil pan as shown in **Fig. A4.3**.<sup>8,9</sup>

<sup>7</sup> The sole source of supply of the parts known to the committee at this time is Test Engineering Inc., 12758 Cimmaron Path, Suite 102, San Antonio, TX 78249-3417.

<sup>8</sup> 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,<sup>1</sup> which you may attend.

<sup>9</sup> The sole source of supply of the apparatus known to the committee at this time is Southwest Research Institute, P.O. Drawer 28510, San Antonio, TX 78228.

**TABLE 2 Warm-up Conditions**

| Parameter                                | Unit  | Stage |      |      |      |      |
|--|-------|-------|------|------|------|------|
|  |       | A     | B    | C    | D    | E    |
| Stage Length                             | min   | 5     | 5    | 5    | 5    | 5    |
| Speed                                    | r/min | 700   | 1200 | 1600 | 1600 | 1600 |
| Torque                                   | Nom   | 135   | 270  | 540  | 1085 | 1470 |
| Coolant Out Temperature <sup>A</sup>     | °C    | 105   | 105  | 105  | 105  | 105  |
| Oil Gallery Temperature <sup>A</sup>     | °C    | 130   | 130  | 130  | 130  | 130  |
| Intake Manifold Temperature <sup>A</sup> | °C    | 70    | 70   | 70   | 70   | 70   |

<sup>A</sup> Maximum.

**TABLE 3 Break-in Conditions**

| Parameter                   | Unit     | Specification       |
|-----------------------------|----------|---------------------|
| Stage Length                | min      | 120                 |
| Speed                       | r/min    | 1600 ± 5 (target)   |
| Torque <sup>A</sup>         | Nom      | 1930                |
| Fuel Flow                   | kg/h     | 64.4 ± 0.9 (target) |
| Coolant Out Temperature     | °C       | 65.5                |
| Fuel In Temperature         | °C       | 40 ± 2              |
| Oil Gallery Temperature     | °C       | 115.5               |
| Turbo Inlet Air Temperature | °C       | record              |
| Intake Manifold Temperature | °C       | 65.5 (target)       |
| Oil Gallery Pressure        | kPa      | record              |
| Oil Filter Delta Pressure   | kPa      | record              |
| Intake Manifold Pressure    | kPa abs. | ≤ 320               |
| Exhaust Pressure            | kPa abs. | 107 ± 1             |
| Crankcase Pressure          | kPa      | record              |
| Inlet Air Pressure          | kPa abs. | record              |
| Coolant System Pressure     | kPa      | 103 ± 4             |

<sup>A</sup> At standard atmospheric temperature and pressure.

**TABLE 4 Normal Shutdown Conditions**

| Parameter                   | Unit  | Stage   |         |         |
|-----------------------------|-------|---------|---------|---------|
|                             |       | B       | A       | Idle    |
| Stage Length                | min   | 5       | 5       | 5       |
| Speed                       | r/min | 1200    | 700     | 700     |
| Torque                      | N·m   | 270     | 135     | <40     |
| Coolant Out Temperature     | °C    | 105 max | 105 max | 105 max |
| Intake Manifold Temperature | °C    | 70 max  | 70 max  | 70 max  |
| Oil Gallery Temperature     | °C    | 130 max | 130 max | 30 max  |

6.1.5 *Engine Control Module (ECM)*—Obtain the ECM from the CPD.<sup>7,8</sup> The ECM programming has been modified to provide overfueling and retarded injection timing to increase soot generation and overhead wear. The de-rate protocols have been disabled. However the de-rate messages will still be displayed when using Cummins electronic service tools.

6.1.6 *Engine Position Sensor*—The engine position sensor has two measurement coils. Disable the secondary coil by cutting the two outside wires colored red and black. The red and black wires are labeled A and D, respectively, on the engine position sensor plug (**Fig. A4.15**).

6.1.7 *Air Compressor and Fuel Pump*—The engine-mounted air compressor is not used for this test method. Remove the air compressor and install the fuel injection pump in its place (**Fig. A4.4**). The fuel injection pump is driven with Cummins coupling P/N 208755.<sup>8,10</sup>

<sup>10</sup> Available from a Cummins parts distributor.

**TABLE 5 300-h Test Sequence**

| Parameter                            | Unit     | Stage     |           |           |           |           |           |
|--------------------------------------|----------|-----------|-----------|-----------|-----------|-----------|-----------|
|                                      |          | A         | B         | C         | D         | E         | F         |
| Stage Length                         | h        | 50        | 50        | 50        | 50        | 50        | 50        |
| Speed                                | r/min    | 1800 ± 5  | 1600 ± 5  | 1800 ± 5  | 1600 ± 5  | 1800 ± 5  | 1600 ± 5  |
| Power                                | kW       | record    | record    | record    | record    | record    | record    |
| Torque (typical) <sup>A</sup>        | Nom      | 1300      | 1930      | 1300      | 1930      | 1300      | 1930      |
| Fuel Flow                            | kg/h     | 58 ± 1    | 64.4 ± 1  | 58 ± 1    | 64.4 ± 1  | 58 ± 1    | 64.4 ± 1  |
| Intake Manifold Temperature          | °C       | 80        | 65.5      | 80        | 65.5      | 80        | 65.5      |
| Blowby Flow                          | L/min    | record    | record    | record    | record    | record    | record    |
| Coolant Out Temperature              | °C       | 65.5 ± 2  | 65.5 ± 2  | 65.5 ± 2  | 65.5 ± 2  | 65.5 ± 2  | 65.5 ± 2  |
| Coolant In Temperature               | °C       | record    | record    | record    | record    | record    | record    |
| Coolant Delta Temperature            | °C       | record    | record    | record    | record    | record    | record    |
| Fuel In Temperature                  | °C       | 40 ± 2    | 40 ± 2    | 40 ± 2    | 40 ± 2    | 40 ± 2    | 40 ± 2    |
| Oil Gallery Temperature              | °C       | 115 ± 2   | 115 ± 2   | 115 ± 2   | 115 ± 2   | 115 ± 2   | 115 ± 2   |
| Turbo Inlet Temperature              | °C       | record    | record    | record    | record    | record    | record    |
| Intake Manifold Pressure             | KPa abs. | ≥ 300     | ≥ 320     | ≥ 300     | ≥ 320     | ≥ 300     | ≥ 320     |
| Exhaust Temperature                  | °C       | record    | record    | record    | record    | record    | record    |
| Fuel Pressure                        | kPa      | record    | record    | record    | record    | record    | record    |
| Oil Gallery Pressure                 | kPa      | record    | record    | record    | record    | record    | record    |
| Oil Filter Delta Pressure            | kPa      | record    | record    | record    | record    | record    | record    |
| Coolant System Pressure <sup>B</sup> | kPa      | 99-107    | 99-107    | 99-107    | 99-107    | 99-107    | 99-107    |
| Exhaust Pressure                     | kPa abs. | 107 ± 1   | 107 ± 1   | 107 ± 1   | 107 ± 1   | 107 ± 1   | 107 ± 1   |
| Crankcase Pressure                   | kPa      | record    | record    | record    | record    | record    | record    |
| Inlet Air Pressure                   | kPa abs. | record    | record    | record    | record    | record    | record    |
| Intake CO <sub>2</sub>               | %        | 0.97-1.09 | 0.78-0.85 | 0.97-1.09 | 0.78-0.85 | 0.97-1.09 | 0.78-0.85 |

<sup>A</sup> At standard atmospheric temperature and pressure.

<sup>B</sup> Measure the coolant pressure on the top of the expansion tank.

## 6.2 Test Stand Configuration:

6.2.1 *Engine Mounting*—Install the engine so that it is upright and the crankshaft is horizontal.

6.2.1.1 The engine mounting hardware should be configured to minimize block distortion when the engine is fastened to the mounts. Excessive block distortion may influence test results.

6.2.2 *Intake Air System*—With the exception of the air filter and the intake air tube, the intake air system is not specified. A typical configuration is shown in Fig. X1.1. The air filter shall have a minimum initial efficiency rating of 99.2 %. Install the intake air tube (Fig. A4.5) at the intake of the turbocharger compressor. To control intake manifold pressure, a restriction plate or valve may be used after the aftercooler and before the inlet air tubing. The system shall allow control of applicable parameters listed in Table 5.

NOTE 1—Difficulty in achieving or maintaining intake manifold pressure or intake manifold temperature, or both, may be indicative of insufficient or excessive restriction.

6.2.3 *Aftercooler*—Use a Modine aftercooler for aftercooling. Instructions for obtaining the correct aftercooler are listed in A2.1.

6.2.4 *Exhaust System*—Install the exhaust tube (Fig. A4.6) at the discharge flange of the turbocharger turbine housing. The piping downstream of the exhaust tube is not specified. A method to control exhaust pressure is required.

6.2.5 *Exhaust Gas Recirculation System*—The set-up components for the exhaust gas recirculation system (Fig. A4.9 and Fig. A4.11) can be obtained from the CPD.<sup>7,8</sup>

6.2.6 *Fuel System*—The fuel supply and filtration system is not specified. A typical configuration is shown in Fig. X1.2. The fuel consumption rate is determined by measuring the rate of fuel flowing into the day tank. A method to control the fuel temperature is required.

6.2.7 *Coolant System*—The system configuration is not specified. A typical configuration consists of a non-ferrous core heat exchanger, a reservoir (expansion tank), and a temperature control valve as shown in Fig. X1.3. Pressurize the system by regulating air pressure at the top of the expansion tank. The system should have a sight glass to detect air entrapment.

6.2.7.1 Although the system volume is not specified, an excessively large volume may increase the time required for the engine fluid temperatures to attain specification. A system volume of 45 L or less, including the volume contained in the engine, has proven satisfactory.

6.2.8 *Pressurized Oil Fill System*—The oil fill system is not specified. A typical configuration includes an electric pump, a 50-L reservoir, and a transfer hose. The location for the pressurized fill is located on the filter head (Fig. A4.8).

6.2.9 *External Oil System*—Configure the external oil system according to Fig. A5.1. Use a Moroso P/N 22660 reservoir<sup>8,11</sup> for the blowby canister.

6.2.9.1 *Oil Sample Valve Location*—Locate the oil sample valve on the return line from the external oil system to the engine. Locate the valve as close to the return pump as possible (Fig. A5.1).

6.2.9.2 *Unacceptable Oil System Materials*—Brass or copper fittings can influence used oil wear metals analyses and shall not be used in the external oil system.

6.2.10 *Crankcase Aspiration*—Vent the blowby gas at the port located on the right side of the valve cover (Fig. A4.2). Route the vent line downward from the valve cover port to the

<sup>11</sup> The sole source of supply of the reservoir known to the committee at this time is Moroso Performance Products Inc., 80 Carter Drive, P.O. Box 1470, Guilford, CT 06437.

blowby canister. The line shall be between 1.2 and 1.8 m in length and 1.5875 cm in diameter.

6.2.11 *Blowby Rate*—The flowrate measurement device is not specified. The blowby canister shall be 37.854 L in volume. The outlet of the blowby canister to the flowrate device shall be 3.175 cm in diameter. The hose connecting the blowby canister to the flowrate device shall be 3.81 cm in diameter. The length of this hose is not specified.

6.3 *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.<sup>12</sup>

6.4 *Oil Sample Containers*—High-density polyethylene containers are recommended for oil samples. (**Warning**—Glass containers may break and may cause injury or exposure to hazardous materials, or both.)

6.5 *Mass Balance*—A balance is required to measure the mass of the crossheads, rod bearings, injector adjusting screws, and piston rings. An electronic or mechanical balance may be utilized. The balance shall have a minimum display resolution of 0.1 mg.

## 7. Engine and Cleaning Fluids

7.1 *Test Oil*—Approximately 115 L of test oil is required to complete the test.

7.2 *Test Fuel*—Approximately 20 000 L of Chevron Phillips RD-9 diesel fuel<sup>8,13</sup> is required to complete the test. Fuel property tolerances are shown in **Annex A6**.

7.3 *Engine Coolant*—Use pre-mixed Fleetguard Compleat PG.

7.4 *Solvent*—Use aliphatic naphtha or equivalent. (**Warning**—Use adequate safety precautions with all solvents and cleaners.)

## 8. Preparation of Apparatus

### 8.1 *Cleaning of Parts:*

8.1.1 *General*—The preparation of test engine components specific to the Cummins M11 EGR test are indicated in this section. Use the Cummins service publications<sup>8,10</sup> (**Annex A7**) for the preparation of other engine components. Take precautions to prevent rusting of iron components.

8.1.2 *Engine Block*—Disassemble the engine, including removal of the crankshaft, camshaft, piston cooling tubes, oil pump, and oil gallery plugs. Thoroughly clean the surfaces and oil passages (galleries). Use a brush to clean the oil passages. Removal of camshaft bearings is at the discretion of the laboratory.

8.1.3 *Cylinder Head*—Disassemble and clean the cylinder head. Use a brush as necessary to remove deposits.

8.1.4 *Rocker Cover and Oil Pan*—Clean the rocker cover and oil pan. Use a brush as necessary to remove deposits.

8.1.5 *External Oil System*—Flush the internal surfaces of the oil lines and the external reservoir with solvent. Repeat until the solvent drains clean. Flush solvent through the oil pumps until the solvent drains clean.

### 8.1.6 *Crosshead Cleaning and Measurement:*

8.1.6.1 *Handling and Orientation*—Avoid handling the crossheads with bare hands, use gloves or plastic-covered tongs. Orient the crossheads in the engine with the elongated slot toward the exhaust valve.

8.1.6.2 Clean the crossheads with solvent. Use a nonmetallic soft bristle brush if necessary.

8.1.6.3 Spray the crossheads with air until dry.

8.1.6.4 Rinse the crossheads in pentane and dry with air.

8.1.6.5 Measure crosshead mass to a tenth of a milligram.

8.1.6.6 If an electronic scale is used for mass measurement, use the following procedure:

(1) Demagnetize (degauss) each crosshead prior to measurement.

(2) Measure the crosshead two times. Make the second measurement with the crossheads in an orientation that is 90° from the original orientation. If the difference between the two mass measurements is greater than 0.2 mg, demagnetize the crosshead and repeat the measurement process.

### 8.1.7 *Rod Bearing Cleaning and Measurement:*

8.1.7.1 Clean the rod bearings with solvent. Use a non-metallic soft bristle brush if necessary. Avoid handling the rod bearings with bare hands. Use gloves or plastic-covered tongs.

8.1.7.2 Spray the rod bearings with air until dry.

8.1.7.3 Rinse the rod bearings in pentane and dry with air.

8.1.7.4 Measure the mass of each bearing half to a tenth of a milligram.

### 8.1.8 *Ring Cleaning and Measurement:*

8.1.8.1 Use the procedure stated in Test Method **D6483** for ring cleaning. Avoid handling the rings with bare hands. Use gloves or plastic-covered tongs.

### 8.1.9 *Injector Adjusting Screw Cleaning and Measurement:*

8.1.9.1 Clean the injector adjusting screws with solvent. Use a soft bristle brush if necessary. Avoid handling the injector adjusting screws with bare hands. Use gloves or plastic-covered tongs.

8.1.9.2 Spray the injector adjusting screws with air until dry.

8.1.9.3 Rinse the injector adjusting screws with pentane and dry with air.

8.1.9.4 Measure injector adjusting screw mass to a tenth of a milligram.

8.1.9.5 If an electronic scale is used for mass measurement, then use the following procedure:

(1) Demagnetize each injector adjusting screw prior to measurement.

(2) Measure the crosshead two times. Make the second measurement with the injector adjusting screws in an orientation that is 90° from the original orientation. If the difference between the two mass measurements is greater than 0.2 mg, demagnetize the injector adjusting screw and repeat the measurement process.

### 8.2 *Engine Assembly:*

8.2.1 *General*—Except as noted in this section, use the procedures indicated in the Cummins service publications<sup>8,10</sup>

<sup>12</sup> Available from the ASTM Test Monitoring Center, 6555 Penn Avenue, Pittsburgh, PA 15206-4489, Attention: Administrator.

<sup>13</sup> The sole source of supply of the fuel known to the committee at this time is Chevron Phillips, 1302 McKinney Street, Suite 2130, Houston, TX 77010-3030.

(Annex A7). Assemble the engine with the components from the Engine Build Parts Kit<sup>7,8</sup> and non-kit parts<sup>7,8</sup> (Annex A3).

8.2.2 *Parts Reuse and Replacement*—Engine components may be reused or replaced at the discretion of the laboratory, except as noted in 8.2.7.

8.2.3 *Build-Up Oil*—Use Cummins Premium Blue<sup>8,10</sup> or test oil to lubricate parts for the engine build. If test oil is used, then the engine build is valid only for the respective test oil.

8.2.4 *Coolant Thermostat*—Lock the engine coolant thermostat open.

8.2.5 *Oil Thermostat*—Remove the oil thermostat and plug the oil passage. This will route all of the oil flow through the oil cooler (Fig. A4.8).

8.2.6 *Fuel Injectors*—The fuel injectors may be reused. Dedicate the injectors to a particular cylinder. Install the injectors according to the torque wrench method as noted in the Cummins service publications (Annex A7).

8.2.7 *New Parts*—The parts listed below are contained in the Engine Build Parts Kit and are not reusable (except as noted in 10.3.3). Clean the parts prior to use. Replacement of any part listed below during a test will invalidate the test.

- 8.2.7.1 Pistons (crown, skirt),
- 8.2.7.2 Piston rings (top, second, oil),
- 8.2.7.3 Cylinder liners,
- 8.2.7.4 Rocker lever shafts,
- 8.2.7.5 Rocker lever assemblies (exhaust, intake, injector),
- 8.2.7.6 Valves (intake, exhaust),
- 8.2.7.7 Valve stem guides,
- 8.2.7.8 Valve inserts,
- 8.2.7.9 Piston cooling nozzles,
- 8.2.7.10 Valve crossheads, and
- 8.2.7.11 Connecting rod bearings.

### 8.3 *Operational Measurements:*

8.3.1 *Units and Formats*—See Annex A8.

8.3.2 *Instrumentation Calibration:*

8.3.2.1 *Fuel Consumption Rate Measurement Calibration*—Calibrate the fuel consumption rate measurement system before each reference oil test. Temperature-compensate volumetric systems, and calibrate them against a mass flow device. The flowmeter located on the test stand shall indicate within 0.2 % of the calibration standard. Trace the calibration standard to national standards.

8.3.2.2 *Temperature Measurement Calibration*—Calibrate the temperature measurement systems at least once every six months. Each temperature measurement system shall indicate within  $\pm 0.5^\circ\text{C}$  of the laboratory calibration standard. Trace the calibration standard to national standards.

8.3.2.3 *Pressure Measurement Calibration*—Calibrate the pressure measurement systems at least once every six months. Trace the calibration standard to national standards.

8.3.3 *Temperatures:*

8.3.3.1 *Measurement Location*—The temperature measurement locations are specified in this section. The measurement equipment is not specified. Install the sensors such that the tip is located midstream of the flow unless otherwise indicated. The accuracy and resolution of the temperature measurement

sensors and the complete measurement system shall follow the guidelines detailed in ASTM Research Report RR:D02-1218.<sup>14</sup>

8.3.3.2 *Coolant Out Temperature*—Install the sensor upstream of the junction of the EGR coolant return (Fig. A4.7).

8.3.3.3 *Coolant In Temperature*—Install the sensor on the right side of the coolant pump intake housing at the 1-in. NPT port (Fig. A4.7).

8.3.3.4 *Fuel In Temperature*—Install the sensor in the fuel pump inlet fitting (Fig. A4.4).

8.3.3.5 *Oil Gallery Temperature*—Install the sensor at the 1/4-in. NPT hole on the left rear of the engine (Fig. A4.4).

8.3.3.6 *Intake Air Temperature*—Install the sensor (Fig. A4.5).

8.3.3.7 *Intake Manifold Temperature*—Install the sensor at the 1/8-in. NPT hole at the flange on the air inlet tube (Fig. A4.7).

8.3.3.8 *Exhaust Temperature*—Install the sensor (Fig. A4.6).

8.3.3.9 *Additional*—Monitor any additional temperatures considered to be beneficial.

NOTE 2—Additional exhaust sensor locations are recommended, such as the exhaust ports and pre-turbine (front and rear). The detection of changes in exhaust temperature(s) is an important diagnostic. Measurement of the EGR cooler gas inlet and outlet temperatures and coolant inlet and outlet temperatures is recommended.

8.3.4 *Pressures:*

8.3.4.1 *Measurement Location and Equipment*—The pressure measurement locations are specified in this section. The measurement equipment is not specified. The accuracy and resolution of the pressure measurement sensors and the complete measurement system shall follow the guidelines detailed in ASTM Research Report RR:D02-1218.<sup>14</sup>

8.3.4.2 A condensation trap should be installed at the lowest elevation of the tubing between the pressure measurement location and the final pressure sensor for crankcase pressure, intake air pressure, and exhaust pressure. Route the tubing to avoid intermediate loops or low spots before and after the condensation trap.

8.3.4.3 *Oil Gallery Pressure*—Measure the pressure at the 1/16 in. Compuchek adapter at the left-front of the engine (Fig. A4.4).

8.3.4.4 *Oil Filter Inlet Pressure*—Measure the pressure at the 7/8 in. O-ring plug located on the oil filter assembly (Fig. A4.8).

8.3.4.5 *Oil Filter Outlet Pressure*—Measure the pressure at the 1/4-in. NPT port located on the oil filter assembly (Fig. A4.8).

8.3.4.6 *Intake Manifold Pressure*—Measure the pressure at the 1/2-in. NPT port at the top-front of the intake manifold (Fig. A4.7).

8.3.4.7 *Crankcase Pressure*—Measure the pressure at the boss on the top-front, right-hand side of the rocker cover (Fig. A4.2).

8.3.4.8 *Intake Air Pressure*—Measure the pressure on the intake air tube (Fig. A4.5).

8.3.4.9 *Exhaust Pressure*—Measure the pressure on the exhaust tube (Fig. A4.6).

<sup>14</sup> Supporting data have been filed at ASTM International Headquarters and may be obtained by requesting Research Report RR:D02-1218.

8.3.4.10 *Fuel Pressure*—Measure the pressure at the  $\frac{1}{16}$  in. Compuchek adapter on fuel pump body (Fig. A4.4).

8.3.4.11 *Coolant Pressure*—Measure the pressure on top of the expansion tank (Fig. X1.3).

8.3.4.12 *Additional Pressures*—Monitor any additional pressures considered to be beneficial.

NOTE 3—Measurement of the EGR cooler inlet and outlet coolant pressures and inlet and outlet gas pressure is recommended.

### 8.3.5 *Flow Rates:*

8.3.5.1 *Flow Rate Location and Measurement Equipment*—The flow rate measurement locations are specified in this section. The equipment for the blowby rate and the fuel rate are not specified. The accuracy and resolution of the flow rate measurement system shall follow the guidelines detailed in ASTM Research Report RR:D02-1218.<sup>14</sup>

8.3.5.2 *Blowby*—The device used to measure the blowby flow rate is not specified. See 6.2.11 for blowby measurement system configuration details.

8.3.5.3 *Fuel Flow*—The fuel consumption rate is determined by measuring the fuel flowing to the day tank (Fig. X1.2).

### 8.3.6 *Intake and Exhaust CO<sub>2</sub> Measurement:*

8.3.6.1 *Sampling Probes*—Obtain the intake CO<sub>2</sub> probe from the CPD.<sup>7,8</sup> Instructions for obtaining general specifications and fabrication details for the exhaust CO<sub>2</sub> probe are shown in Annex A15.

8.3.6.2 *Sampling Probe Locations*—The locations of the CO<sub>2</sub> probes for the intake and exhaust are shown in Fig. A4.14 and Fig. A4.6, respectively.

8.3.6.3 *Sampling Probe Insertion Depth*—Diagrams of the insertion depths for the intake and exhaust probes are shown in Fig. A4.13 and Fig. A4.16, respectively.

## 9. Engine/Stand Calibration and Non-Reference Oil Tests

9.1 *General*—Calibrate the test stand by conducting a test with a blind reference oil.<sup>12</sup> Submit the results to the ASTM Test Monitoring Center (TMC) for determination of acceptance according to the Lubricant Test Monitoring System (LTMS).<sup>12</sup>

9.2 *New Test Stand*—A new test stand is defined as a test stand that has never been calibrated or has not completed an acceptable reference oil test within 18 months of the end of test (EOT) date of the last acceptable reference oil test. Under special circumstances, such as industry-wide parts or fuel shortages, the TMC may extend the time period beyond 18 months. Perform the following to introduce a new test stand.

9.2.1 *New Test Stand Calibration*—New stand calibration is determined according to the LTMS.<sup>12</sup>

9.3 *Stand Calibration Period*—The calibration period is 6 months from the EOT date of the last acceptable reference oil test.

9.3.1 The TMC may schedule more frequent reference oil tests or extend the calibration period.

9.4 *Stand Modification and Calibration Status*—Stand calibration status may be invalidated by conducting any non-standard test or modification of the test and control systems or both. A non-standard test includes any test conducted under a modified procedure, nonprocedural hardware, controller set-

point modifications, or any combination thereof. The TMC should be contacted prior to any changes to determine the effect on the calibration status.

### 9.5 *Test Numbering System:*

9.5.1 *General*—The test number has three parts, X-Y-Z. X represents the test stand number, Y represents the engine serial number, and Z represents the engine block run number. For example, test number 27-4B4607-2 indicates stand number 27, engine serial number 4B4607, and the second test on the engine block. Increment Z by one for each test start (reference oil and non-reference oil) with the exception stated in 9.5.2.

9.5.2 *Reference Oil Tests*—A reference oil test conducted subsequent to an unacceptable reference oil test shall include a letter suffix after Z. The letter suffix shall begin with A and increment alphabetically until an acceptable reference oil test is completed. For example, if two consecutive unacceptable reference oil tests were conducted and the first test number was 27-4B4607-10, the second test number would be 27-4B4607-10A. A third calibration attempt would have the test number 27-4B4607-10B. If the third test was acceptable, then 27-4B4607-10B would identify the reference oil test in the test report.

9.5.3 *Non-Reference Oil Tests*—No letter suffix shall be added to Z for aborted or operationally invalid non-reference oil tests.

9.6 *Reference Oil Test Acceptance*—Reference oil test acceptance and laboratory severity adjustments (SA) are determined in accordance with the LTMS.<sup>12</sup>

### 9.7 *Unacceptable Reference Oil Test:*

9.7.1 It is recognized that some reference oil test results will not be within the LTMS acceptance limits. The laboratory, in conjunction with the TMC, shall attempt to determine the cause of the deviation. The TMC may solicit input from industry authorities to help determine the cause and extent of the problem.

9.7.2 If the laboratory is not within the LTMS acceptance limits and the TMC has determined that probable cause is isolated to an individual stand, then non-reference oil testing on other calibrated stands may continue.

9.7.3 If the laboratory is not within the LTMS acceptance limits and the TMC has determined that probable cause involves more than one stand, then the TMC may declare the particular stands non-calibrated. Non-reference oil tests in progress at the time of the calibration status change are not affected.

9.7.4 The laboratory shall attempt to identify and correct the cause and conduct an acceptable reference oil test in at least one of the stands to demonstrate resolution of the problem.

9.7.5 The TMC will assign reference oil when satisfied that no particular problems exist or the problem has been resolved. The laboratory shall provide adequate documentation of findings to support the conclusions reached during this process. The conclusions shall be documented in the acceptable reference oil test report.

### 9.8 *Reference Oil Accountability:*

9.8.1 Laboratories shall provide a full accounting of the identification and quantities of all reference oils used. With the



exception of the oil analyses required in 11.7, no physical or chemical analyses of reference oils shall be performed without written permission from the TMC. In such an event, include the written confirmation and the data generated in the reference oil test report.

9.8.2 Retain used reference oil samples for 90 days from the EOT date.

#### 9.9 Non-Reference Oil Tests:

9.9.1 This test method incorporates the use of a Severity Adjustment (SA) for non-reference oil test results. A control chart technique described in the LTMS is used to determine if a significant bias exists for crosshead mass loss, average sludge, or oil filter plugging, or combination thereof. When calibration results indicate a significant bias, an SA is determined according to the LTMS and applied to the non-reference oil test result. The SA will remain in effect until a new SA is determined from subsequent calibration tests.

9.9.2 *Last Start Date*—A non-reference oil test shall commence engine warm-up (10.5) prior to the expiration of the calibration period (9.3).

## 10. Test Procedure

10.1 *Engine Installation and Stand Connections*—Install the test engine on the stand and connect the engine to the stand support equipment.

NOTE 4—A final check of valve and injector settings is recommended at this time.

10.2 *Coolant System Fill*—Install a new coolant filter, Cummins WF-2071. Fill the cooling system with pre-mixed Fleet-guard Compleat PG.<sup>8,10</sup> The coolant for non-reference oil tests may be reused provided the level of inhibitors is within specification as determined by DCA Level Test Kit, Cummins P/N CC2602.<sup>8,10</sup> Use new coolant for each reference oil test.

NOTE 5—The coolant system should be pressurized to specification and checked for leaks prior to adding the test oil.

#### 10.3 Oil Fill for Break-In:

10.3.1 Install a new Cummins LF-3000 oil filter.<sup>8,10</sup>

10.3.2 Use the pressurized oil fill system (6.2.8) to charge the engine with 24.7 kg of test oil at the location shown in Fig. A4.8.

10.3.3 *Engine Build Committed*—After the test oil has been introduced into the engine, the engine build and the test number are valid only for the respective test. However, if the engine has not been cranked (whereby the test parts have not been subjected to wear or injected fuel, or both), then the new parts may be used again. Disassemble and clean the engine according to 8.1.

10.4 *Fuel Samples*—Take a 1.0 L fuel sample at the start of the test and at EOT.

10.5 *Engine Warm-Up*—The engine warm-up conditions are shown in Table 2.

10.5.1 *Shutdown During Warm-Up*—The warm-up timer shall stop at the initiation of a shutdown. When the laboratory is ready to resume warm-up, start the engine, and continue warm-up from the stage in which the shutdown occurred. The warm-up timer shall resume when the engine speed and torque are within specifications.

10.6 *Engine Break-In*—Perform a break-in on each new engine build prior to the start of the 300-h test procedure. The break-in conditions are shown in Table 3.

10.6.1 Start the engine, perform the warm-up (Table 2), and proceed directly to the break-in (Table 3).

10.6.1.1 *Shutdown during Break-In*—Stop the break-in timer at the initiation of a shutdown. When the laboratory is ready to resume the break-in, start the engine, perform the warm-up, and proceed to the break-in conditions. The break-in timer shall resume when the engine speed and torque are within specifications. If a shutdown occurs within the last 10 min of break-in, the break-in may be considered complete. Note such an occurrence in *Other Comments* of Form 21, listed in Table A9.1.

10.6.2 At the completion of the break-in, perform a normal shutdown (Table 4) and shut off the engine.

10.6.3 Drain the oil from the engine and the external oil system.

10.6.4 Remove the LF-3000 oil filter.

10.6.5 Properly dispose of the drain oil and oil filter.

10.6.6 Once completed, the break-in is not repeated for the respective test.

NOTE 6—Use the break-in as an opportunity to confirm engine performance and to make repairs prior to the start of the 300-h test procedure.

10.7 *Shutdown and Maintenance*—The test may be shut down at the discretion of the laboratory to perform repairs. However, the intent of this test method is to conduct the 300-h test procedure without shutdowns.

10.7.1 *Normal Shutdown*—Proceed directly from the operating conditions to the shutdown schedule (Table 4).

10.7.2 *Emergency Shutdown*—An emergency shutdown occurs when the normal shutdown cannot be performed, such as an alarm condition. Note such an occurrence in the *Other Comments* section of Form 21, listed in Table A9.1.

10.7.3 *Maintenance*—Engine components or stand support equipment, or both, may be repaired or replaced at the discretion of the laboratory and in accordance with this test method.

10.7.3.1 Removal of the crossheads prior to test completion shall invalidate the test.

10.7.3.2 Removal and replacement of the oil filter due to engine gallery pressure below 200 kPa shall be determined solely at the discretion of the laboratory. Use the following guidelines for oil filter replacement:

(1) If the test is on a non-reference oil test and the test has not completed Stage E in Table 5, the test is considered non-interpretable (11.12).

(2) If the test is on a non-reference oil test and the test has completed Stage E in Table 5, the test can be continued with a new oil filter with the appropriate shutdown correction as per 11.7.2. Note an oil filter change in the *Other Comments* section of Form 21, listed in Table A9.1.

(3) Reference oil tests shall be completed using the original oil filter in order to be considered operationally valid reference tests.

10.7.4 *Downtime*—The limit for total downtime and number of shutdowns is not specified. Record all shutdowns, pertinent

actions, and total downtime during the 300-h test procedure on Form 21, listed in [Table A9.1](#).

#### 10.8 300-h Test Procedure:

10.8.1 Measure and record the mass of a new test oil filter, Cummins P/N 390383200 ([Table A3.1](#)), and install the oil filter on the engine.

10.8.2 *Oil Fill for Test*—Use the pressurized oil fill system ([6.2.8](#)) to charge the engine with 24.7 kg of test oil at the location shown in [Fig. A4.2](#).

10.8.2.1 *Zero-Hour Oil Sample*—Take a 0.23-kg oil sample of the fresh oil from the original oil container.

10.8.3 Start the engine and perform the warm-up ([Table 2](#)).

10.8.4 *Operating Conditions*—After warm-up, proceed directly to the 300-h Test Sequence ([Table 5](#)).

10.8.4.1 *Intake CO<sub>2</sub> Level*—If the required CO<sub>2</sub> level cannot be obtained when a restriction plate on the EGR cooler is not used, the intake manifold pressure should be decreased to no lower than the specified limit using the location specified in [6.2.2](#).

10.8.4.2 *Stage Transition Times*—1 min (r/min only), 15 min (Intake Manifold Temperature).

10.8.5 *Injection Timing Change*—Injection timing may be adjusted to ensure the oil soot level falls within the windows shown in [10.8.6](#). Injection timing must be run at 16.1 degrees TVC (timing valve closed) for the first 25 h. Injection timing may be adjusted after 25 h for Stages A, C, and E if the soot level is greater than 2.0 mass %.

#### 10.8.6 Mass % Soot Validity:

10.8.6.1 *Reference Oil Test*—Mass % soot shall be 8.5 ± 0.5 % at 250 h, and the average mass % soot shall be 4.6 % minimum.

10.8.6.2 *Non-Reference Oil Test*—Mass % soot shall be 8.0 % minimum at 250 h, and the average mass % soot shall be 4.6 % minimum.

10.8.7 *Test Timer*—The 300-h test timer starts when all controlled parameters in Stage A shown in [Table 5](#) are within specification. If a shutdown occurs, stop the test timer immediately at the initiation of the shutdown. The test timer shall resume when the test has been returned to the appropriate stage and all controlled parameters are within specification.

10.8.7.1 The test timer continues incrementing test time throughout stage transitions.

10.8.8 *Operational Data Acquisition*—Record all operational parameters shown in [Table 5](#), except blowby flowrate, intake, and exhaust CO<sub>2</sub>, with automated data acquisition at a minimum frequency of once every 6 min. Record blowby flowrate a minimum of once every 8 h. Record intake and exhaust CO<sub>2</sub> once every 10 h, but not during a test stage transition. Recorded values shall have minimum resolution in accordance with [Annex A8](#).

10.8.8.1 The operational data is reported on Form 5 listed in [Table A9.1](#).

10.8.9 *Oil Purge, Sample, and Addition*—Perform a forced oil drain, oil sample, and oil addition at the end of each 25-h period. Add new oil and purge sample returns to the external oil system reservoir.

10.8.9.1 Do not shut down the engine for oil sampling and oil addition. Purge oil samples are retained at the discretion of the laboratory.

10.8.9.2 *Full and Drain Weight*—Record the oil weight indicated by the external oil system at the completion of the first test hour; this value establishes the full weight. Subtract 1.4 kg from the full weight; this value establishes the drain weight. The full weight and the drain weight are fixed for the test.

10.8.9.3 At the end of each 25-h period, take a 0.23-kg oil purge sample followed by a 0.23-kg oil analysis sample. Identify the oil sample container with the test number, oil code, date, and test hour.

10.8.9.4 If the remaining oil weight is greater than the drain weight, remove an additional purge sample of sufficient quantity to equal the drain weight.

10.8.9.5 If the remaining oil weight is less than the drain weight, add a maximum of 0.23 kg of the current purge oil sample to attain the drain weight. Do not add any new oil or a previous purge oil sample to attain the drain weight.

10.8.9.6 Add 1.4 kg of new oil, except at 300 h.

#### 10.9 End of Test (EOT):

10.9.1 After completing the test procedure, perform a normal shutdown ([Table 4](#)), and shut down the engine. Release the coolant system pressure and drain the coolant. Disconnect the test stand support equipment. (**Warning**—The coolant and oil may be hot. The installation of a valve to safely vent the coolant system pressure is recommended.)

10.9.2 Drain the oil from the engine and the external oil system. Begin the oil drain within 2 h after shutdown and allow a minimum duration of 30 min.

10.9.3 Retain a minimum of two 3.5-L samples of test oil. Identify the oil sample container with the test number, oil code, EOT date, and test hour. Properly dispose of any residual drain oil.

10.9.4 *Engine Disassembly*—Disassemble the engine and remove the following components for ratings and measurements:

10.9.4.1 *Rocker Cover and Oil Pan*—The rocker cover and oil pan may either remain on the engine or be removed from the engine. Maintain the rocker cover and oil pan in a horizontal position for a minimum of 6 h after the EOT oil drain.

10.9.4.2 *Rocker Cover and Oil Pan Sludge Rating*—After 6 h in a horizontal plane, place the oil pan and rocker cover at a 60° angle from horizontal (lengthwise) with the front end and the inside surface down for a minimum of 8 h in a temperature-controlled environment. Maintain the temperature between 24 ± 3°C.

10.9.4.3 *Crossheads*.

10.9.4.4 *Adjusting Screws*.

10.9.4.5 *Pistons*.

10.9.4.6 *Piston Rings*.

10.9.4.7 *Rod Bearings*.

## 11. Calculations, Ratings, and Test Validity

11.1 *Crosshead Mass Loss*—Use the procedure shown in [8.1.6](#) to determine individual EOT crosshead mass.

11.1.1 Separate the crossheads into intake and exhaust groups.

11.1.2 Calculate the mass loss for each crosshead (pre-test–post-test).

11.1.3 Calculate the average mass loss,  $\bar{x}$ , and the standard deviation of the mass loss,  $s$ , for each group and report as *Measured* in the *Intake/Exhaust Summary* section of Form 6, listed in **Table A9.1**.

11.1.4 Calculate the  $\Delta/s$  for each crosshead as follows:

$$\Delta/s = (|x_i - \bar{x}|)/s \quad (1)$$

where:

$x_i$  = individual crosshead mass loss, mg,

$\bar{x}$  = average mass loss of crosshead group (intake or exhaust), and

$s$  = standard deviation of the mass loss of the group.

11.1.5 A  $\Delta/s$  value greater than 1.887 is an outlier. Remove the maximum outlier from each group (intake and exhaust). Remove only one outlier per group. Recalculate  $\bar{x}$  and  $s$  for each group and report as *Outlier Screened* in the *Intake/Exhaust Summary* section of Form 6, listed in **Table A9.1**.

11.1.6 Calculate the average and the standard deviation of all mass loss values combined (intake and exhaust). Report the average, minimum, maximum, and standard deviation as *As Measured* in the *Overall Summary* section of Form 6, listed in **Table A9.1**.

11.1.7 Calculate the average and the standard deviation of all mass loss values combined (intake and exhaust) with outliers removed and report as *Outlier Screened* in the *Overall Summary* section of Form 6, listed in **Table A9.1**.

11.1.8 Calculate the following and report as *Adjusted to 4.6 Mass % Average Soot* in the *Overall Summary* section of Form 6, listed in **Table A9.1**:

$$10^{\Delta}[\log(X) - 0.2575*(AS - 4.6\%)] \quad (2)$$

where:

$X$  = *Outlier Screened Crosshead Average Mass Loss* value in the *Overall Summary*, and

$AS$  = 13 point average of the 25 h reported soot values (calculated).

11.2 *Injector Adjusting Screw Mass Loss*—Use the procedure shown in **8.1.9** to determine individual EOT adjusting screw mass.

11.2.1 Separate the adjusting screws into injector, intake, and exhaust groups.

11.2.2 Calculate the mass loss for each adjusting screw (pre-test–post-test).

11.3 *Rod Bearing Mass Loss*—Use the procedure shown in **8.1.7** to determine individual EOT rod bearing mass.

11.3.1 Calculate the mass loss for each rod bearing section (pre-test–post-test).

11.3.2 Calculate the average mass loss and the standard deviation of the mass loss.

11.4 *Ring Mass Loss*—Use the procedure shown in **8.1.8** to determine individual EOT ring mass.

11.4.1 Calculate the mass loss and gap increase for the top, second, and oil rings (pre-test–post-test).

11.4.2 Calculate the average mass loss,  $\bar{x}$ , and the standard deviation of the mass loss,  $s$ , for the top, second, and oil ring groups.

11.4.3 Calculate the  $\Delta/s$  for each top ring as follows:

$$\Delta/s = (|x_i - \bar{x}|)/s \quad (3)$$

where:

$x_i$  = individual ring mass loss, mg,

$\bar{x}$  = average mass loss of the top ring group, and

$s$  = standard deviation of the mass loss of the top ring group.

11.4.4 A  $\Delta/s$  value greater than 1.887 is an outlier. Remove the maximum outlier from the top ring group. Remove only one outlier from the top ring group, and recalculate  $\bar{x}$  and  $s$ . Report the maximum, minimum, average mass loss, and the standard deviation of the mass loss for the top ring group as *Outlier Screened* in the *Other Comments* section of Form 21, listed in **Table A9.1**.

11.5 *Sludge Ratings*:

11.5.1 Rate the rocker arm cover sludge and the oil pan sludge according to CRC Manual No. 20 at the locations specified in **Figs. A10.1 and A10.2**.

11.5.2 Average the rocker arm cover sludge and oil pan sludge ratings. Report as *Average Sludge Rating* on Form 8, listed in **Table A9.1**.

11.6 *Piston Ratings*—Rate the pistons according to CRC Manual No. 20 at the locations specified using the special instructions noted in **Annex A11**. For the varnish ratings, use the CRC expanded varnish scale and convert to demerits.

11.7 *Oil Filter Plugging*—Oil filter plugging ( $\Delta P_{FP}$ ) is indicated by the increase of the oil filter differential pressure ( $\Delta P$ ) during the test. The general equation for oil filter plugging is as follows:

$$\Delta P_{FP} = \Delta P_{ADJ(MAX)} - \Delta P_{INIT} \quad (4)$$

$$\Delta P = \text{Oil Filter Outlet Pressure} - \text{Oil Filter Inlet Pressure} \quad (5)$$

where:

$\Delta P_{ADJ(MAX)}$  = maximum adjusted  $\Delta P$  during the test, and

$\Delta P_{INIT}$  = first  $\Delta P$  reading of the test with target and range parameters within specification.

11.7.1 *No Shutdowns*—If no shutdowns occur, no correction is performed. **Eq 4** becomes:

$$\Delta P_{FP} = \Delta P_{MAX} - \Delta P_{INIT} \quad (6)$$

where:

$\Delta P_{MAX}$  = maximum  $\Delta P$  during the test.

11.7.2 *Shutdowns*—Separate the test into segments demarcated by shutdowns (see **Fig. A13.1**). Segment 1 is from the start of test to shutdown 1, segment 2 is from shutdown 1 to shutdown 2, and so on.

11.7.2.1  $\Delta P$  *Correction*—Determine the correction for each shutdown:

$$\text{If } \Delta P_{BS(N)} - \Delta P_{AS(N)} < 4 \text{ kPa, then } \Delta P_{CORR(N)} = 0 \quad (7)$$

$$\text{If } \Delta P_{BS(N)} - \Delta P_{AS(N)} > 4 \text{ kPa, then } \Delta P_{CORR(N)} = \Delta P_{BS(N)} - \Delta P_{AS(N)} \quad (8)$$

**TABLE 6 Test Precision**

| Parameter <sup>A</sup>                          | Intermediate Precision ( <i>i.p.</i> ) | Reproducibility ( <i>R</i> ) |
|---|--|------------------------------|
| Average Sludge                                  | 0.73                                   | 1.54                         |
| Crosshead Mass Loss                             | 8.46                                   | 8.46                         |
| Oil Filter Plugging Delta P (transformed units) | 2.4685                                 | 2.6936                       |

<sup>A</sup> Precision data are periodically updated and are available from the TMC.

where:

- $N$  = shutdown number,  
 $\Delta P_{BS(N)}$  = last  $\Delta P$  reading before initiation of shutdown  $N$ ,  
 $\Delta P_{AS(N)}$  = first  $\Delta P$  reading after shutdown  $N$  with target and range parameters within specification, and  
 $\Delta P_{CORR(N)}$  =  $P$  correction due to shutdown  $N$ .

11.7.3 *Adjusted  $\Delta P$* —Add  $\Delta P_{CORR}$  to each  $\Delta P$  reading subsequent to the shutdown. In general, sum the  $\Delta P_{CORR}$  of prior shutdowns and add to each  $\Delta P$  reading of the current segment (see Fig. A13.2).

$$\Delta P_{ADJ(N)} = \Delta P_N + \left[ \sum \Delta P_{CORR(N-1)} \right]_{2, \dots, N} \quad (9)$$

where:

- $N$  = segment number,  
 $\Delta P_{ADJ(N)}$  = adjusted  $\Delta P$  readings during segment  $N$ ,  
 $\Delta P_N$  = individual  $\Delta P$  readings during segment  $N$ ,  
 $\Delta P_{CORR(N)}$  =  $\Delta P$  correction at shutdown  $N$ , and  
 $\Delta P_{ADJ(1)}$  =  $\Delta P_1$

11.7.4 Perform separate calculations to determine 250-h and 300-h oil filter plugging values.

11.7.5 For all tests completed on or after February 21, 2002, transform the Filter Plugging Delta P result by taking the square root of the calculated result (11.7.3) and adding 3.15. Report the transformed value on Form 4, listed in Table A9.1. Square the transformed value to convert the value back to original units. Report this result in original units on Form 4, listed in Table A9.1.

11.7.6 Plot oil filter  $\Delta P$  versus test hour on Form 7, listed in Table A9.1.

11.8 *Oil Analyses*—Analyze the oil samples for viscosity at 100°C, wear metals (iron, copper, lead, chromium, and aluminum), TAN, TBN, and mass % soot (TGA) according to the schedule and methods shown in Annex A12.

11.9 *Oil Consumption*—Sum the weight of the oil consumed for the test.

11.10 *Fuel Analyses*—Report the analyses provided by the fuel supplier on Form 19, listed in Table A9.1. Report the analyses of the final batch if more than one fuel batch was used.

11.10.1 *Additional Analyses*—Perform the following analyses on the 1 L new and EOT fuel samples:

11.10.1.1 API Gravity at 15.6°C (60°F), Test Method D287 or equivalent.

11.10.1.2 Total Sulfur, % wt., Test Method D129 or equivalent.

11.11 *Assessment of Operational Validity*—Determine operational validity in accordance with Annex A12.

11.12 *Assessment of Test Interpretability*—A test is non-interpretable when the total oil consumption exceeds 21 kg. A non-reference test is non-interpretable when the 250-h soot is less than 8.0 mass % (10.8.6). A non-reference test is non-interpretable when the oil gallery pressure drops below 200 kPa before 250 h (10.7.3.2).

## 12. Test Report

12.1 *Report Forms*—For reference oil tests, the standardized report form set and data dictionary for reporting test results and for summarizing the operational data are required. The report forms and data dictionary are available from the TMC. Instructions for obtaining the report forms and data dictionary and a list of report forms are shown in Annex A9.

12.1.1 Report all wear, deposits, engine operational data, oil analysis, and fuel analysis on the appropriate form in the test report.

12.2 *Reference Oil Test*—Send the test report forms and any other supporting information to the TMC<sup>12</sup> by facsimile or electronic transmission within five days of the EOT date for test acceptance determination. Reference oil test reports should be mailed or electronically transmitted to the TMC within 30 days of the EOT date.

12.2.1 *Electronic Transmission of Test Results*—Use ASTM Data Communications Committee Test Report Transmission Model (Section 2—Flat File Transmission Format).<sup>12</sup>

## 13. Precision and Bias

13.1 *Precision*—Precision is based on operationally valid calibration test results monitored by the TMC. The research report contains industry data developed prior to the establishment of this test method.

13.1.1 *Intermediate Precision (formerly called repeatability) Conditions*—Conditions where test results are obtained with the same test method using the same test oil, with changing conditions such as operators, measuring equipment, test stands, test engines, and time.

13.1.1.1 *Intermediate Precision Limit (i.p.)*—The difference between two results obtained under intermediate precision conditions that would in the long run, in the normal and correct conduct of the test method, exceed the values shown in Table 6 in only one case in twenty.

13.1.2 *Reproducibility Conditions*—Conditions where test results are obtained with the same test method using the same test oil in different laboratories with different operators using different equipment.

13.1.2.1 *Reproducibility Limit (R)*—The difference between two results obtained under reproducibility conditions that would, in the long run, in the normal and correct conduct of the test method, exceed the values in Table 6 in only one case in twenty.

13.2 *Bias*—Bias is determined by applying a defined statistical technique to calibration test results. When a significant bias is determined, a severity adjustment is applied to the non-reference oil test result.

## **14. Keywords**

14.1 crosshead wear; Cummins M11 EGR; de-rate protocols; diesel engine oil; exhaust gas recirculation; lubricants; oil filter delta pressure; sludge; top ring weight loss; valve train

## **ANNEXES**

### **(Mandatory Information)**

#### **A1. SAFETY PRECAUTIONS**

A1.1 The operation of engine tests may expose personnel and facilities to safety hazards. Personnel trained and experienced with engine testing should perform the design, installation, and operation of test stands.

A1.2 Guards (shields) should be installed around all external moving, hot, or cold components. Design the guard to contain the energy level of a rotating component should the component break free. Fuel, oil, coolant, and electrical wiring should be properly routed, guarded, grounded, and kept in good order.

A1.3 The test stand should be kept free of oil and fuel spills and tripping hazards. Containers of oil or fuel, or both, should not be permitted to accumulate in the testing area. Fire fighting equipment should be immediately accessible. Normal precautions should be observed whenever using flammable solvents for cleaning purposes.

A1.4 Safety masks, glasses, or hearing protection, or a combination thereof, should be worn by personnel working on

the test stand. No loose or flowing clothing, including long hair or other accessory to dress, should be worn near rotating equipment. Personnel should be cautioned against working alongside the engine and driveline while the engine is running.

A1.5 Interlocks should automatically shutdown the engine when an anomaly of any of the following occur: engine or dynamometer coolant temperature, engine oil pressure, dynamometer field current, engine speed, exhaust temperature, excessive vibration, or when the fire protection system is activated. The interlock should include a method to cut off the fuel supply to the engine at the injector pump (including the return line). A remote fuel cut off station (external to the test stand) is recommended.

A1.6 Employ other safety precautions as required by regulations.

#### **A2. INTAKE AIR AFTERCOOLER**

A2.1 Obtain the Modine aftercooler from a Mack Truck dealer. Order the aftercooler using part number 5424 03 928 031. This is a non-stocked part in the Mack Parts Distribution System and will appear as an invalid part number. Instruct the

dealer to expedite the aftercooler on a Ship Direct purchase order. The aftercooler will be shipped directly from Modine, bypassing the normal Mack Parts Distribution System.

**A3. ENGINE BUILD PARTS KIT**

A3.1 See [Tables A3.1 and A3.2](#).

**TABLE A3.1 Engine Build Parts Kit**

| Description                            | Cummins<br>P/N     | Per Kit | Critical |
|--|--------------------|---------|----------|
| <b>Cam Follower Parts</b>              |                    |         |          |
| Injector cam follower assy             | 3417645            | 6       | Y        |
| Valve cam follower                     | 3161475            | 12      | Y        |
| Cam follower shaft                     | 3417766            | 2       | Y        |
| Cam follower shaft support<br>(end)    | 3064583            | 1       | Y        |
| Cam follower shaft support<br>(center) | 3895830            | 5       | Y        |
| Cam follower shaft support<br>(end)    | 3064582            | 1       | Y        |
| Plain washer                           | 3009330            | 7       |          |
| <b>Cylinder Head Parts</b>             |                    |         |          |
| Expansion plug                         | 3007632            | 2       |          |
| Expansion plug                         | 3895479            | 2       |          |
| Expansion plug                         | 206741             | 2       |          |
| Expansion plug                         | 3007635            | 8       |          |
| Valve seat (exhaust)                   | 3090704            | 12      |          |
| Valve insert (intake)                  | 3088978            | 12      |          |
| Valve stem guide                       | 3328785            | 24      |          |
| Valve spring                           | 3895860            | 24      | Y        |
| Intake valve                           | 3417778            | 12      |          |
| Valve collet                           | 3275354            | 48      |          |
| Exhaust valve                          | 3417779            | 12      |          |
| Valve spring retainer                  | 3883512            | 24      | Y        |
| Spring guide                           | 3070072            | 24      |          |
| Pipe plug                              | 3008465            | 16      |          |
| Orifice plug                           | 3820749            | 6       |          |
| Valve stem seal, intake                | 3328781            | 12      | Y        |
| Valve stem seal, exhaust               | 3328781            | 12      | Y        |
| <b>Overhead Components</b>             |                    |         |          |
| Rocker lever assembly<br>(exhaust)     | 3400974<br>4003906 | 3       | Y        |
| Rocker lever assembly<br>(exhaust)     | 3400971<br>4003903 | 3       | Y        |
| Rocker lever assembly<br>(intake)      | 3400973<br>4003905 | 3       | Y        |
| Rocker lever assembly<br>(intake)      | 3400972<br>4003904 | 3       | Y        |
| Rocker lever assembly<br>(injector)    | 3069020<br>3068947 | 6       | Y        |
| Rocker lever shaft                     | 3417765            | 2       | Y        |
| Valve crosshead (EGR<br>batch)         | 3070175            | 12      | Y        |
| Push rod                               | 3068390            | 12      |          |
| Push rod                               | 3076046            | 6       |          |
| Rocker lever support                   | 3893584            | 4       |          |
| Rocker lever support                   | 3079662            | 2       |          |
| Rocker lever support                   | 3079661            | 2       |          |
| Retaining clamp                        | 3077444            | 8       |          |
| <b>Pistons/Rings/Liners</b>            |                    |         |          |
| Piston top                             | 3896030            | 6       | Y        |
| Piston skirt                           | 3081334            | 6       | Y        |
| Piston pin                             | 3063843            | 6       |          |
| Retaining ring                         | 3016652            | 12      |          |
| Top compression ring                   | K171646            | 6       | Y        |
| Second compression ring                | 3899413            | 6       | Y        |
| Oil ring                               | 3161808            | 6       |          |
| Cylinder liner                         | 3080760            | 6       | Y        |
| <b>Miscellaneous Components</b>        |                    |         |          |
| Pressure regulator plunger             | 3068979            | 1       |          |
| Compression spring                     | 3010146            | 1       |          |
| Retainer plug                          | 3895718            | 1       |          |
| Piston cooling nozzle                  | 3080708            | 6       |          |
| Rectangular seal                       | 3047188            | 6       |          |
| Oil cooler                             | 3161781            | 1       |          |
| Connecting rod bearing                 | 3016760            | 12      | Y        |
| Gasket, Stainless Steel EGR            | 3680850            | 2       | Y        |
| Gasket, Exhaust to EGR                 | EX239064AM         | 1       | Y        |
| Cooler                                 |                    |         |          |
| EGR Hose                               | EX3101632          | 2       | Y        |
| Oil filter<br>(EGR-3)                  | 3401544            | 1       | Y        |

TABLE A3.2 Non-Kit Parts Available from the CPD

| Description                           | P/N           | Critical Part |
|---------------------------------------|---------------|---------------|
| EGR Cooler                            | 3101174       | Y             |
| Gasket                                | 3680850       | Y             |
| EGR Flex Pipe                         | Y4006151      | Y             |
| Mounting Plate                        | Y4006095      | Y             |
| Exhaust Gasket                        | EX239064AM    | Y             |
| Exhaust Manifold Assembly             | Y4006116      | Y             |
| Cylinder Head                         | 4004086       | Y             |
| Injector (400 hp)                     | 3411753       | Y             |
| Turbocharger                          | V00382 HX52wc | Y             |
| Engine Block with disabled capacitors | 3329058       | Y             |
| Test Stand Setup Kit                  |               |               |
| EGR Cooler Exhaust Gas Exit Pipe      | TEGR0002      | Y             |
| EGR Cooler Coolant Pipe               | TEGR0004      | Y             |
| EGR Hose                              | 3101632       | Y             |
| EGR Exhaust Gas Elbow                 | TEGR0003      | Y             |

A4. SENSOR LOCATIONS AND SPECIAL HARDWARE

A4.1 See Figs. A4.1-A4.16.

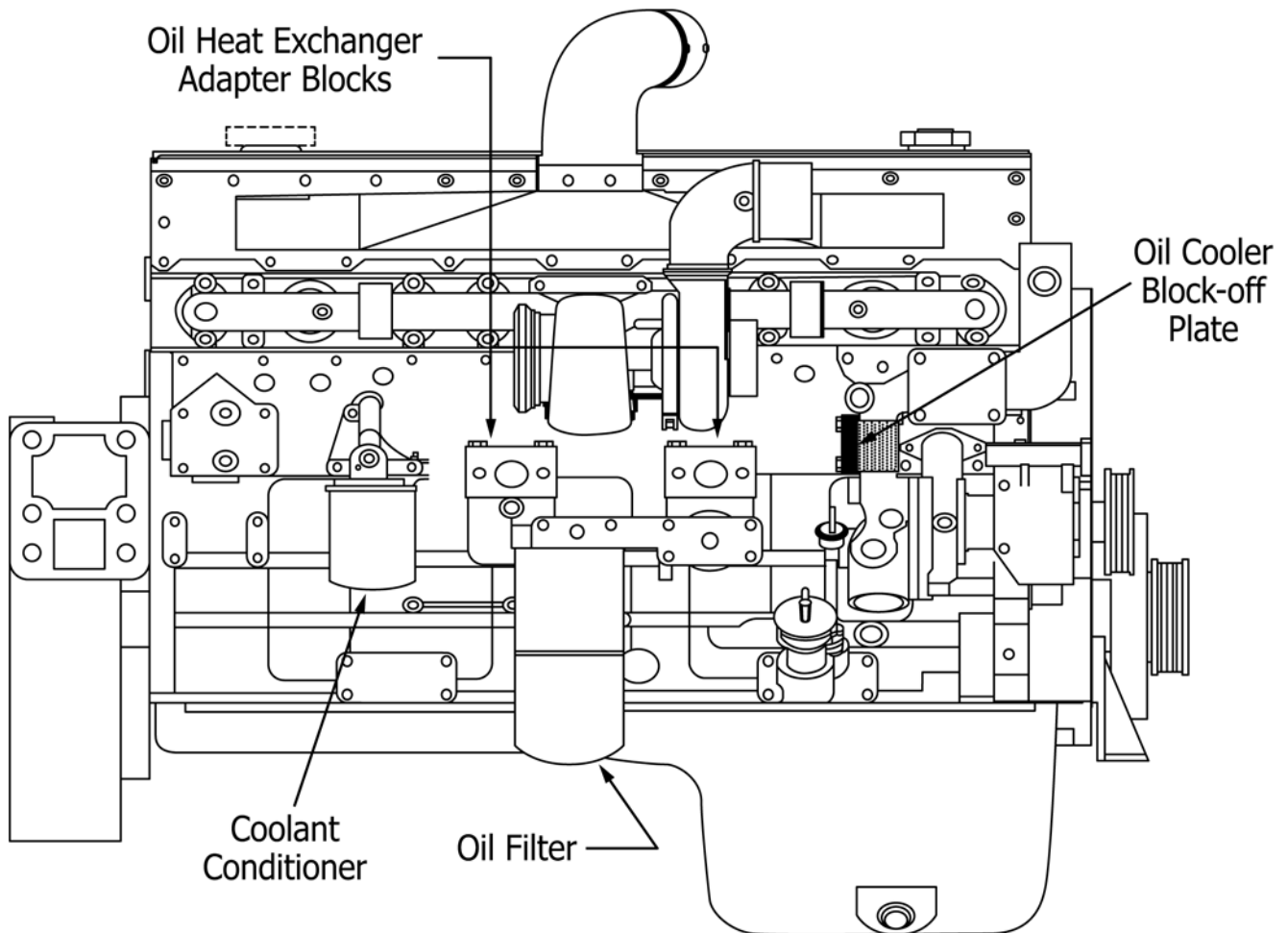


FIG. A4.1 Oil Heat Exchanger Adapter Blocks, and Oil Cooler Block-off Plate



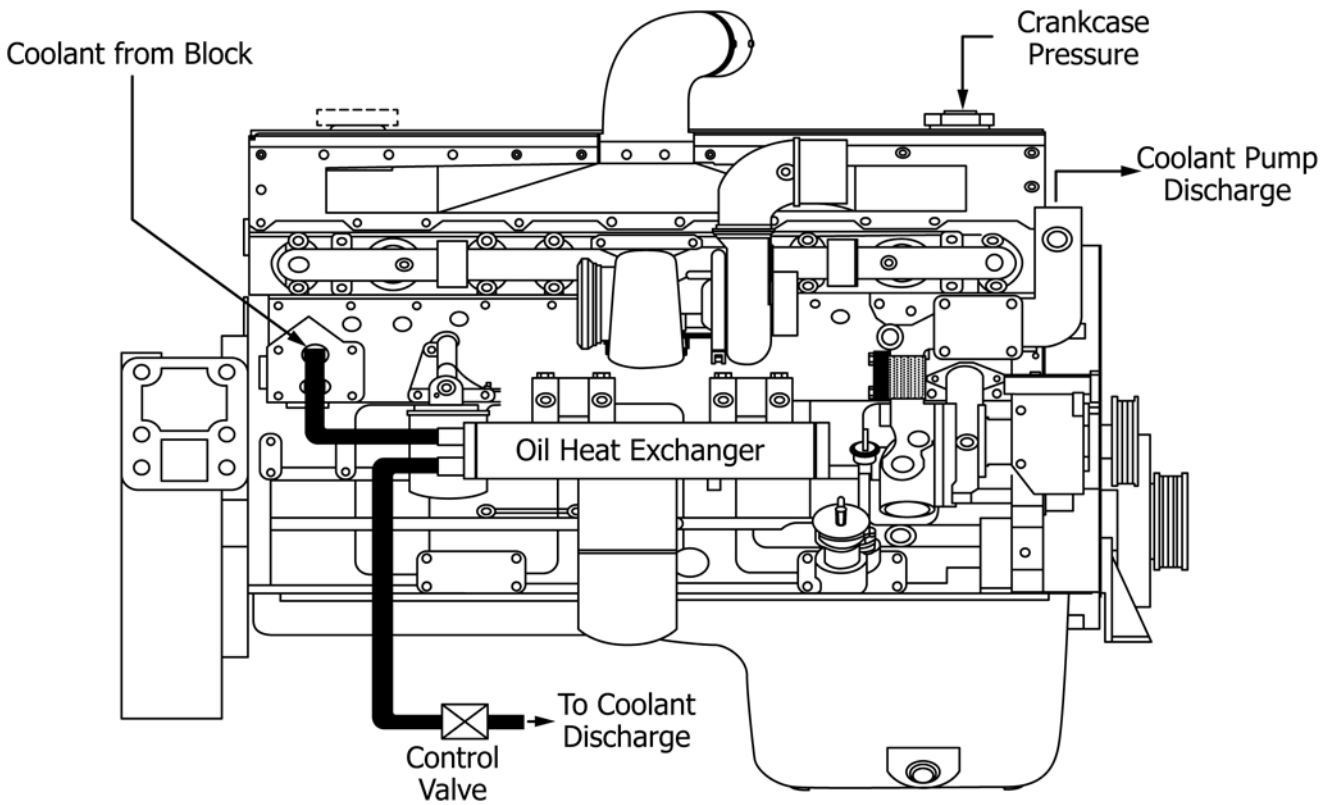


FIG. A4.2 Oil Heat Exchanger, Crankcase Pressure and Coolant Discharge Locations

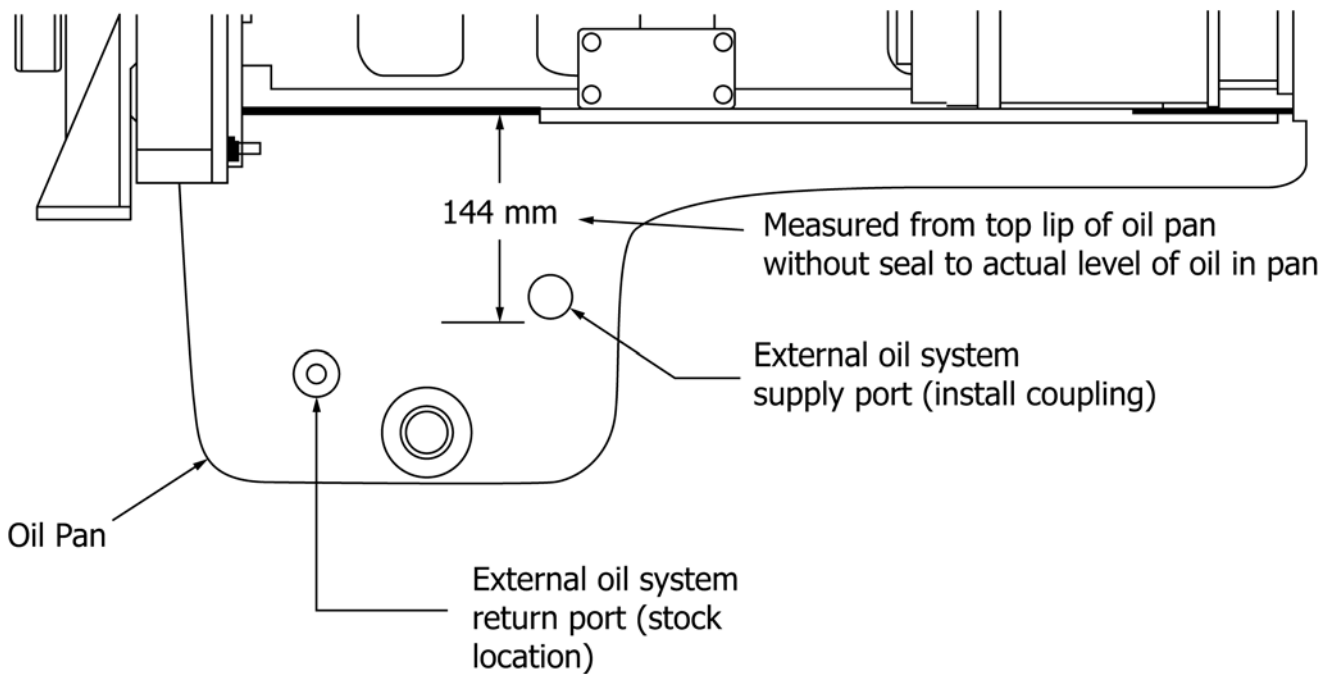


FIG. A4.3 Oil Pan Modifications

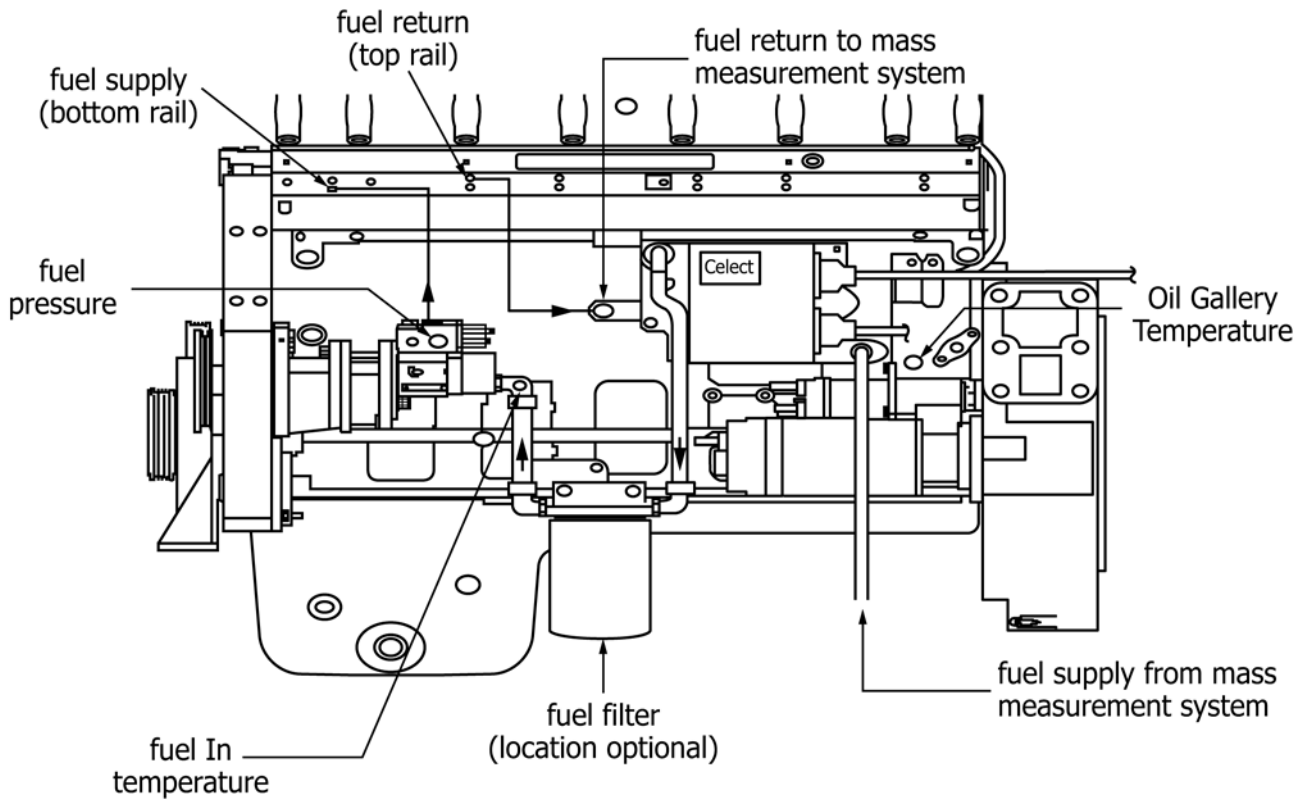
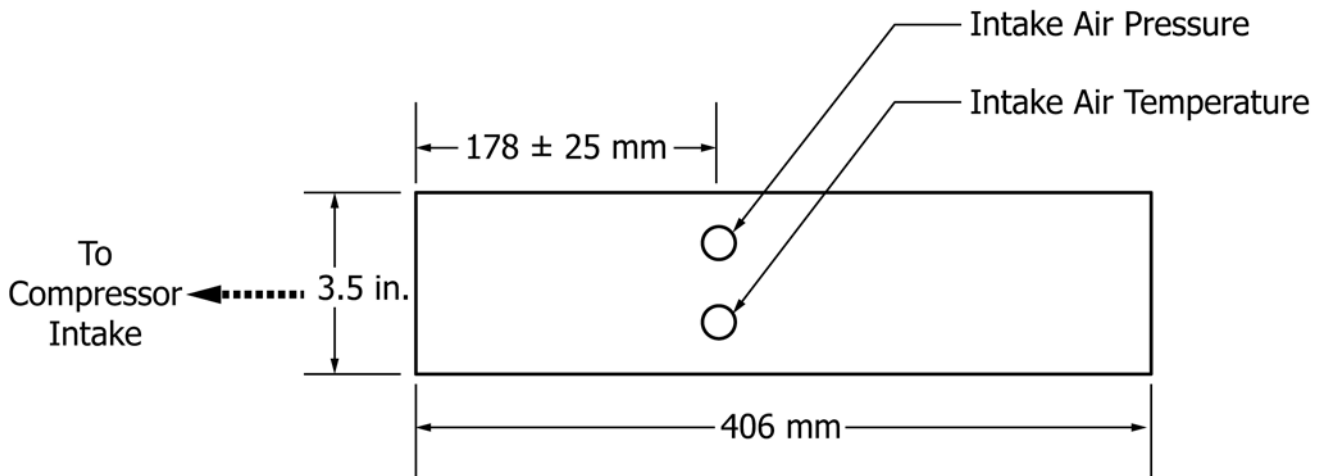


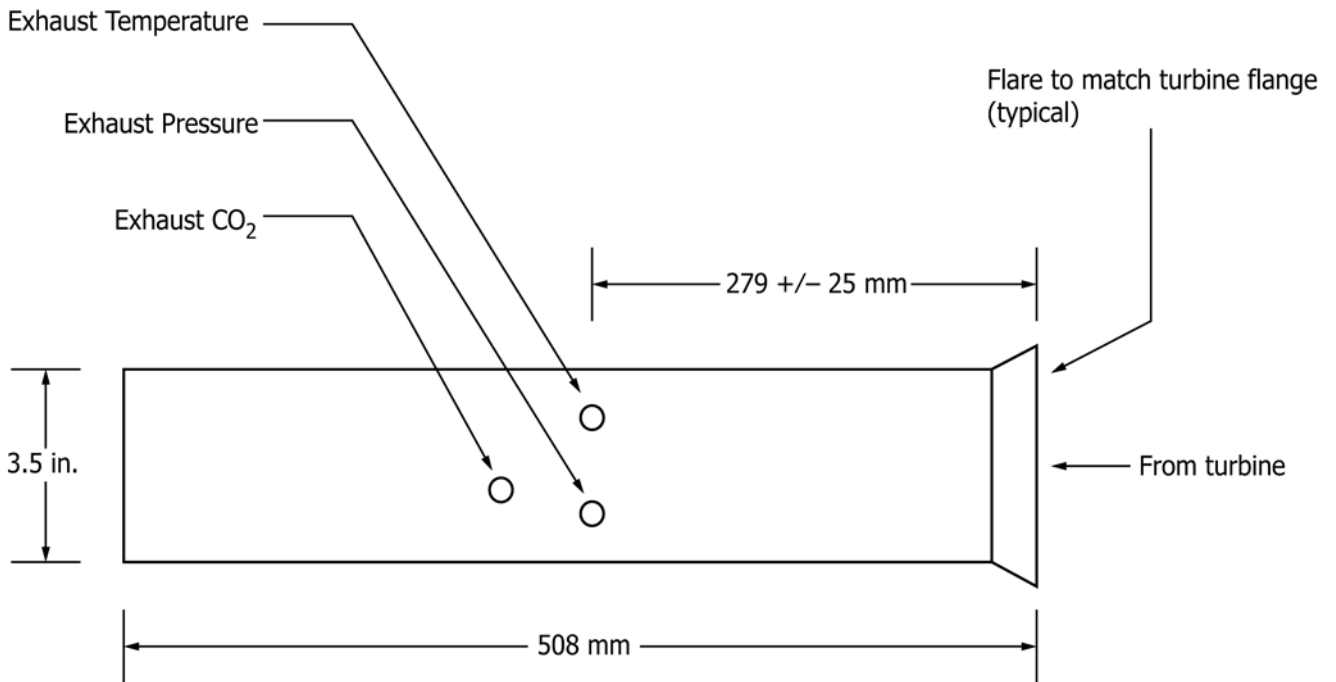
FIG. A4.4 Fuel In Temperature, Fuel Pressure, Oil Gallery Temperature, and Oil Gallery Pressure Locations



NOTE 1—The relative radial position and spacing of the Intake Air Pressure and Intake Air Temperature taps is not specified.

NOTE 2—Tubing: 3.5 in. O.D. by 0.0625 in. wall thickness.

FIG. A4.5 Intake Air of the Pressure and Temperature Locations



NOTE 1—The relative radial position and spacing of the Exhaust Pressure, Exhaust Temperature, and Exhaust CO<sub>2</sub> taps is not specified.

NOTE 2—Tubing dimensions: 3.5 in. O.D. with 0.0625 in. wall thickness.

FIG. A4.6 Exhaust Temperature, Exhaust Pressure and Exhaust CO<sub>2</sub> Probe Locations

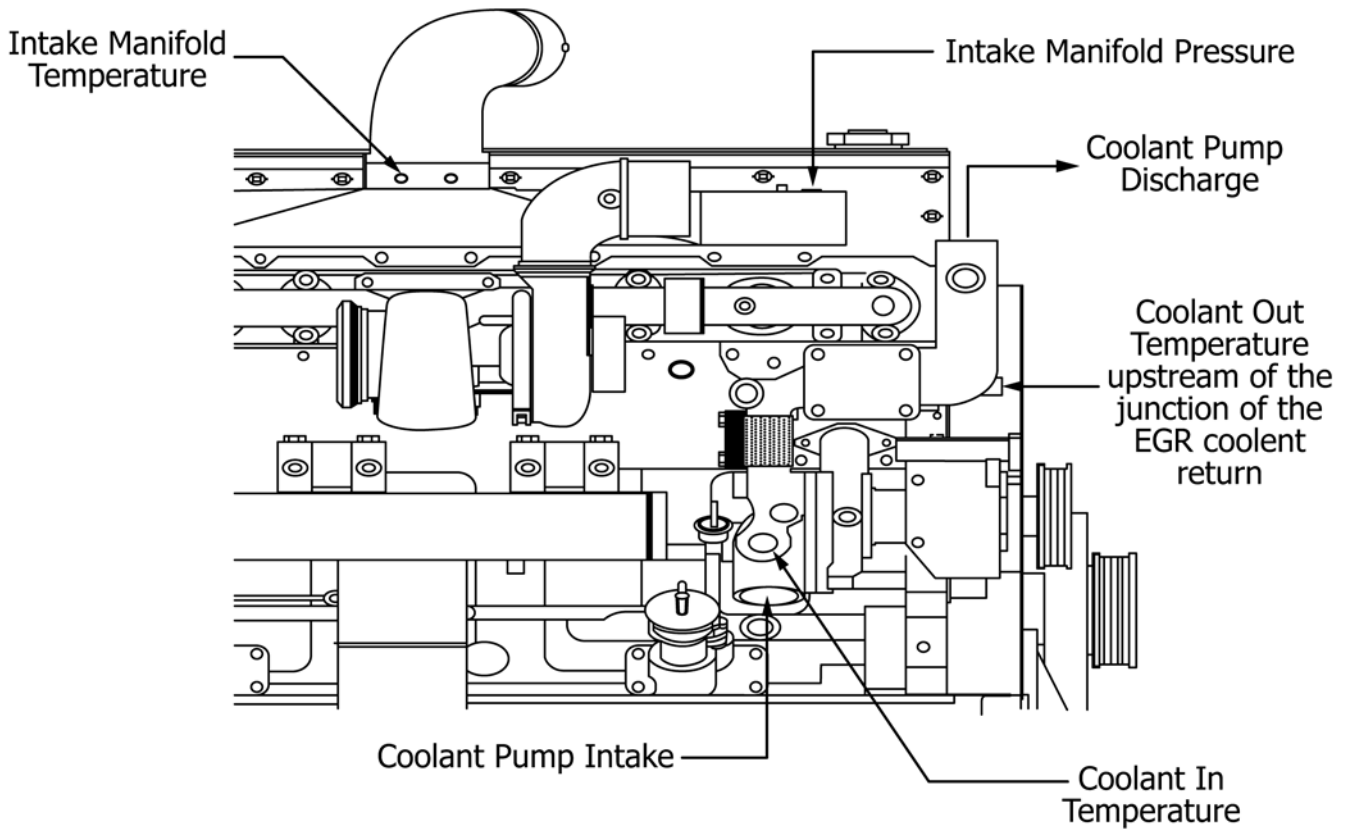


FIG. A4.7 Intake Manifold Pressure, Intake Manifold Temperature, Coolant Out Temperature, and Coolant In Temperature Measurement Locations

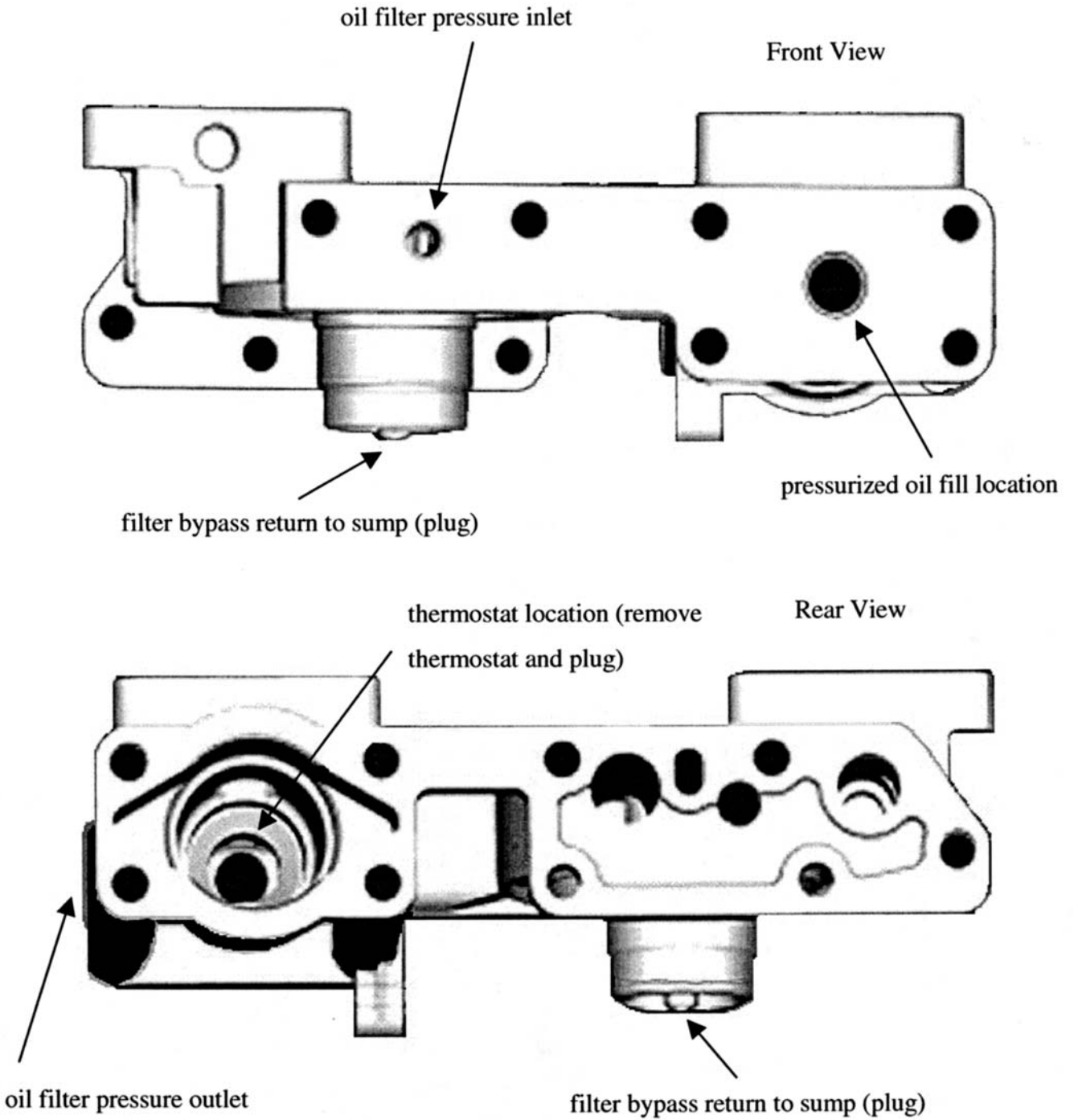
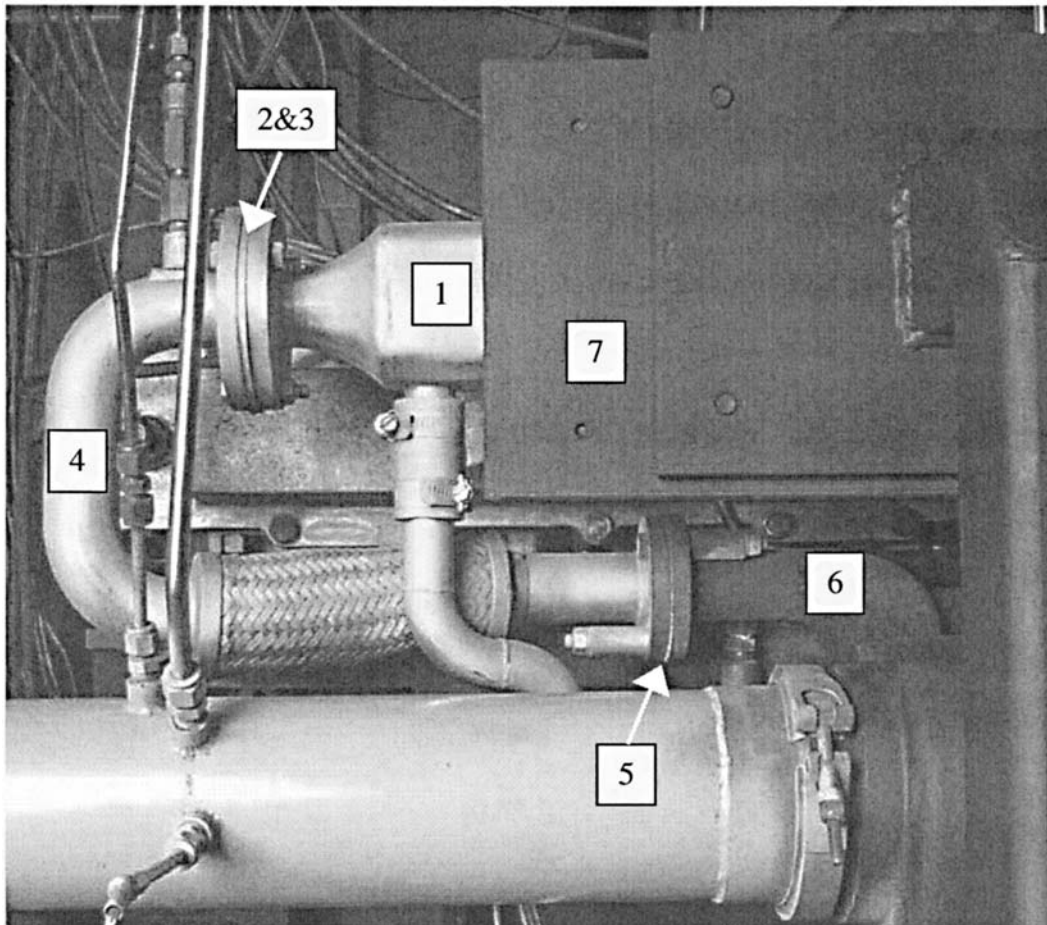


FIG. A4.8 Oil Filter Pressure Measurement Locations and Pressurized Oil Fill Location



NOTE 1—EGR Cooler, Part Number 3101174

NOTE 2—Gasket (2), Part Number 3680850

NOTE 3—Restrictor Plate (no part number)

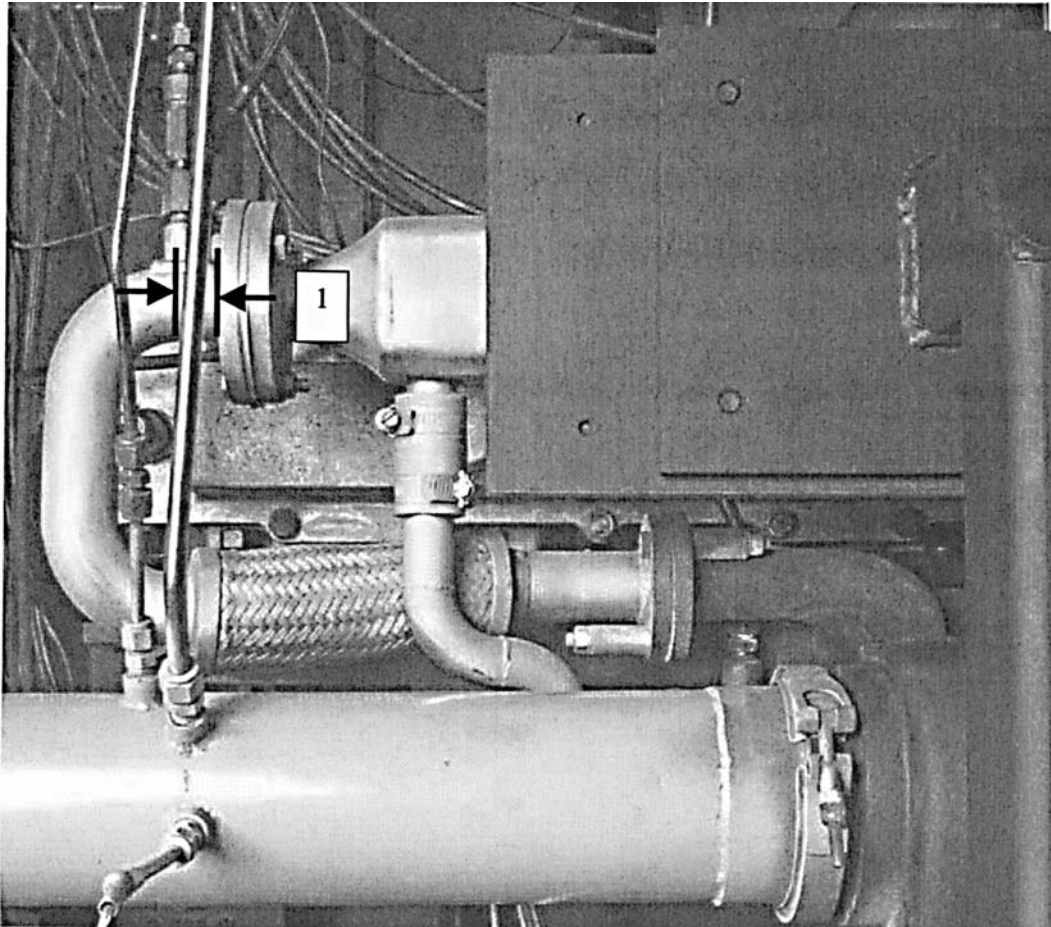
NOTE 4—EGR Flex Pipe, Part Number Y4006151

NOTE 5—Exhaust Gasket, Part Number EX239064AM

NOTE 6—Exhaust Manifold Assembly, Part Number Y4006116

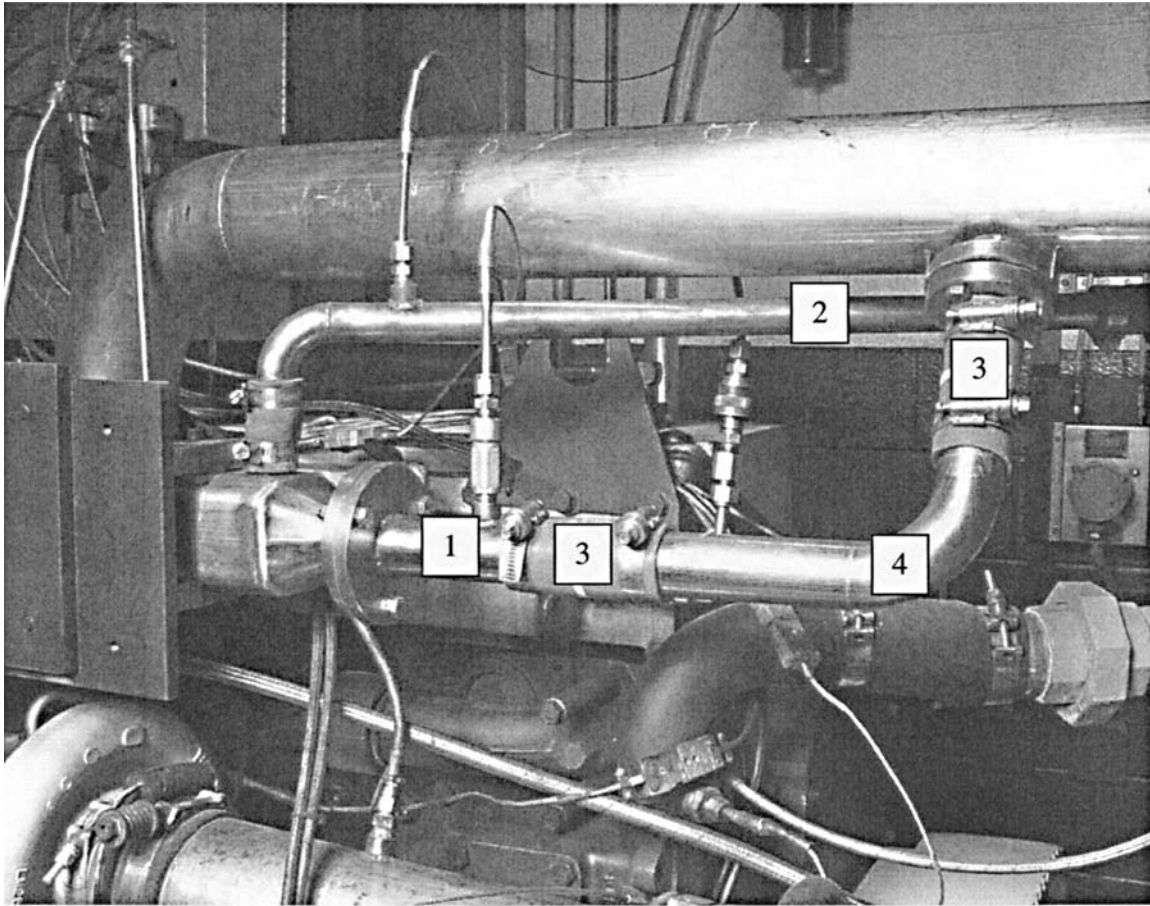
NOTE 7—Mounting Plate, Part Number Y4006095

**FIG. A4.9 EGR Components on EGR Cooler Inlet Side**



NOTE 1—Temperature and pressure tap located 25 mm (nominal) from flange surface.

**FIG. A4.10 EGR Cooler Inlet Temperature and Pressure Measurement Location**



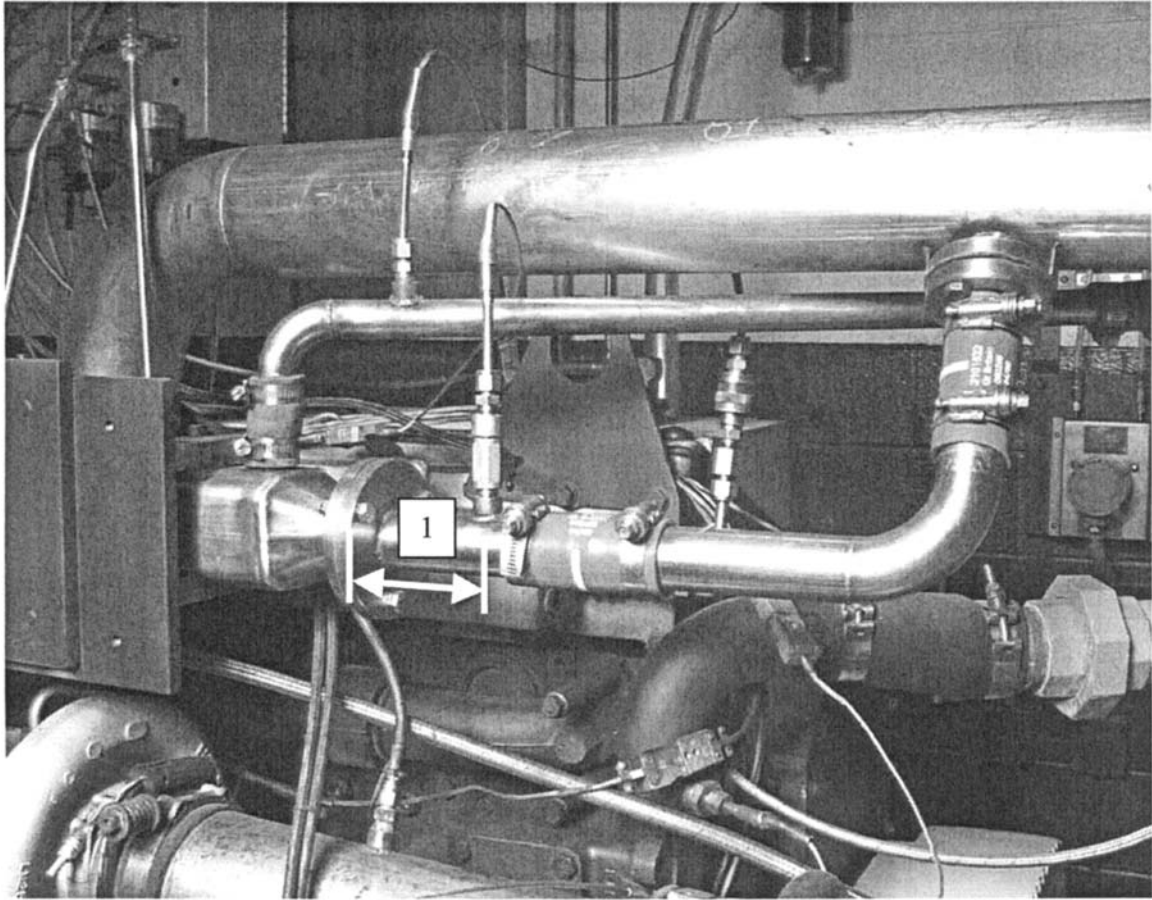
NOTE 1—Part Number, TEGR0002

NOTE 2—Part Number TEGR0004

NOTE 3—Part Number 3101632

NOTE 4—Part Number TEGR0003

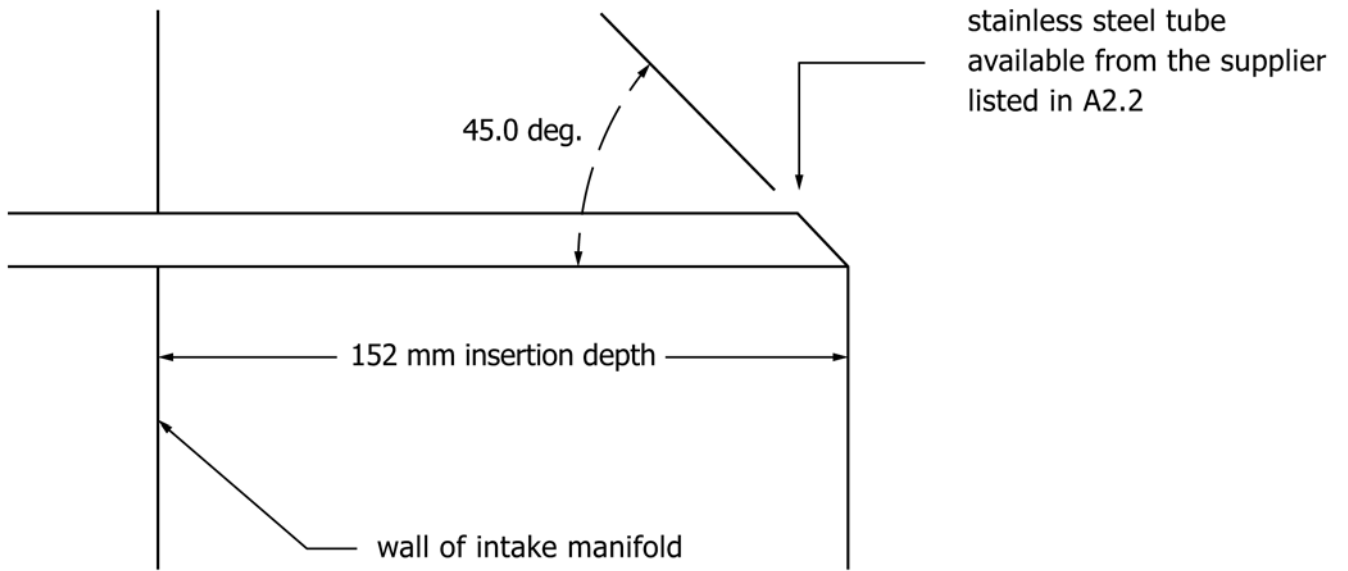
**FIG. A4.11 EGR Components on EGR Cooler Outlet Side**



NOTE 1—Temperature and pressure tap located 85 mm (nominal) from flange surface.

**FIG. A4.12 EGR Cooler Outlet Temperature and Pressure Measurement Location**





Probe is installed into the front of the intake manifold behind the engine water outlet.

Tip faces intake manifold, away from intake ports

FIG. A4.13 Intake Manifold CO<sub>2</sub> Probe Insertion Depth

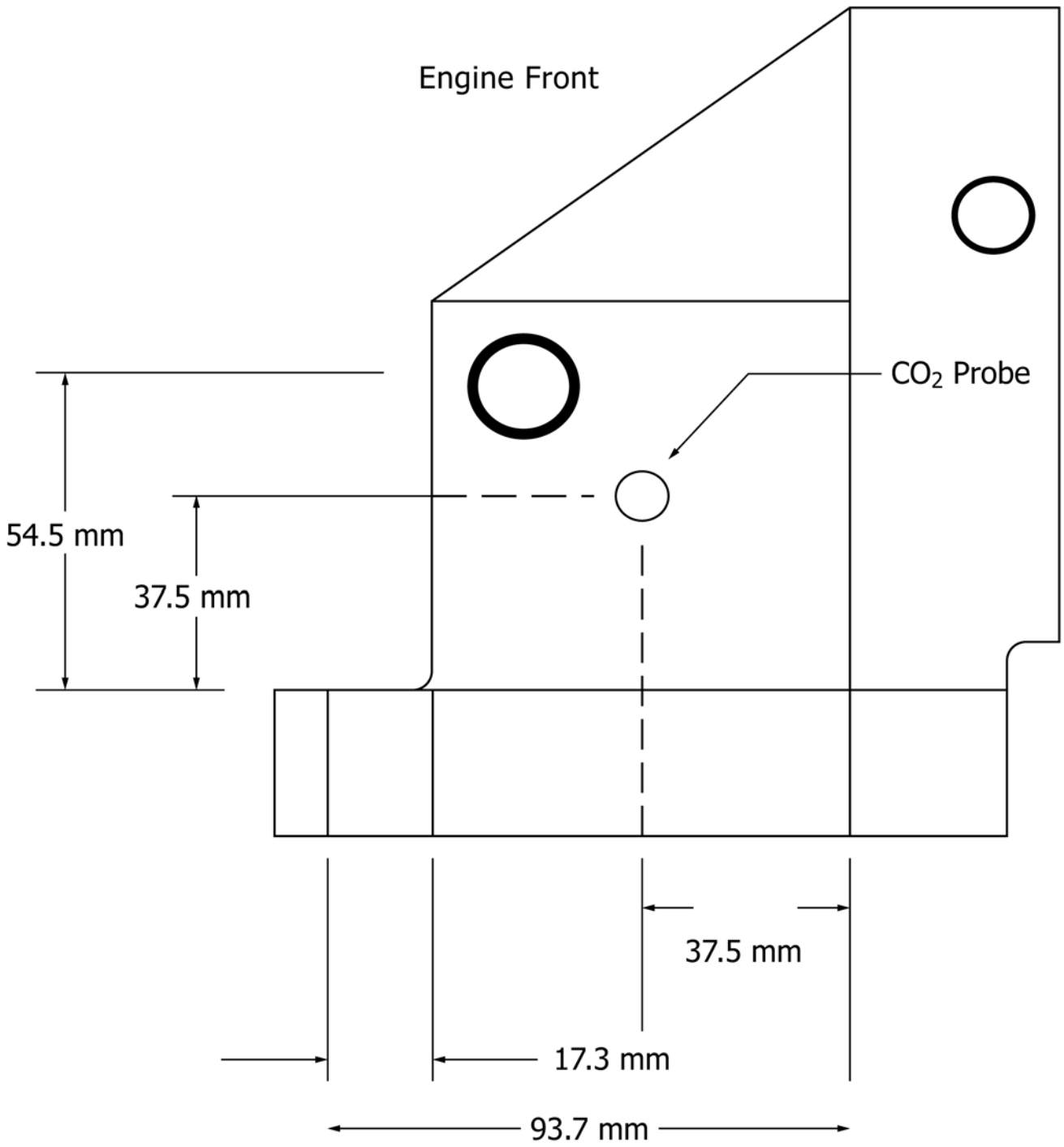
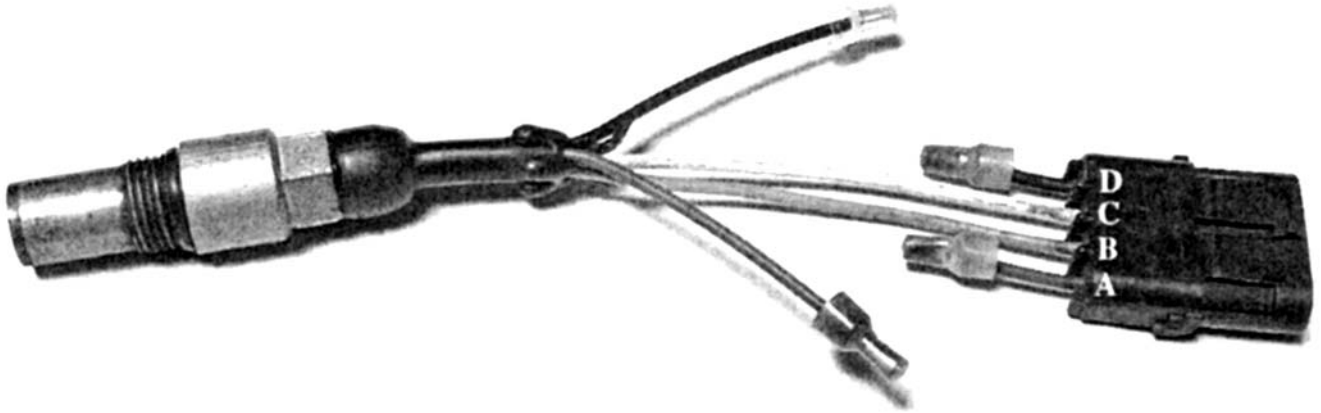
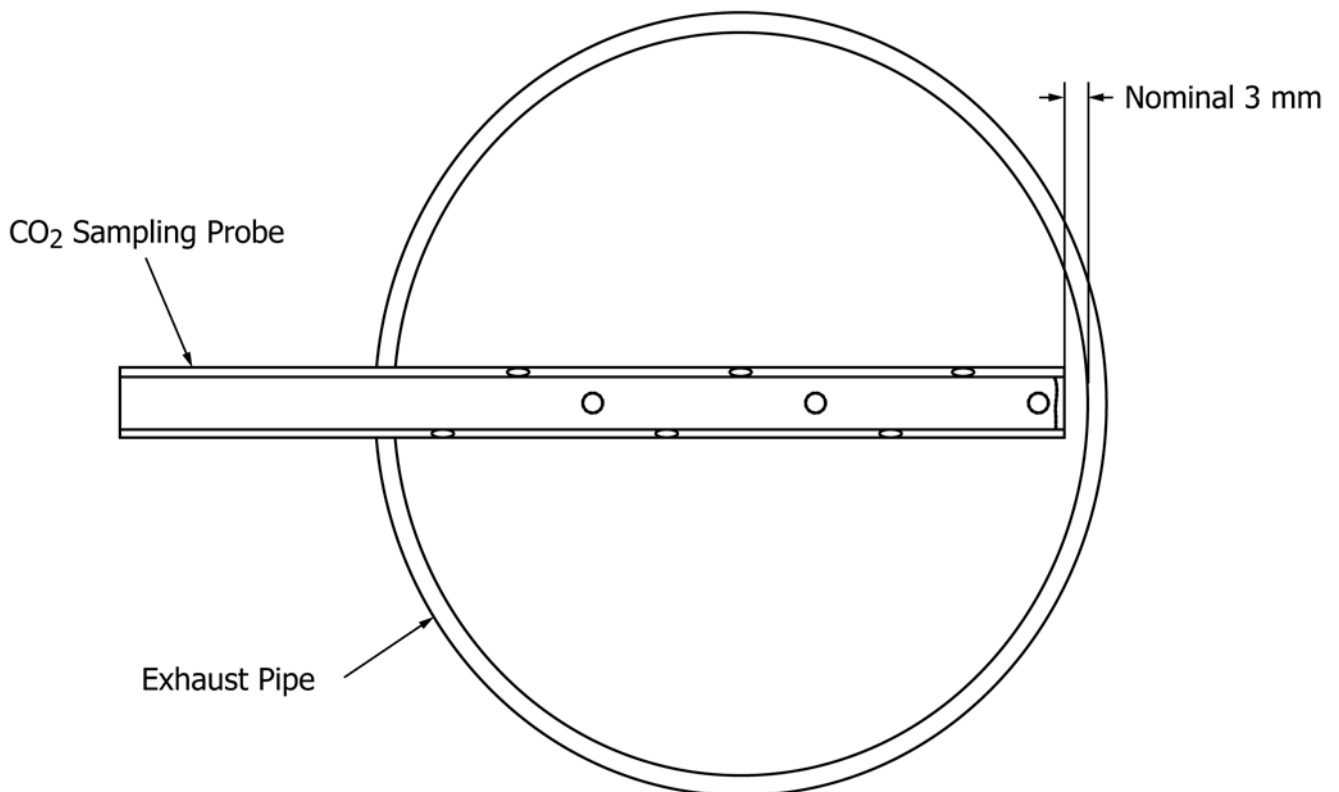


FIG. A4.14 Intake Manifold CO<sub>2</sub> Probe Location



NOTE 1—Cut red and black leads (shown as A and D, respectively, in image above).

FIG. A4.15 Engine Position Sensor Modifications



NOTE 1—Fabricate probe according to details referenced in [A15.1](#).

FIG. A4.16 Exhaust CO<sub>2</sub> Sampling Probe Insertion Depth

A5. EXTERNAL OIL SYSTEM

A5.1 See Fig. A5.1.

Pump Flowrate:  
 $P_r = 4 - 8 \text{ L/min}$   
 $P_s = 1.5 * P_r$   
 Hoses:  
 Supply - 12 mm (1/2 in.)  
 Return - 10 mm (3/8 in.)  
 Vent - 12 mm (1/2 in.) minimum

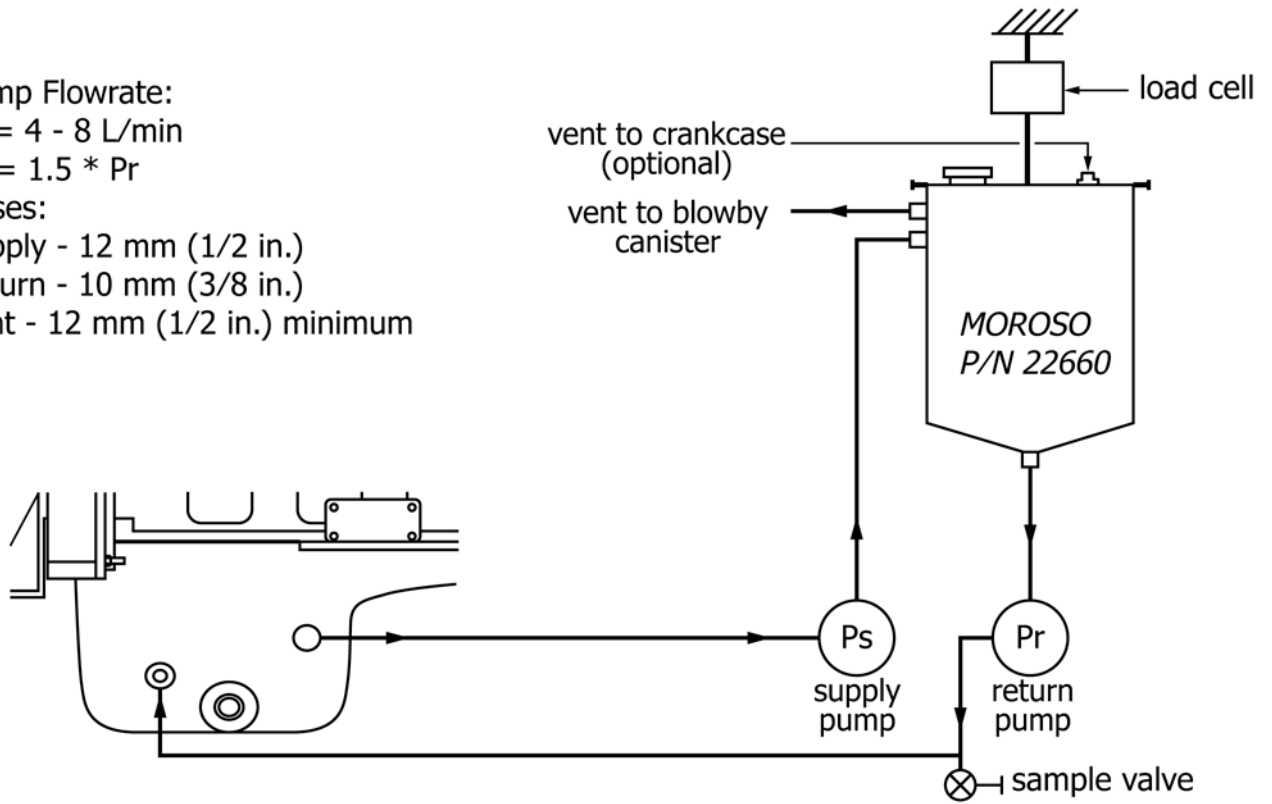


FIG. A5.1 External Oil System

A6. FUEL SPECIFICATIONS

A6.1 See Table A6.1.

**TABLE A6.1 Fuel Specifications**

| Property                            | Test Method         | Minimum <sup>A</sup> | Maximum <sup>A</sup> |
|-------------------------------------|---------------------|----------------------|----------------------|
| Sulfur, % mass                      | D2622               | 0.04                 | 0.05                 |
| Gravity, degrees API                | D287 or D4052       | 34.5                 | 36.5 (37)            |
| Hydrocarbon Composition, % volume   |                     |                      |                      |
| Aromatics                           | D1319 (FIA)         | 28 (27)              | 33                   |
| Olefin                              | D1319 (FIA)         |                      | Report               |
| Cetane Number                       | D613                | 42 (40)              | 48                   |
| Cetane Index                        | D4737 and D976      |                      | Report               |
| Copper Strip Corrosion              | D130                |                      | 1                    |
| Flash Point, °C                     | D92                 | 54                   |                      |
| Pour Point, °C                      | D97                 |                      | -18                  |
| Cloud Point, °C                     | D2500               |                      | Report               |
| Carbon Residue on 10 % Residuuum, % | D524 (10 % Bottoms) |                      | 0.35                 |
| Water and Sediment, % volume        | D2709               |                      | 0.05                 |
| Viscosity, cSt at 40°C              | D445                | 2.4                  | 3.0                  |
| Ash, % mass                         | D482                |                      | 0.005                |
| Total Acid Number                   | D664                |                      | 0.05                 |
| Strong Acid Number                  | D664                |                      | 0.00                 |
| Accelerated Stability               | D2274               |                      | TBD                  |
| Distillation, °C                    | D86                 |                      |                      |
| IBP                                 |                     |                      | Report               |
| 10 %                                |                     |                      | Report               |
| 50 %                                |                     |                      | Report               |
| 90 %                                |                     | 282                  | 338                  |
| EP                                  |                     |                      | Report               |

<sup>A</sup> Minimum and Maximum numbers in parentheses are EPA Certification Fuel Specifications.

## A7. CUMMINS SERVICE PUBLICATIONS

A7.1 General preparation techniques for Cummins M11 engines are detailed in the Cummins publication titled, Shop Manual—M11 Series Engines, Bulletin No. 3666075-00.

A7.2 Engine specifications, component specifications and torque values can be found in the Cummins publication titled, Specification Manual—M11 Series Engines, Bulletin No. 3666076-00.

A7.3 Troubleshooting and repair information can be found in the Cummins publication titled, Troubleshooting and Repair Manual—M11 Series Engines, Bulletin No. 3666074-00.

A7.4 Valve train overhead adjustments are shown in the video tape titled, N14/L10 Command Select Overhead Adjustments, Bulletin No. 3387746.

A7.5 Information concerning the reuse of overhead components can be found in the Cummins publication titled, Cummins Overhead Reuse Guidelines L-10 Series Engines, Bulletin No. 3810388-00.

## A8. SPECIFIED UNITS AND FORMATS

### A8.1 Specified Units:

A8.1.1 The parameters in this test method are specified in metric units except for pipe fittings, tubing, tubing fittings, and Compucheck fittings. Pipe fittings, tubing, and tubing fittings are available worldwide and are not interchangeable with metric-sized equivalents because of differences in thread dimensions. Therefore no metric conversion is stated. The Compucheck fittings are diagnostic ports in the Cummins M11 engine block. The ports are standard straight thread and are not interchangeable with metric-sized equivalents.

A8.1.2 *Test Report*—Record operational parameters according to **Table A8.1**. Report test results in the units and with the significant digits shown in **Table A8.2**. Round test results in compliance with Practice **E29**.

A8.1.3 *Measurements and Conversions*—With the exceptions noted in **A8.1.1**, all parameters have been specified in SI units. The intent of this test method is to measure all parameters directly in SI units. If parameters are measured in inch-pound units, then the laboratory shall be able to demonstrate to the TMC that the measurements are within the tolerance after conversion to SI units.

A8.1.3.1 Significant error may occur due to rounding or tolerance stacking, or both, when converting from inch-pound units to SI units.

A8.2 *Specification Format*—Specifications are listed in three formats:

- (1) Target,
- (2) Target and range, and
- (3) Range with no target.

A8.2.1 *Target*—A target specification has no tolerance. Therefore the only acceptable value is the target. A representative specification format is xx.xx (target). For example, the oil pan oil charge is listed as 24.7 kg.

A8.2.1.1 A parameter with a target shall not be intentionally calibrated or controlled at a level other than the target.

A8.2.2 *Target and Range*—A target and a range specification implies the correct value is the target, and the range is intended as a guide for maximum acceptable variation about the mean. A representative specification format is xx.xx ± x.xx (target ± range). For example, the engine speed is 1800 ± 5 r/min.

NOTE A8.1—The mean of a random sample should be equivalent to the target. Operation within the range does not imply that parameter will not bias the final test results.

A8.2.3 *Range with No Target*—A range with no target specification is used when (1) the parameter is not critical and control within the range is sufficient or (2) the measurement technique is not precise, or both. A representative specification format is xx.xx - xx.xx (rangelow—rangehigh). For example, the coolant system pressure is 99 to 107 kPa.

**TABLE A8.1 Minimum Resolution of Recorded Measurements**

| Parameter                      | Record Data to Nearest |
|--------------------------------|------------------------|
| Speed                          | 1 r/min                |
| Power                          | 1 kW                   |
| Torque                         | 1 N-m                  |
| Fuel Flow                      | 0.1 kg/h               |
| Coolant In Temperature         | 0.1°C                  |
| Coolant Out Temperature        | 0.1°C                  |
| Fuel In Temperature            | 0.1°C                  |
| Oil Gallery Temperature        | 0.1°C                  |
| Intake Air Temperature         | 0.1°C                  |
| Exhaust (Tailpipe) Temperature | 1°C                    |
| Intake Manifold Pressure       | 0.1 kPa                |
| Crankcase Pressure             | 0.01 kPa               |
| Exhaust Pressure               | 0.1 kPa                |

**TABLE A8.2 Significant Digits for Test Results**

| Parameter       | Round Off to Nearest |
|-----------------|----------------------|
| Mass Loss       | 0.1 mg               |
| Sludge          | 0.1 merit            |
| Filter Plugging | 1 kPa                |

## A9. REPORT FIGURES (FORMS) AND DATA DICTIONARY

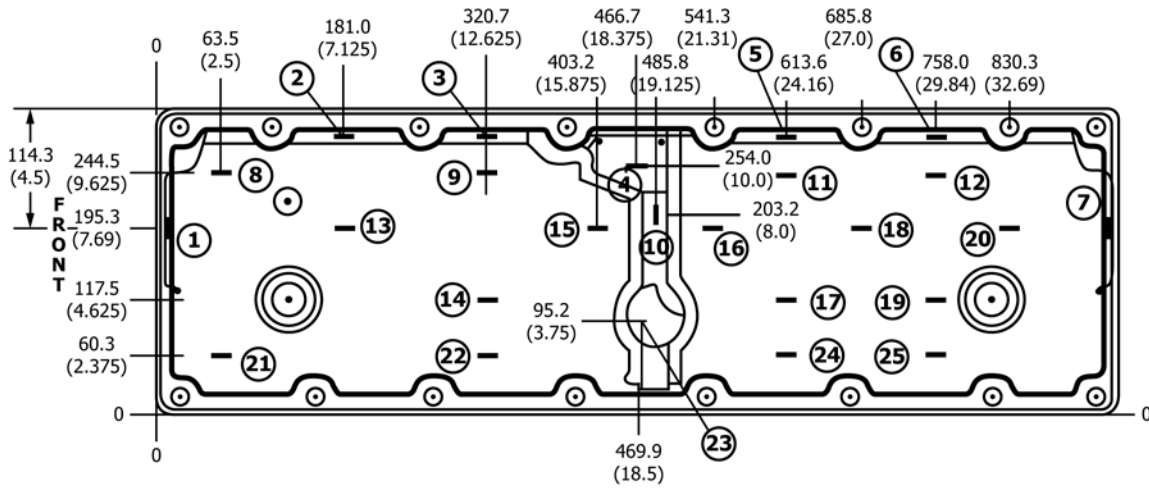
A9.1 Download the actual report figures (forms) and data dictionary separately from the ASTM Test Monitoring Center Web Page at <http://www.tmc.astm.cmri.cmu.edu/> or they can be obtained in hardcopy format from the TMC.

**TABLE A9.1 List of Report Forms**

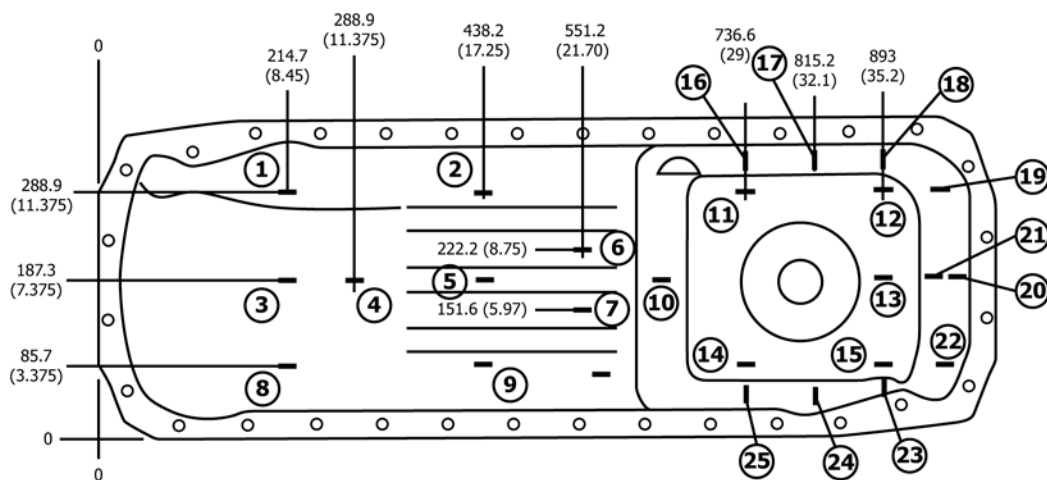
|  |         |
|--|---------|
| Final Report Cover Sheet                       | Form 1  |
| Table of Contents                              | Form 2  |
| Summary of Test Method                         | Form 3  |
| Test Results Summary                           | Form 4  |
| Operational Summary                            | Form 5  |
| Crosshead Mass Loss Summary                    | Form 6  |
| Oil Filter Delta Pressure Plot                 | Form 7  |
| Sludge Rating Summary                          | Form 8  |
| Rod Bearing Mass Loss                          | Form 9  |
| Piston Rating Summary                          | Form 10 |
| Piston 1 Deposit Ratings                       | Form 11 |
| Piston 2 Deposit Ratings                       | Form 12 |
| Piston 3 Deposit Ratings                       | Form 13 |
| Piston 4 Deposit Ratings                       | Form 14 |
| Piston 5 Deposit Ratings                       | Form 15 |
| Piston 6 Deposit Ratings                       | Form 16 |
| Ring Mass Loss Summary                         | Form 17 |
| Oil Analysis Summary                           | Form 18 |
| Test Fuel Analysis                             | Form 19 |
| Injector Adjusting Screw Mass Loss             | Form 20 |
| Unscheduled Downtime and Maintenance Summary   | Form 21 |
| Characteristics of the Data Acquisition System | Form 22 |

**A10. SLUDGE RATING WORKSHEETS**

A10.1 See Figs. A10.1 and A10.2.



**FIG. A10.1 Rocker Arm Cover Sludge Rating Worksheet**



- Note 1 — Dimensions are in millimeters and (inches).
- Note 2 — Rating sites 3, 4, 5, 13, 20, and 21 are located along the longitudinal centerline.
- Note 3 — Rating sites 3, 4, and 5 are 215.9 mm (8.5 in.), 304.8 mm (12 in.), and 431.8 mm (17 in.) respectively from the outside edge of the gasket surface on the shallow end.
- Note 4 — Rating site 13 is located 114.3 mm (4.5 in.) from the outside edge of the gasket surface on the deep end.
- Note 5 — Rating sites 20 and 21 are located 127 mm (5 in.) and 228.6 mm (9 in.) respectively from the gasket surface on the deep end vertical wall.
- Note 6 — Rating sites 16, 17, 18, 19, 22, 23, 24, and 25 are located 127 mm (5 in.) from the gasket surface on the deep end vertical wall.
- Note 7 — Rating sites 11, 12, and 14 are located 50.8 mm (2 in.) from the vertical wall.
- Note 8 — Rating site 15 is located 25.4 mm (1 in.) from the vertical surface.
- Note 9 — Rating site 10 is located on the centerline 88.9 mm (3.5 in.) from the bottom of the oil pan sump.
- Note 10 — The depth gauge should be oriented as indicated by the (-) symbol at each rating site and the dimensions shown on the drawing.

| Depth Scale | Site        |   |   |   |   |   |   |   |   |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    | Total Checks | % Coverage | Volume Factor |  |  |  |  |  |  |  |  |  |  |  |
|-------------|-------------|---|---|---|---|---|---|---|---|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|--------------|------------|---------------|--|--|--|--|--|--|--|--|--|--|--|
|             | 1           | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | 25 |              |            |               |  |  |  |  |  |  |  |  |  |  |  |
| Clean       |             |   |   |   |   |   |   |   |   |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |              |            |               |  |  |  |  |  |  |  |  |  |  |  |
| 1/4A        |             |   |   |   |   |   |   |   |   |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |              |            |               |  |  |  |  |  |  |  |  |  |  |  |
| 1/2A        |             |   |   |   |   |   |   |   |   |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |              |            |               |  |  |  |  |  |  |  |  |  |  |  |
| 3/4A        |             |   |   |   |   |   |   |   |   |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |              |            |               |  |  |  |  |  |  |  |  |  |  |  |
| A           |             |   |   |   |   |   |   |   |   |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |              |            |               |  |  |  |  |  |  |  |  |  |  |  |
| AB          |             |   |   |   |   |   |   |   |   |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |              |            |               |  |  |  |  |  |  |  |  |  |  |  |
| B           |             |   |   |   |   |   |   |   |   |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |              |            |               |  |  |  |  |  |  |  |  |  |  |  |
| BC          |             |   |   |   |   |   |   |   |   |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |              |            |               |  |  |  |  |  |  |  |  |  |  |  |
| C           |             |   |   |   |   |   |   |   |   |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |              |            |               |  |  |  |  |  |  |  |  |  |  |  |
| D           |             |   |   |   |   |   |   |   |   |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |              |            |               |  |  |  |  |  |  |  |  |  |  |  |
| E           |             |   |   |   |   |   |   |   |   |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |              |            |               |  |  |  |  |  |  |  |  |  |  |  |
| F           |             |   |   |   |   |   |   |   |   |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |              |            |               |  |  |  |  |  |  |  |  |  |  |  |
| G           |             |   |   |   |   |   |   |   |   |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |              |            |               |  |  |  |  |  |  |  |  |  |  |  |
| H           |             |   |   |   |   |   |   |   |   |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |              |            |               |  |  |  |  |  |  |  |  |  |  |  |
| I           |             |   |   |   |   |   |   |   |   |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |              |            |               |  |  |  |  |  |  |  |  |  |  |  |
| J           |             |   |   |   |   |   |   |   |   |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |              |            |               |  |  |  |  |  |  |  |  |  |  |  |
|             | Grand Total |   |   |   |   |   |   |   |   |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |              |            |               |  |  |  |  |  |  |  |  |  |  |  |

Oil Pan Sludge Rating \_\_\_\_\_

FIG. A10.2 Oil Pan Sludge Rating Worksheet



**A11. PISTON RATING LOCATIONS**

A11.1 See [Table A11.1](#).

**TABLE A11.1 Piston Rating Locations**

| Location/Deposit         | Special Instructions                   |
|--------------------------|--|
| Grooves:                 |  |
| Top Groove Fill          |  |
| Second Groove Fill       |  |
| Grooves No. 1, No. 3     | Rate HC, MC, LC                        |
| Groove No. 2             | Rate HC, LC                            |
| Lands:                   |  |
| Top Land Heavy Carbon    |  |
| Top Land % Flaked Carbon |  |
| Lands No. 1—No. 4        | Rate HC, LC only                       |
| Other:                   |  |
| Oil Cooling Gallery      | Rate separately from grooves and lands |
| Undercrown               | Rate separately from grooves and lands |

**A12. OIL ANALYSES**

A12.1 See [Table A12.1](#).

**TABLE A12.1 Oil Analysis**

| Sample Hour | Parameter           |                  |                  |                           |                   |
|-------------|---------------------|------------------|------------------|---------------------------|-------------------|
|             | Metals <sup>A</sup> | TAN <sup>B</sup> | TBN <sup>C</sup> | Vis at 100°C <sup>D</sup> | Soot <sup>E</sup> |
| 0           | X                   | X                | X                | X                         | X                 |
| 25          | X                   | X                | X                | X                         | X                 |
| 50          | X                   | X                | X                | X                         | X                 |
| 75          | X                   | X                | X                | X                         | X                 |
| 100         | X                   | X                | X                | X                         | X                 |
| 125         | X                   | X                | X                | X                         | X                 |
| 150         | X                   | X                | X                | X                         | X                 |
| 175         | X                   | X                | X                | X                         | X                 |
| 200         | X                   | X                | X                | X                         | X                 |
| 225         | X                   | X                | X                | X                         | X                 |
| 250         | X                   | X                | X                | X                         | X                 |
| 275         | X                   | X                | X                | X                         | X                 |
| 300         | X                   | X                | X                | X                         | X                 |

<sup>A</sup> [D5185](#) (Copper, Iron, Lead, Chromium, Aluminum).

<sup>B</sup> [D664](#).

<sup>C</sup> [D4739](#) and [D2896](#).

<sup>D</sup> [D5967](#) Annex 3 or [D445](#).

<sup>E</sup> [D5967](#) Annex 4.

A13. OIL FILTER PLUGGING

A13.1 See Fig. A13.1 and Fig. A13.2.

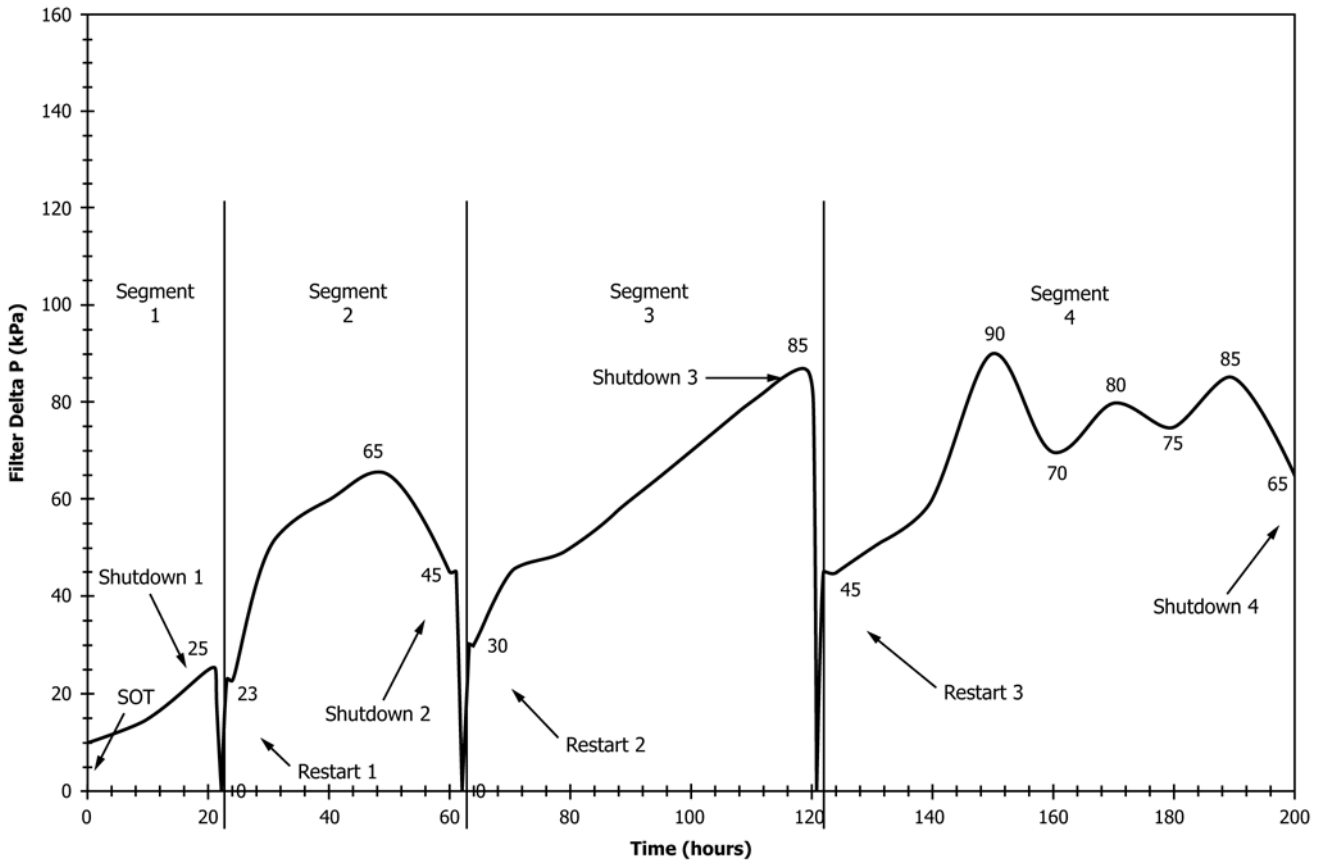


FIG. A13.1 Non-Adjusted Oil Filter Delta P

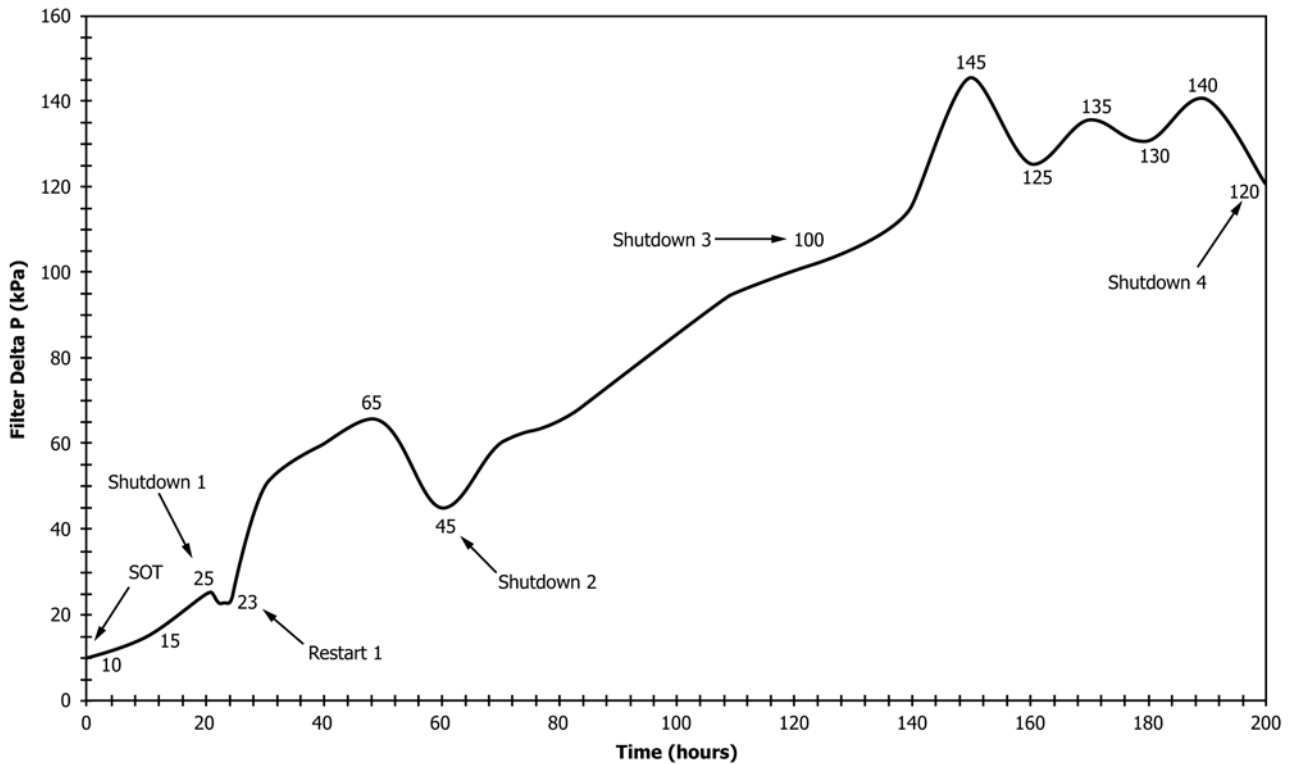


FIG. A13.2 Adjusted Oil Filter Delta P

#### A14. DETERMINATION OF OPERATIONAL VALIDITY

##### A14.1 *Quality Index Calculation:*

A14.1.1 Calculate Quality Index (QI) for all control parameters according to the DACA II Report. Account for missing or bad quality data according to the DACA II Report.

A14.1.2 Use the U, L, Over Range, and Under Range values shown in [Table A14.1](#) for the QI calculations.

A14.1.3 Round the calculated QI values to the nearest 0.001.

A14.1.4 Report the QI values on Form 5, listed in [Table A9.1](#).

##### A14.2 *Averages :*

A14.2.1 Calculate the average for control and non-control parameters, and report the values on Form 5 shown in [Table A9.1](#). Note that the averages are not directly used to determine operational validity but may be helpful when an engineering review is required ([A14.4](#)).

##### A14.3 *Determining Operational Validity:*

A14.3.1 QI threshold values for operational validity are shown in [Table A14.1](#).

A14.3.1.1 A test with all control parameter QI values greater than or equal to the threshold value is operationally valid.

A14.3.1.2 Perform an engineering review to determine operational validity for a test with any control parameter QI value less than the threshold value shown in [Table A14.1](#).

##### A14.4 *Engineering Review:*

A14.4.1 An engineering review shall be performed when a control parameter QI value is below the threshold value. A typical engineering review involves investigation of the test data to determine the cause of the QI value below threshold. The purpose of the review is to determine whether a real control problem existed and the possible impact on the test. For example, a test has a low QI value for fuel flow. An examination of the fuel flow data may show that the fuel flow data contains several over range values. An examination of exhaust temperatures may help determine whether the instrumentation problem affected real fuel flow or only affected the data acquisition.

A14.4.2 Conduct engineering reviews for reference tests jointly with the TMC. For non-reference tests, optional input is available from the TMC for the engineering review.

A14.4.3 Determine operational validity based upon the engineering review and summarize the decision in the comment section of Form 1, listed in [Table A9.1](#). Supporting documentation may be included at the end of the test report. The final decision regarding operational validity rests with the

**TABLE A14.1 Quality Index Calculation Values**

| Control Parameter           | Units | Quality Index Threshold | Quality Index U and L Values <sup>A</sup> |     | Over and Under Range Values <sup>B</sup> |      |
|-----------------------------|-------|-------------------------|---|-----|--|------|
|                             |       |                         | U   | L   | Low                                      | High |
| Speed <sup>C</sup>          | r/min | 0.000                   | TBD                                       | TBD | TBD                                      | TBD  |
| Fuel Flow <sup>C</sup>      | kg/h  | 0.000                   | TBD                                       | TBD | TBD                                      | TBD  |
| Coolant Out Temperature     | °C    | 0.000                   | TBD                                       | TBD | TBD                                      | TBD  |
| Fuel In Temperature         | °C    | 0.000                   | TBD                                       | TBD | TBD                                      | TBD  |
| Oil Gallery Temperature     | °C    | 0.000                   | TBD                                       | TBD | TBD                                      | TBD  |
| Intake Manifold Temperature | °C    | 0.000                   | TBD                                       | TBD | TBD                                      | TBD  |
| Exhaust Back Pressure       | kPa   | 0.000                   | TBD                                       | TBD | TBD                                      | TBD  |

<sup>A</sup> Quality Index U and L Values to be determined.

<sup>B</sup> Over and Under Range Values to be determined.

<sup>C</sup> U and L values for speed are split by test stage.

laboratory.

### A15. EXHAUST CO<sub>2</sub> SAMPLING PROBE

A15.1 Details concerning fabrication of the exhaust sampling probe are shown in the Code of Federal Regulations (CFR), Title 40, Part 86. CFR Title 40, Part 86 can be downloaded from the following Internet address: <http://www.access.gpo.gov/nara/about-cfr.html>

Hardcopy of the CFR Title 40 Part 86 may be obtained from:

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## APPENDIX

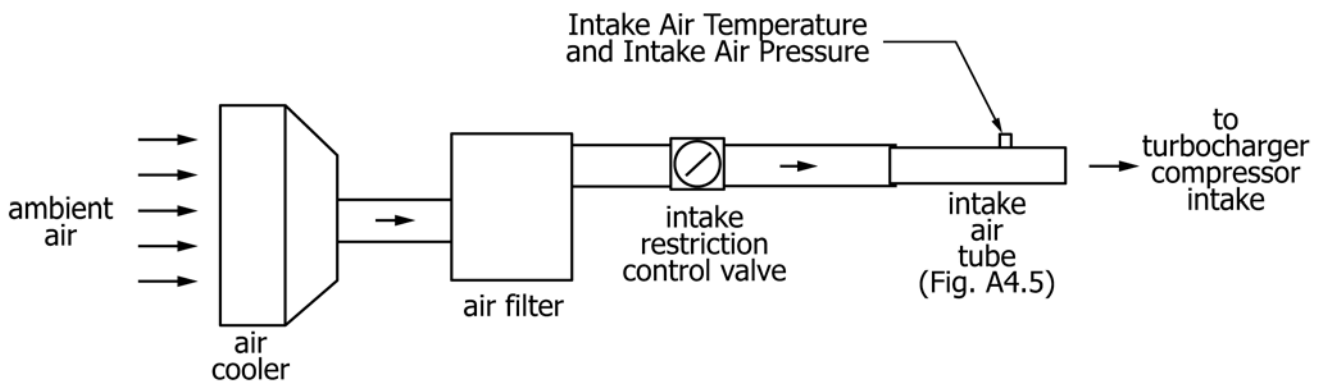
(Nonmandatory Information)

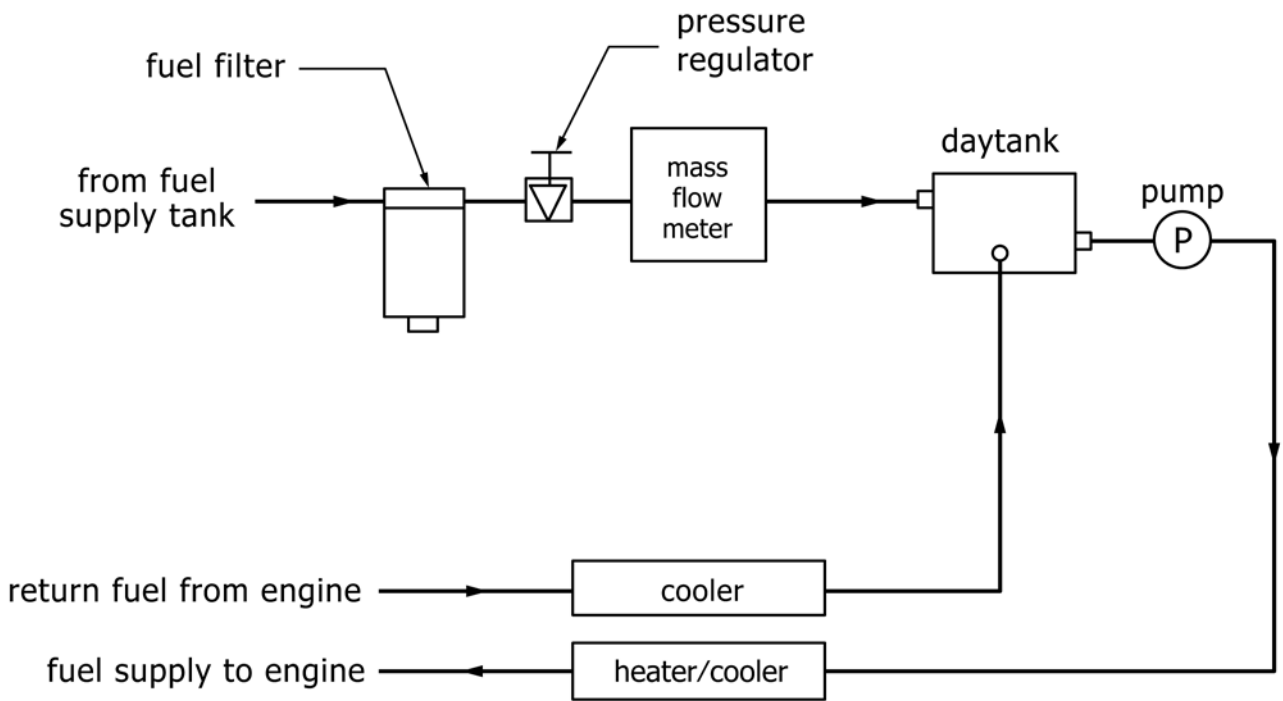
### X1. TYPICAL SYSTEM CONFIGURATIONS

X1.1 Intake Air System (Fig. X1.1)

X1.3 Coolant System (Fig. X1.3)

X1.2 Fuel System (Fig. X1.2)





NOTE 1—Heating or cooling, or both, may be necessary to maintain fuel temperature.

FIG. X1.2 Fuel System (Typical)

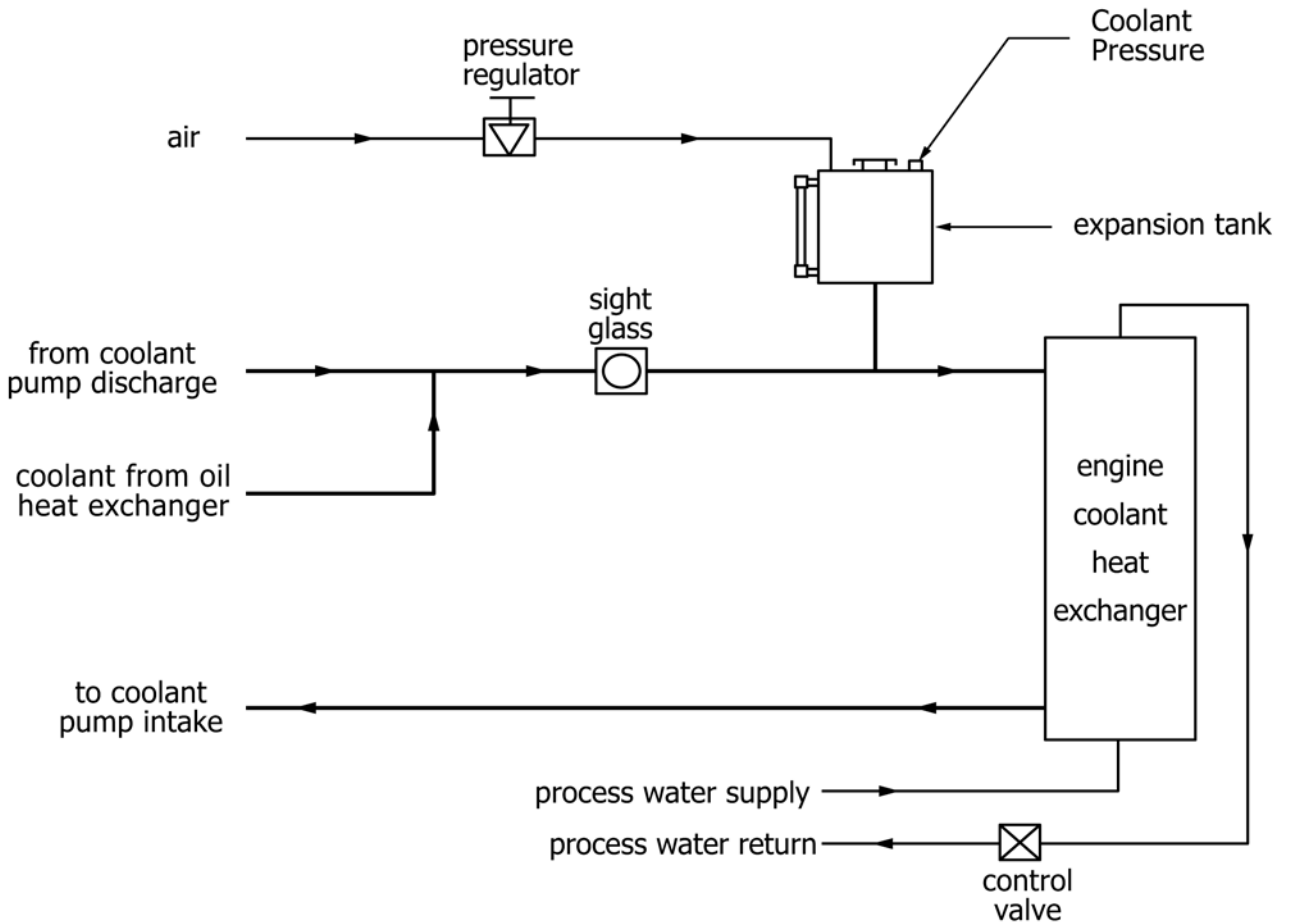


FIG. X1.3 Coolant System (Typical)

 **D6975 – 04 (2010)**

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