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Test Method Manuscript  
ASTM Designation: DXXXX – XX

## **Standard Test Method for Caterpillar C13 Test<sup>1</sup>**

### **1. Scope**

1.1 This test method is commonly referred to as the Caterpillar C13 Heavy-Duty Engine Oil Test<sup>2</sup>. The test method defines a heavy-duty diesel engine test procedure conducted under high output conditions to evaluate engine oil performance with regard to piston deposit formation, piston ring sticking and oil consumption control in a combustion environment designed to minimize exhaust emissions.

1.2 The values stated in SI units are to be regarded as the standard. The values given in parenthesis are for information only. The only exception is where there is no direct SI equivalent such as screw threads, national pipe threads/diameters, and tubing sizes.

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.

### **2. Referenced Documents (TBD)**

#### 2.1 ASTM Standards:

- D 86 Standard Test Method for Distillation of Petroleum Products<sup>4</sup>
- D 92 Standard Test Method for Flash and Fire Points by Cleveland Open Cup<sup>4</sup>
- D 97 Standard Test Method for Pour Point of Petroleum Products<sup>4</sup>
- D 130 Standard Test Method for Detection of Copper Corrosion from Petroleum Products by the Copper Strip Tarnish Test<sup>4</sup>
- D 235 Standard Specification for Mineral Spirits<sup>20</sup>
- D 287 Standard Test Method for API Gravity of Crude Petroleum and Petroleum Products (Hydrometer Method)<sup>4</sup>
- D 445 Standard Test Method for Kinematic Viscosity of Transparent and Opaque Liquids (and the Calculation of Dynamic Viscosity)<sup>4</sup>
- D 482 Standard Test Method for Ash from Petroleum Products<sup>4</sup>
- D 524 Standard Test Method for Ramsbottom Carbon Residue of Petroleum Products<sup>4</sup>
- D 613 Standard Test Method for Cetane Number of Diesel Fuel Oil<sup>5</sup>
- D 664 Standard Test Method for Acid Number of Petroleum Products by Potentiometric Titration<sup>4</sup>
- D 1319 Standard Test Method for Hydrocarbon Types in Liquid Petroleum Products by

Fluorescent Indicator Absorption<sup>4</sup>

D 2500 Standard Test Method for Cloud Point of Petroleum Products<sup>4</sup>

D 2622 Standard Test Method for Sulfur in Petroleum Products by x-ray Spectrometry<sup>6</sup>

D 2709 Standard Test Method for Water and Sediment in Middle Distillate Fuels by Centrifuge<sup>6</sup>

D 4485 Specification for Performance of Engine Oils<sup>6</sup>

D 4737 Standard Test Method for Calculated Cetane Index by Four Variable Equation<sup>7</sup>

D 4739 Standard Test method for Base Number Determination by Potentiometric Titration<sup>7</sup>

D 5185 Standard Test Method for Determination of Additive Elements, Wear Metals, and Contaminants in Used Lubricating Oils and Determination of Selected Elements in Base Oils by Inductively Coupled Plasma Atomic Emission Spectrometry (ICP-AES)<sup>7</sup>

D 5302 Test Method for Evaluation of Automotive Engine Oils for Inhibition of Deposit Formation and Wear in a Spark-Ignition Internal Combustion Engine Fueled with Gasoline and Operated Under Low-Temperature, Light Duty Conditions<sup>7</sup>

D 5844 Standard Test Method for Evaluation of Automotive Engine Oils for Inhibition of Rusting (Sequence IID)<sup>7</sup>

D 5967 Standard Test Method for Evaluation of Diesel Engine Oils in T-8 Diesel Engine<sup>7</sup>

D 6483 Standard Test Method for Evaluation of Diesel Engine Oils in T-9 Diesel Engine<sup>5</sup>

D 6618 Standard Test Method for Evaluation of Engine Oils in Diesel Four-Stroke Cycle Supercharged 1M-PC Single Cylinder Test Engine<sup>5</sup>

E 29 Practice for Using Significant Digits in Test Data to Determine Conformance with Specifications<sup>8</sup>

E 178 Standard Practice for Dealing with Outlying Observations

E 344 Terminology Relating to Thermometry in Hydrometry<sup>9</sup>

## 2.2 Coordinating Research Council:

CRC Manual No. 20<sup>10</sup>

## 2.3 National Archives and Records Administration:

Code of Federal Regulations Title 40 Part 86.310-79<sup>11</sup>

### 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. **D 5844**

3.1.2 blowby, n — in internal combustion engines, the combustion products and unburned air-and-fuel mixture that enter the crankcase. **D 5302**

3.1.3 calibrate, v — to determine the indication or output of a measuring device with respect to that of a standard. **E 344**

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. **D 4485**

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. **D 4485**

3.1.6 non-reference oil, n — any oil other than a reference oil, such as a research formulation, commercial oil or candidate oil. **D 5844**

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 an non-calibrated test stand or using different test equipment, applying different equipment assembly procedures, or using modified operating conditions. **D 5844**

3.1.8 reference oil, n – an oil of known performance characteristics, used as a basis for comparison. **D 4485**

3.1.9 test oil, n— any oil subjected to evaluation in an established procedure. **D 6557**

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

3.1.10.1 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. **D 5302**

3.2 Definitions of Terms Specific to This Standard:

3.2.1 overhead, n – in internal combustion engines, the components of the valve train located in or above the cylinder head.

3.2.2 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 Caterpillar production C13 diesel engine. (See Annex A3 for ordering information). Test operation includes a 60-min. warm-up and break-in, followed by a 4-h cool down and a valve lash adjustment. Following the valve lash adjustment and any other needed adjustments, a 500 h test is begun. The engine is operated under steady-state, rated power conditions known to generate excessive piston deposits and/or oil consumption in field service. Oil consumption is reported as measured in 50 h increments.

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

4.3 An oil sample is removed and an oil addition, equivalent to the total oil consumed plus the sample, is made at the end of each 50-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 oil consumption, piston deposits, and ring sticking.

#### **5. Significance and Use**

5.1 This test method was developed to assess the performance of an engine oil with respect to control of piston deposits and maintenance of oil consumption control under heavy-duty operating conditions selected to accelerate deposit formation in a turbocharged, intercooled four-stroke-cycle diesel engine equipped with a combustion system designed to minimize federally controlled exhaust gas emissions.

5.2 This test method may be used for engine oil specification acceptance when all details of this test method are followed.

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: The engine configuration is that of a production 2004 Caterpillar 430 bhp C13 engine, designed for heavy duty on-highway truck use. Critical parts that can affect piston deposit formation are controlled specifically for oil test engine use.

6.1.1 Test Engine — The Caterpillar C13 engine is an electronically controlled, turbocharged, aftercooled, direct injected, six cylinder Diesel engine with an in-block camshaft and a four-valve per cylinder arrangement. The engine uses Caterpillar's ACERT technology featuring multiple injections per cycle and inlet valve actuation control. It features a 2004 US EPA emissions configuration with electronic control of fuel metering, fuel injection timing and inlet valve actuation timing. Information needed to obtain the test engine and required parts may be found in Annex A3.

6.1.2 Oil Heat Exchanger and Engine Oil System — The standard Caterpillar oil heat exchanger core shall be removed and replaced with a stainless core, CAT p/n 1Y-4026. Additionally, a remotely mounted heat exchanger is installed. Control the oil temperature with a dedicated cooling loop and control system which is separate from the engine coolant. The details of the system are shown in Annex A13. Be sure that the oil cooler bypass valve shall be blocked closed.

6.1.3 Oil Pan Modification — Modify the oil pan as shown in Fig. A4.1.

6.1.4 Engine Control Module (ECM) — The ECM defines the desired engine fuel timing and quantity and limits maximum engine speed and engine power. Caterpillar electronic governors are designed to maintain a speed indicated by the throttle position signal. Speed error drives fuel demand (rack). Rack and engine speed are input to the injection duration and timing maps to determine duration and timing commands for the fuel injectors. Use the ECM provided with the engine. Obtain special Oil Test Engine Control software (personality module P/N 250-6675-03) for correct control maps, contact Caterpillar Oil Test Engine Representative (current contact information is available through the TMC) for installation of this software. The Caterpillar Engine Technician (circle R) (ET) service software package, version 2004B SP1 or later, is used to monitor engine parameters, flash software, and change power and injector trim values. The Full Dealer Version is required and must be purchased from a Caterpillar dealer with a yearly subscription.

6.1.5 Crankshaft Position Sensor – The crankshaft position is sensed using a primary sensor at the crankshaft gear and a secondary sensor at the camshaft gear. The secondary sensor provides position information during cranking and in the event of a primary sensor failure. Calibration of the engine control software is required prior to the start of timed test operation.

6.1.6 Air Compressor— The engine-mounted air compressor is not used for this test method. Remove the air compressor and install a block-off plate kit in its place (P/N 227-2574, cover group<sup>14</sup> and P/N 223-3873, plug group<sup>14</sup>) (Fig. A4.2) or equivalent.

**Note: The Turbo-charger Wastegate must be modified for manual control by replacing the supplied pressure control with a manual linkage. See Figures A4.18 – A4.20.**

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. Use a suitable air filter. Install the intake air tube (Fig A4.3) at the intake of the turbocharger compressor. The intake air tube leading into the turbocharger compress shall be a minimum 12” of straight, nominal 4” diameter tubing. The system configuration upstream of the air tub is not specified.

**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 Charge Air Cooler – In addition to the Caterpillar supplied charge air cooler, which is engine mounted, a Modine (P/N 1A012865) cooler can be used to simulate the air-to-air charge air cooler used in most field applications. Instructions for obtaining this cooler are shown in A2.1. Alternatively, other charge air coolers can be used with the following limitations: it must provide sufficient cooling capacity to control inlet manifold temperatures in the range specified elsewhere in this test method, the boost air pressure drop across the cooler should not exceed 15 kPa and it must be equipped with a drain system to continuously remove condensate from the boost air cooler outlet side. It is recommended that the coolant diverter valve diaphragm for the Caterpillar supplied charge air cooler be removed.

6.2.4 Exhaust System – Install the exhaust tube (Fig A4.4) 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 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 fresh fuel flowing into the day tank. A method to control the fuel temperature is required. The fuel returning from the engine flows into the day tank.

6.2.6 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.

6.2.6.1 — Although the system volume is not specified, an excessively large volume may increase the time required for the engine fluid temperatures to attain specification.

6.2.7 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 pressurized fill is located as shown in Fig A4.21.

6.2.8 External Oil System — Configure the external oil system according to Fig. A5.1. Use a 10 – 13 L volume for the oil reservoir. (Fig. A4.6) Be sure that the oil return is drawn from the bottom of the oil reservoir. Use Viking Pump Model No. SG053514. The external oil pumps are to be at an elevation that is below the pump supply fitting on the oil pan. Nominal pump motor speed is 1725 r/min. The pump supply and return port locations are shown in Fig. A4.1.

6.2.8.1 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 & Fig. A4.6)

6.2.8.2 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.

6.2.9 Crankcase Aspiration – Vent the blowby gas at the blowby filter housing located at the left front side of the cylinder head cover, as shown in Fig. A4.7. Use crankcase breather p/n 9Y-4357. Use breather spacer p/n 221-3934 or equivalent 20 mm thick plate with a fully open center. Use a p/n 9Y-1758 gasket on each side of the spacer.

6.2.10 Blowby Rate — The general configuration of this system is shown in Annex

Figure A4.7. The blowby canister shall be 26.5 L minimum internal volume. The pipe connecting the breather outlet to the blowby canister shall be 3.175 cm, nominal inside diameter, and inclined downward to the canister. The hose connecting the blowby canister to the flow rate device is not specified but should match closely the inlet of the flow rate device. The flow rate measurement device is not specified; however the TEC Associates, Inc. Model No. YF563C has been shown to give satisfactory results under the conditions specified in this test method.

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>15</sup>.

**Table 1 Maximum Allowable System Time Responses**

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

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.

## 7. Engine and Cleaning Fluids

7.1 Test Oil — Approximately 150 L of test oil is required to complete the test.

7.2 Test Fuel — Approximately 45,000 L of Chevron Philips PC-10 Ultra Low Sulfur Diesel fuel<sup>16</sup> is required to complete the test. Fuel property tolerances are shown in Annex A6.

7.3 Engine Coolant – Use a mixture of 50% mineral-free water and 50% Caterpillar brand coolant, P/N 136-3707 for engine coolant. Mineral-free water is defined as water having a mineral content no higher than 34.4 ppm total dissolved solids. As an option, pre-mixed coolant, P/N 101-2845 may be used directly. The coolant mixture may be reused for 6 test starts or up to 3400 h. Keep the mixture at a 50-50 ratio as determined by using either Caterpillar testers 5P3514 or 5P0957 or an equivalent tester. Keep the coolant mixture free of contamination. Total solids shall remain below 5000 ppm. Keep the additive level correct using Caterpillar test kit P/N 8T5296.

**Table 7.3.1 Cat® ELC™ Coolant Concentrate and Premix 50/50 Options**

Container Size	1 Gal	5 Gal	55 Gal	275gTote
Concentrate P/N	119-5150	(-)	136-3707	(-)
Premixed 50/50 P/N	101-2844	129-2151	101-2845	222-1534

7.4 Solvent – Use a solvent which meets D 235, Type II, Class C requirements for

Aromatic Content (0-2% vol), Flash Point (142°F/61°C, min) and Color (not darker than +25 on Saybolt Scale or 25 on Pt-Co Scale). Obtain a Certificate of Analysis for each batch of solvent from the supplier. (**Warning**—Combustible. Health Hazard. 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 Caterpillar C13 test are indicated in this section. Use the Caterpillar service publications<sup>14</sup> (Annex A7) for the preparation of other engine components. Take precautions to prevent rusting of iron components. In general, the use of an engine parts washer is permitted provided that it is followed by a solvent wash.

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, Intake System and Duct – Disassemble and clean before each test. Scrub using a nylon brush and solvent. It is permissible to wash using an engine parts washer. Finish the cleaning with a solvent wash.

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, then air dry.

8.1.6 High Pressure Turbocharger – Carefully remove turbine housing from the turbocharger and clean the wastegate valve with solvent and a soft wire brush.

8.1.7 Cam Follower Assembly – It is recommended that the cam follower assembly be taken apart to inspect the bushings and pins. The replacement of parts is at the discretion of the test laboratory.

### **8.2 Engine Assembly:**

8.2.1 General — Except as noted in this section, use the procedures indicated in the Caterpillar Service Manual Form SENR9700<sup>14</sup> (Annex A7). Assemble the engine with the components from the Engine Build Parts List (Annex A3).

8.2.2 Parts Reuse and Replacement — Engine components can be reused (except as noted in 8.2.7) provided these meet production tolerances as described in the Caterpillar Service Manual.

8.2.3 Build-Up Oils – For the head, main caps, and rod bolts, use Exxon Mobil 600N<sup>13</sup> as the build oil. For the rest of the engine build, use Mobil EF-411<sup>13</sup> or test oil to lubricate parts. 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 Fuel Injectors – Use p/n 239-4908 fuel injectors. The fuel injectors may be reused, but extreme caution must be exercised to avoid mechanical damage or contamination of the nozzels. Dedicate the injectors to a particular cylinder. Install the injectors according to the method described in the Caterpillar Service Manual Form SENR9700(Annex A7). Use EF-411 as the build lubricant for the injector o-rings.

8.2.6 Piston Cooling Tubes – targeting of the piston cooling tubes is recommended. Details are available from the TMC.

8.2.7 New Parts – The parts listed below are included in the Engine Build Parts List 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

8.2.7.2 piston rings (top, second, oil)

8.2.7.3 cylinder liners

8.2.7.4 valves (intake, exhaust)

8.2.7.5 valve guides

8.2.7.6 valve seats

8.2.7.7 connecting rod bearings, main bearings, and thrust plate

### 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 sequence and within six months after completion of the last successful calibration 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 before each reference oil test sequence and within six months after completion of the last successful calibration test. Each temperature measurement system shall indicate within  $\pm 0.5$  °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 before each reference oil test sequence and within six months after completion of the last successful calibration test. Trace the calibration standard to national standards.

8.3.3 Temperatures: Note 2: Table A4.1 lists required and optional temperature, pressure and flow measurement locations.

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>17</sup>.

8.3.3.2 Coolant Out Temperature — Install the sensor in the fitting on the thermostat housing (Fig. A4.9).

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 A4.10).

8.3.3.4 Fuel In Temperature — Install the sensor in the fuel pump inlet fitting (Fig. A4.12).

8.3.3.5 Oil Gallery Temperature — Install the sensor at the 1/4-in. NPT female boss on the right rear of the engine (Fig. A4.11).

8.3.3.6 Intake Air Temperature – Install the sensor in the inlet air tube 5” upstream of the compressor connection, as shown in Fig. A4.3.

8.3.3.7 Intake Manifold Temperature — Install the sensor at the 1/8-in. NPT female boss



on the outside radius of the inlet manifold elbow (Fig. A4.13)

8.3.3.8 Exhaust Temperature – Install the sensor in the exhaust tube (Fig. A4.4).

8.3.3.9 Additional – Monitor any additional temperatures considered to be beneficial to operational analysis.

**Note 3:** 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.

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>17</sup>.

8.3.4.2 It may be necessary to install a condensation trap 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 1/4 in. NPT fitting on the right rear of the engine (Fig. A4.11).

8.3.4.4 Oil Filter Inlet Pressure — Measure the pressure at the plug located on the inlet side of the oil filter assembly (Fig. A4.5).

8.3.4.5 Intake Manifold Pressure — Measure the pressure at the 1/4-in. NPT port on the outside radius of the inlet manifold elbow (Fig. A4.13).

8.3.4.6 Crankcase Pressure — Measure the pressure by installing a bulkhead fitting in the valve cover, top-front (Fig. A4.8).

8.3.4.7 Intake Air Pressure — Measure the pressure at a wall tap on the intake air tube 6” upstream of the compressor connection, as shown in Fig. A4.3.

8.3.4.8 Exhaust Pressure — Measure the pressure on the exhaust tube (Fig. A4.4).

8.3.4.9 Fuel Pressure — Measure the pressure at the fuel filter head (Fig. A4.22).

8.3.4.10 Coolant Pressure – Measure the pressure on top of the expansion tank (Fig. X1.3).

8.3.4.11 Intercooler Delta Pressure – Measure the pressure drop across the intercooler. The intercooler inlet pressure is measured at the elbow outlet of the CAT charge air cooler (Fig. A4.16). Use the intake manifold pressure (Section 8.3.4.5) as the intercooler outlet pressure. The intercooler delta pressure is the difference between these two values.

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

**Note:** Additional instrument placement information can be found in Figures A4.16 & A4.17.

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: DO2-1218<sup>17</sup>.

8.3.5.2 Blowby — The device used to measure the blowby flow rate is not specified. See 6.2.10 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).

8.3.5.3 Coolant Flow – Coolant flow rate measurement may be useful for diagnostic purposes, but it is not required. The design and use of a coolant flow rate measurement system is at the discretion of the test laboratory.

8.3.6 Humidity – Measure intake air humidity anywhere in the intake air system between air conditioning and the turbo inlet.

## **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>15</sup>. Submit the results to the ASTM Test Monitoring Center (TMC) for determination of acceptance according to the Lubricant Test Monitoring System (LTMS)<sup>15</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 24 months of the end of test (EOT) date of the last acceptable reference oil test. 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>16</sup>.

9.3 Stand Calibration Period – The calibration period is 12 operationally valid (see Annex A12) non-reference oil tests or 12 months, whichever comes first, from the EOT date of the last acceptable reference oil test.

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, non-procedural 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 two parts, X-Y. X represents the test stand number, Y represents the sequential test stand run number. For example, test number 27-15 indicates stand number 27, test stand run number 15. Increment Y by one for each test start (reference oil and non-reference oil). A letter suffix may be necessary as well, as 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 Y. 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 27-15, the second test number would be 27-16A. A third calibration attempt would have the test number 27-17B. If the third test was acceptable, then 27-17B would identify the reference oil test in the test report.

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

### 9.6 Reference Oil Test Acceptance:

9.6.1 Reference oil test acceptance is determined in accordance with the LTMS<sup>15</sup>.

### 9.7 Reference Oil Accountability:

9.7.1 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 section 11.4, 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.

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

9.8 Non-Reference Oil Tests:

9.8.1 Last Start Date — For a non-reference oil test to be run during the calibration period, the engine shall be cranked prior to the expiration of the calibration period (9.3).

9.9 Donated Reference Oil Test Programs - The surveillance panel is charged with maintaining effective reference oil test severity and precision monitoring. During times of new parts introductions, new or re-blended reference oil additions, and procedural revisions, it may be necessary to evaluate the possible effects on severity and precision levels. The surveillance panel may choose to conduct a program of donated reference oil tests in those laboratories participating in the monitoring system, in order to quantify the effect of a particular change on severity and precision. Typically, the surveillance panel requests its panel members to volunteer enough reference oil test results to create a robust data set. Broad laboratory participation is needed to provide a representative sampling of the industry. To ensure the quality of the data obtained, donated tests are conducted on calibrated test stands. The surveillance panel shall arrange an appropriate number of donated tests and ensure completion of the test program in a timely manner.

9.10 Adjustments to Reference Oil Calibration Periods

9.10.1 Procedural Deviations – On occasions when a laboratory becomes aware of a significant deviation from the test method, such as might arise during an in-house review or a TMC inspection, the laboratory and the TMC shall agree on an appropriate course of action to remedy the deviation. This action may include the shortening of existing reference oil calibration periods.

9.10.2 Parts and Fuel Shortages - Under special circumstances, such as industry-wide parts or fuel shortages, the surveillance panel may direct the TMC to extend the time intervals between reference oil tests. These extensions shall not exceed one regular calibration period.

9.10.3 Reference Oil Test Data Flow - To ensure continuous severity and precision monitoring, calibration tests are conducted periodically throughout the year. There may be occasions when laboratories conduct a large portion of calibration tests in a short period of time. This could result in an unacceptably large time frame when very few calibration tests are conducted. The TMC can shorten or extend calibration periods as needed to provide a consistent flow of reference oil test data. Adjustments to calibration periods are made such that laboratories incur no net loss (or gain) in calibration status.

9.10.4 Special Use of the Reference Oil Calibration System - The surveillance panel has the option to use the reference oil system to evaluate changes that have potential impact on test severity and precision. This option is only taken when a program of donated tests is not feasible. The surveillance panel and the TMC shall develop a detailed plan for the test program. This plan requires all reference oil tests in the program to be completed as close to the same time as possible, so that no laboratory/stand calibration is left in an excessively long pending status. In order to maintain the integrity of the reference oil monitoring system, each reference oil test is conducted so as to be interpretable for stand calibration. To facilitate the required test scheduling, the surveillance panel may direct the TMC to lengthen and shorten reference oil calibration periods within laboratories such that the laboratories incur no net loss (or gain) in calibration status.

## 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.

10.2 Coolant System Fill — Fill the cooling system with pre-diluted Caterpillar Extended Life Coolant (see 7.3 for part numbers and available container sizes). The coolant for non-reference oil tests may be reused provided the level of inhibitors is within specification. Use new coolant for each reference oil test.

**Note 6:** 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 and test:

10.3.1 Install a new Caterpillar 1R-0716 oil filter<sup>14</sup>.

10.3.2 Use the pressurized oil fill system (6.2.8) to charge the engine with  $32.8 \pm 0.2$  kg of test oil at the location shown in Fig. A4.5.

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 minimum 60 ml fuel sample at the start of the test and at EOT.

10.5 Engine Warm-up and Break-in — Prior to firing the engine, ensure that the oil temperature is at least 15 °C. The minimum oil gallery startup pressure is 350 kPa. Perform a timing calibration for the engine control software and timing sensor components as specified in the C13 Service Manual. If coolant temperature is less than 18C the engine will operate under cold mode strategy and the timing calibration procedure cannot be performed. In this situation, start the engine and allow it to idle until the speed drops from 1000 r/m to 600 r/m, signaling that the coolant temperature has exceeded 18C. After the timing calibration is complete, continue break-in conditions as shown in Table 2. Turn on the external oil weigh system pumps at the beginning of stage 2.

**Table 2**  
**Break-in Conditions**

Parameter	unit	Stage				
		1	2	3	4	5
Stage Length	min	5	5	10	20	20
Speed	r/min	1100	1200	1600	1800	1800 $\pm$ 5
Fuel Flow	g/min	record	record	record	record	1200 $\pm$ 6
Torque	N•m	0	480	1000	1160	record
Coolant Out Temperature <sup>A</sup>	°C	88	88	88	88	88 $\pm$ 2
Oil Gallery Temperature <sup>A</sup>	°C	record >>				98 $\pm$ 2
Intake Manifold Temperature <sup>A</sup>	°C	40	40	40	40	40 $\pm$ 2

<sup>A</sup> This is the control set-point, can require up to 30 minutes of operation to achieve.

10.5.1 Shutdown during Break-in – If a shutdown occurs during the break-in, resume the break-in from the point the shutdown occurred. Note such an occurrence in Other Comments of Fig. A9.11 (Form 11) listed in Table A9.1.

**Note 7:** Use the break-in as an opportunity to confirm engine performance and to make repairs prior to the start of the 500-h test procedure.

10.5.2 Valve Lash Adjustment – At the completion of the 60-m break-in, shut the engine

down, using the normal shut down procedure as shown in 10.7.1. Allow the engine to cool for a minimum of 4 hours and then perform the valve lash adjustment as defined in the Caterpillar Service Manual. Inlet valve actuator lash adjustment should also be made at this time.

10.6 Warm-up -- Start the engine, perform the warm-up (Table 3) and proceed directly to the test conditions. At engine start, the oil gallery temperature is to be at least 15 °C. The startup oil gallery pressure is to be at least 350 kPa.

**Table 3**  
**Warm-up Conditions**

Parameter	unit	Stage				
		1	2	3	4	5
Stage Length	min	2.5	2.5	5	10	10
Speed	r/min	1100	1200	1600	1800	1800
Fuel Flow	g/min	record	record	record	record	1200
Torque	N•m	0	480	1000	1160	record
Coolant Out Temperature <sup>A</sup>	°C	88	88	88	88	88
Oil Gallery Temperature <sup>A</sup>	°C	record	record	record	record	98±2
Intake Manifold Temperature <sup>A</sup>	°C	40	40	40	40	40

<sup>A</sup> This is a control set-point, and can require up to 30 minutes of operation to achieve.

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 500-h test procedure without shutdowns.

10.7.1 Normal Shut Down: A normal shut down is accomplished by ramping in 30 seconds from test conditions to stage 2 of the Warm-up Conditions (Table 3), running for 5 minutes at stage 2, ramping in 30 seconds to stage 1, running for 5 minutes at stage 1 and then stopping the engine.

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 Fig. A9.11 (Form 11) 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 Caution deposits tend to build up with time and prevent free movement of the turbo-charger wastegate shaft. If the engine is shut down for maintenance at any time the shaft should be freed mechanically. Otherwise, such a procedure must be followed if the IMP falls outside the 275 to 285 kPa range and does not respond to normal adjustment techniques.

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 500-h test procedure on Fig. A9.11 (Form 11) listed in Table A9.1.

10.8 500-h Test Procedure:

10.8.1 Start test following break-in, normal shutdown, valve lash adjustment and warm-up, as described in 10.2 through 10.7.

10.8.2.1 New Oil Sample – Take a 120 ml oil sample of the fresh oil from the original oil container.

10.8.3 Operating Conditions – After warm-up, proceed directly to the 500-h Test Schedule (Table 4).

**Table 4**  
**500-h Test Schedule of Conditions**

Parameter	unit	
Test Length	h	500
Speed	r/min	1800
Power	kW	record
Torque (typical) <sup>A</sup>	N•m	1760
Fuel Flow	g/m	1200
Intake Manifold Temp.	°C	40
Blowby Flow	L/min	record
Coolant Out Temp.	°C	88
Coolant In Temp.	°C	record
Coolant Delta Temp.	°C	record
Fuel In Temp.	°C	40
Oil Gallery Temp.	°C	98
Inlet Air Temp.	°C	25
Intake Manifold Press.	kPa g	275-285
Exhaust Temp.	°C	record
Fuel Pressure	kPa	record
Oil Gallery Pressure	kPa	record
Oil Filter Delta Press.	kPa	record
Coolant System Press. <sup>B</sup>	kPa	99-107
Exhaust restriction	kPa	6
Crankcase Press.	kPa	record
Inlet Air Press.	kPa abs.	93.0 ± 1.5
Intercooler Delta Press	kPa	tbd
Humidity	g/kg	record

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

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

10.8.4 Test Timer – The 500-h test timer starts when all controlled parameters shown in Table 4 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 test operation schedule and all controlled parameters are within specification.

10.8.5 Operational Data Acquisition — Record all operational parameters shown in Table 4 with automated data acquisition at a minimum frequency of once every 6 min. Recorded values shall have minimum resolution in accordance with Annex A8.

10.8.5.1 The operational data is reported on Form 5 listed in Table A9.1.

10.8.6 Oil Purge, Sample and Addition — Perform a purge and oil sample at 4 h. Do not add fresh oil a 4 h. Perform a purge, oil sample, and oil addition at the end of each 50-h period. Add new oil, and purge sample to the external oil system reservoir.

10.8.6.1 Do not shut down the engine for oil sampling and oil addition.

10.8.6.2 Full Weight — Record the oil weight indicated by the external oil system at the completion of the fourth test hour and before removal of the 150 ml purge and the 120 ml oil sample; this value establishes the full weight

10.8.6.3 At the end of each 50-h period, record the oil weight indicated by the external oil system and take a 150 ml oil purge sample followed by a 120 ml oil analysis sample. Identify the oil sample container with the test number, oil code, date and test hour.

10.8.6.4 Add new oil equivalent to Full Weight minus the external oil system weight (as determined in step 10.8.6.3), plus the 120 ml sample. Add back the purge sample taken in 10.8.6.3. At 500 hours make no oil additions.

10.8.6.5 Emergency Oil Adds If the external oil weigh system retained weight falls to 0.5 kg or less at any time before the next scheduled 50-h oil add point calculate, based on the immediately preceding oil consumption history, calculate the amount of oil required to maintain the external oil weigh system weight above 0.5 kg until the next scheduled add. Add this amount of fresh oil to the system.

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

10.9.1 After completing the test procedure, perform a normal shutdown. 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.

10.9.3 Engine Disassembly – Disassemble the engine and remove the following components for ratings and measurements:

10.9.3.1 Pistons

10.9.3.2 Piston Rings (**Caution:** do not remove rings from pistons until ring sticking has been rated.)

## 11. Calculations, Ratings, Test Validity, and Test Results

11.1 Piston Ratings — Rate the pistons according to CRC Manual No. 20<sup>10</sup> at the locations specified using the special instructions noted in Annex A10. Deposit weighting factors are those used for the Caterpillar 1P Test. For the varnish ratings, use the CRC expanded varnish scale and convert to demerits.

11.1.1 Pistons are rated for ring sticking prior to removal of the rings for cleaning and rating.

#### 11.2 Ring Cleaning and Rating

11.2.1 Use the procedure stated in the C13 Ring Cleaning and Rating Procedure (available from the TMC) for ring cleaning and rating.

11.3 Oil Analyses — Analyze the oil samples according to the schedule and methods shown in A11.

11.4 Oil Consumption — Determine the oil consumption rate for each 50-h segment of the test by use of a regression analysis of the external oil system weights recorded over the 50 hour period. Do not include in the regression any values obtained within 4 hours following an oil addition or after the engine is shut down for any reason.

11.5 Fuel Analyses — Report the analyses provided by the fuel supplier on Fig. A9.12 (Form 12) listed in Table A9.1. Report the analyses of the final batch if more than one fuel batch was used.

11.5.1 Additional Analyses — Perform the following analyses on the 60 ml new and EOT fuel samples:

11.5.1.1 API Gravity at 15.6 °C (60 °F), Test Method D 4052

11.5.1.2 Total Sulfur, % wt., Test Method D 5453 (D 2622, or D 4294 can be substituted)

11.6 Assessment of Operational Validity – Determine operational validity according to

Annex A12.

11.7 Test Results – the specified reference oil test results are average top groove carbon (demerits), average top land carbon (demerits), average second ring top carbon (demerits), and delta oil consumption (g/h). The non-reference oil test specified result is the C13 Merit Rating as found in Annex A15.

11.7.1 Average Top Groove Carbon – Screen the data for outliers according to Annex A14. Calculate the average top groove carbon, excluding any outliers, and report the data on the appropriate forms.

11.7.2 Average Top Land Carbon – Screen the data for outliers according to Annex A14. Calculate the average top land carbon, excluding any outliers, and report the data on the appropriate forms.

11.7.3 Average Second Ring Top Carbon – Screen the data for outliers according to Annex A14. Calculate the average second ring top carbon, excluding any outliers, and report the data on the appropriate forms.

11.7.4 Delta Oil Consumption – Calculate the delta oil consumption according to the following:

$$\text{Delta Oil Consumption (g/h)} = [(OC450+OC500) / 2] - [(OC100+OC150) / 2] \quad (1)$$

where:

OC100 = the average oil consumption (g/h) for the 50-h period from 50 to 100 h as determined in Section 11.3

OC150 = the average oil consumption (g/h) for the 50-h period from 100 to 150 h as determined in Section 11.3

OC450 = the average oil consumption (g/h) for the 50-h period from 400 to 450 h as determined in Section 11.3

OC500 = the average oil consumption (g/h) for the 50-h period from 450 to 500 h as determined in Section 11.3

## 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 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>18</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>15</sup>

## 13. Precision and Bias

13.1 Precision — Precision is based on operationally valid calibration test results monitored by the TMC.



13.1.1 Intermediate Precision 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. **Note** – Intermediate precision is the appropriate term for this test method rather than repeatability which defines more rigorous within-laboratory conditions.

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. When only a single test result is available, the Intermediate Precision Limit can be used to calculate a range (test result  $\pm$  Intermediate Precision Limit) outside of which a second test result would be expected to fall about one time 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. When only a single test result is available, the Reproducibility Limit can be used to calculate a range (test result  $\pm$  Reproducibility Limit) outside of which a second test result would be expected to fall about one time in twenty.

13.1.3 Test Precision, as of May 11, 2006 is shown in Table 6.

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.

**Table 6**  
**Test Precision**

Measured Units		
Test Result	Intermediate Precision, (i.p.)	Reproducibility, (R)
Average Top Groove Carbon, Demerits	18.1	20.2
Average Top Land Carbon, Demerits	13.1	16.4
Oil Consumption Delta, g/h (transformed units) <sup>A</sup>	1.600	3.255
Average Second Ring Top Carbon, Demerits (transformed units) <sup>B</sup>	0.825	0.882

<sup>A</sup>This parameter is transformed using a square root. When comparing two test results on this parameter, first apply this transformation to each test result. Compare the absolute difference between the transformed results with the appropriate (intermediate or reproducibility) precision limit.

<sup>B</sup>This parameter is transformed using a natural log. When comparing two test results on this parameter, first apply this transformation to each test result. Compare the absolute difference between the transformed results with the appropriate (intermediate or reproducibility) precision limit.

## 14. Keywords

14.1 Caterpillar C13, diesel engine oil, lubricants, piston ring sticking, piston deposits, top groove carbon, top land carbon, 2<sup>nd</sup> ring top carbon, oil consumption.

ANNEXES  
**(Mandatory Information)**

- A1. Safety Precautions
- A2. Intake Air Aftercooler
- A3. Engine Build Parts Kit
- A4. Sensor Locations and Special Hardware
- A5. External Oil System
- A6. Fuel Specification
- A7. Caterpillar Service Publications
- A8. Specified Units and Formats
- A9. Report Forms and Data Dictionary
- A10. Piston Ring Loss of Side Clearance and Piston Ring Sticking Worksheets
- A11. Piston Rating Locations
- A12. Oil Analysis
- A13. Determination of Operational Validity
- A14. Oil Temperature Control System
- A15. C13 Outlier Screening Methods
- A16. C13 Merit Rating Calculation

## **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 AND ENGINE BUILD PARTS KIT<sup>12</sup>

A3.1 Obtain the Caterpillar C13 Engine Arrangement Number 244-4803 or 249-8361 by contacting the Caterpillar Oil Test Engine Representative. Current contact information is maintained at the ASTM Test Monitoring Center (TMC).

A3.2 Critical parts are shown in Table A3.1.

A3.2.1 Obtain Critical Parts by contacting the Caterpillar Oil Test Engine Representative. Current contact information is maintained at the TMC.

A3.3 A listing of non-critical engine build parts is available from the TMC. This list shows current part numbers so that these may be obtained from a Caterpillar Dealer.

**Table A3.1 Engine Build Parts**

Item	Part Number
Piston	1Y-4106
Liner-Cylinder	1Y-4107
Ring-Top	1Y-4108
Ring-Intermediate	1Y-4109
Ring-Oil	1Y-4110
Valve – Intake	224-3028
Valve – Exhaust	224-3030
Valve Guide	259-2186
Valve seat – Intake	224-2410
Valve seat – Exhaust	224-1270
Connecting Rod Bearing	116-1089
Main Bearing	211-0587 and 211-0588
Thrust Plate	1Y4118 or 116-1107

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#### A4. SENSOR LOCATIONS AND SPECIAL HARDWARE

A4.1 See Table A4.1 and Figs. A4.1 — A4.19

Table A4.1 Temperature, Pressure and Flow Measurements locations Summary  
(Includes optional measurements)

Description	Instrument	Location
Total Coolant In	Temperature	Coolant pump inlet pipe
Engine Coolant In	Temperature	Coolant pump suction
Primary Turbo Compressor Out	Temperature	Cast aluminum pipe between turbos
Inlet Manifold	Temperature	Inlet manifold elbow
Oil Gallery	Temperature	Side of Block
Coolant Out	Temperature	Thermostat Housing
Secondary Turbo Turbine Out	Temperature	Facility Piping - Locate 12 inches after flange/bend and 4 inches before transition
Secondary Turbo Compressor Out	Temperature	Facility Piping
Oil Filter In	Temperature	Oil Filter Housing
Oil Filter Out	Temperature	Oil Filter Housing
Primary Turbo Drain	Temperature	Turbo Drain
Secondary Turbo Drain	Temperature	Turbo Drain
Oil Sump	Temperature	Oil pan plug below oil level
Cyl 1	Temperature	Exhaust Manifold
Cyl 2	Temperature	Exhaust Manifold
Cyl 3	Temperature	Exhaust Manifold
Cyl 4	Temperature	Not accessible
Cyl 5	Temperature	Exhaust Manifold
Cyl 6	Temperature	Exhaust Manifold
Exhaust Manifold Front	Temperature	Exhaust Manifold
Exhaust Manifold Rear	Temperature	Exhaust Manifold
Fuel at Pump	Temperature	Transfer Pump
Oil Regulator	Temperature	Oil Filter Housing
Charge Air Cooler Water In	Temperature	Facility Piping
Total Coolant In	Pressure	Coolant pump inlet pipe
Secondary Turbo Compressor Out	Pressure	Facility Piping
Inlet Manifold	Pressure	Inlet manifold elbow
Oil Gallery	Pressure	Side of Block
Secondary Turbo Turbine Out	Pressure	Facility Piping - Locate 12 inches after flange/bend and 4 inches before transition
Secondary Turbo Compressor Out	Pressure	Facility Piping
Crankcase	Pressure	Valve Cover. Use a bulkhead with seal fitting

Table A4.1 (cont'd)

Fuel at Filter Housing	Pressure	Fuel Filter Housing
Oil Filter In	Pressure	Filter Housing
Oil Filter Out	Pressure	Oil Filter Housing
Exhaust Manifold Front	Pressure	Exhaust Manifold
Exhaust Manifold Rear	Pressure	Exhaust Manifold
Fuel at Pump	Pressure	Transfer Pump
Coolant	Flow	Facility Piping
Fuel	Flow	
Blowby	Flow	

## A4.1 Oil Pan Modifications for External Oil System

Figure A4.1.1 Auxiliary oil system suction port location

# CAT C13 Oil Suction Port Location

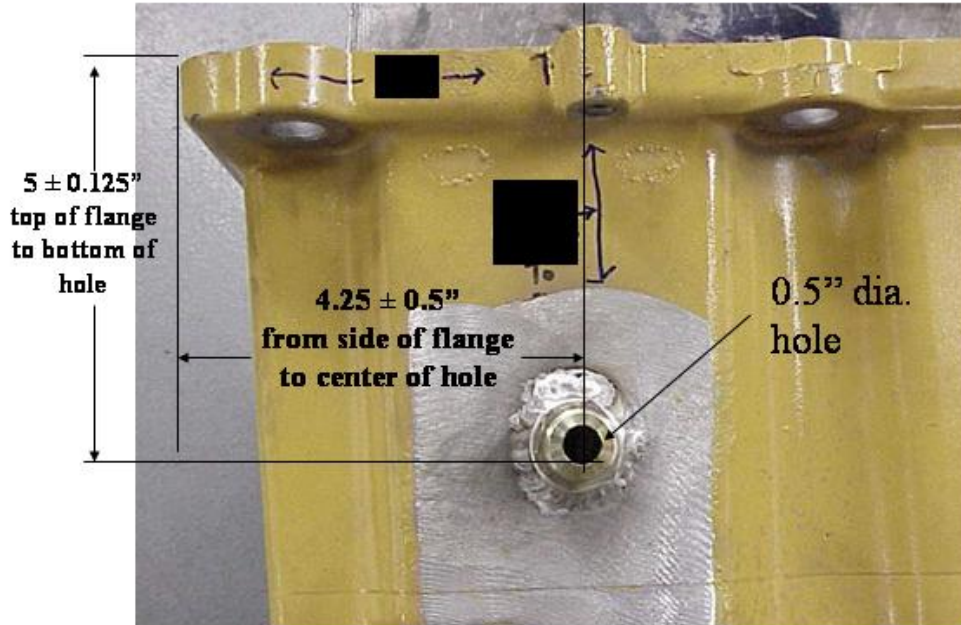
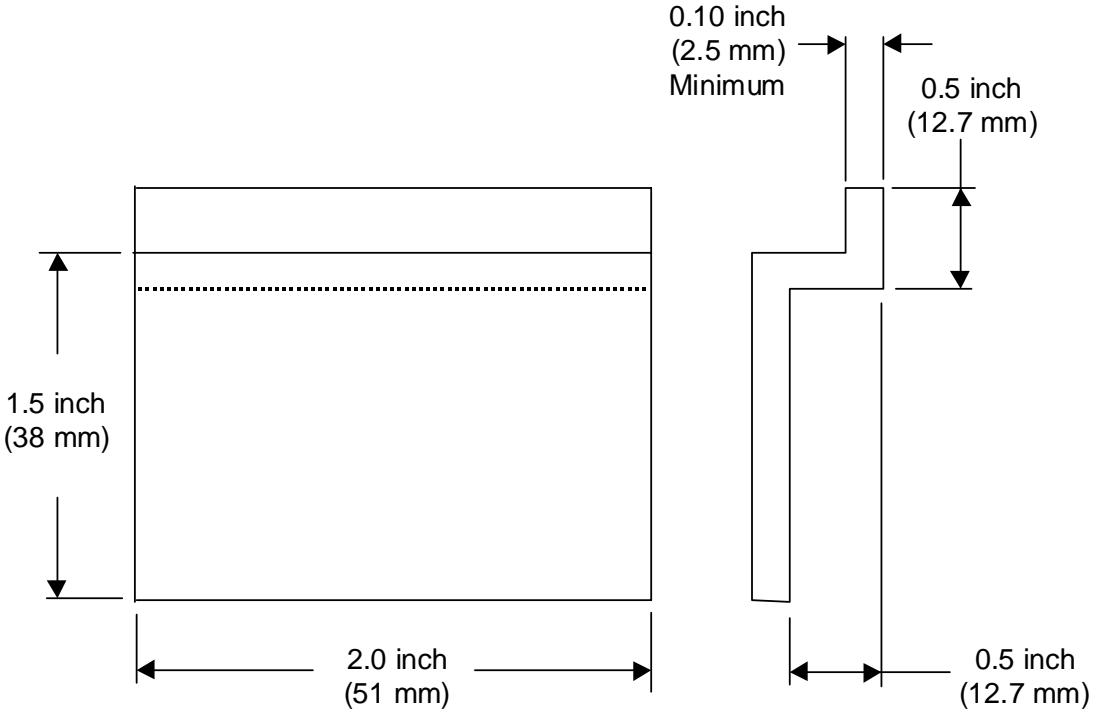


Figure A4.1.2 Suction port baffle design



Note: Bend radii to be compatible with material thickness



Figure A4.1.3 Baffle placement on oil pan

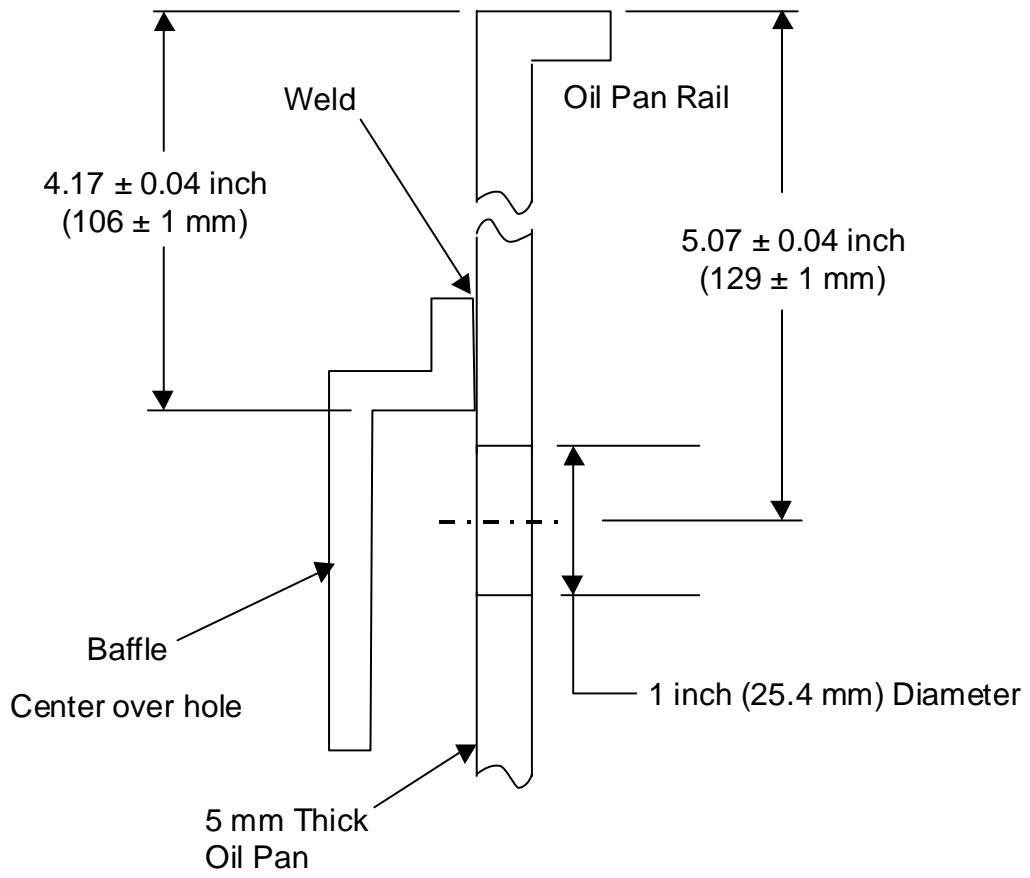
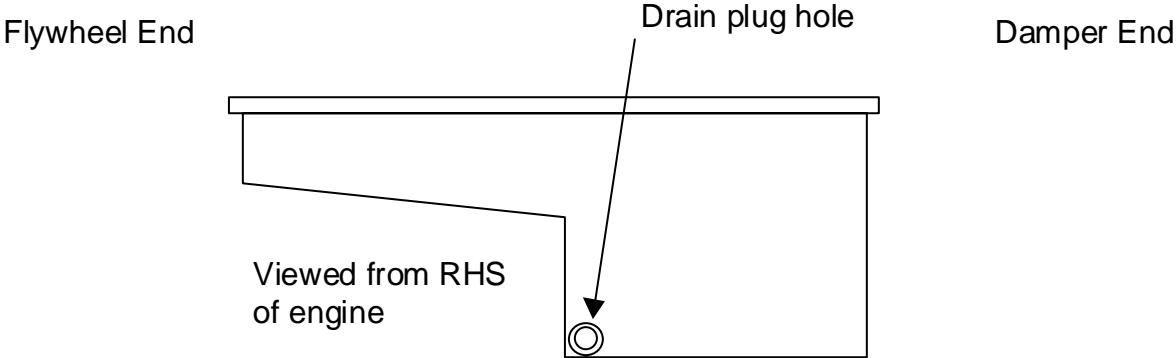
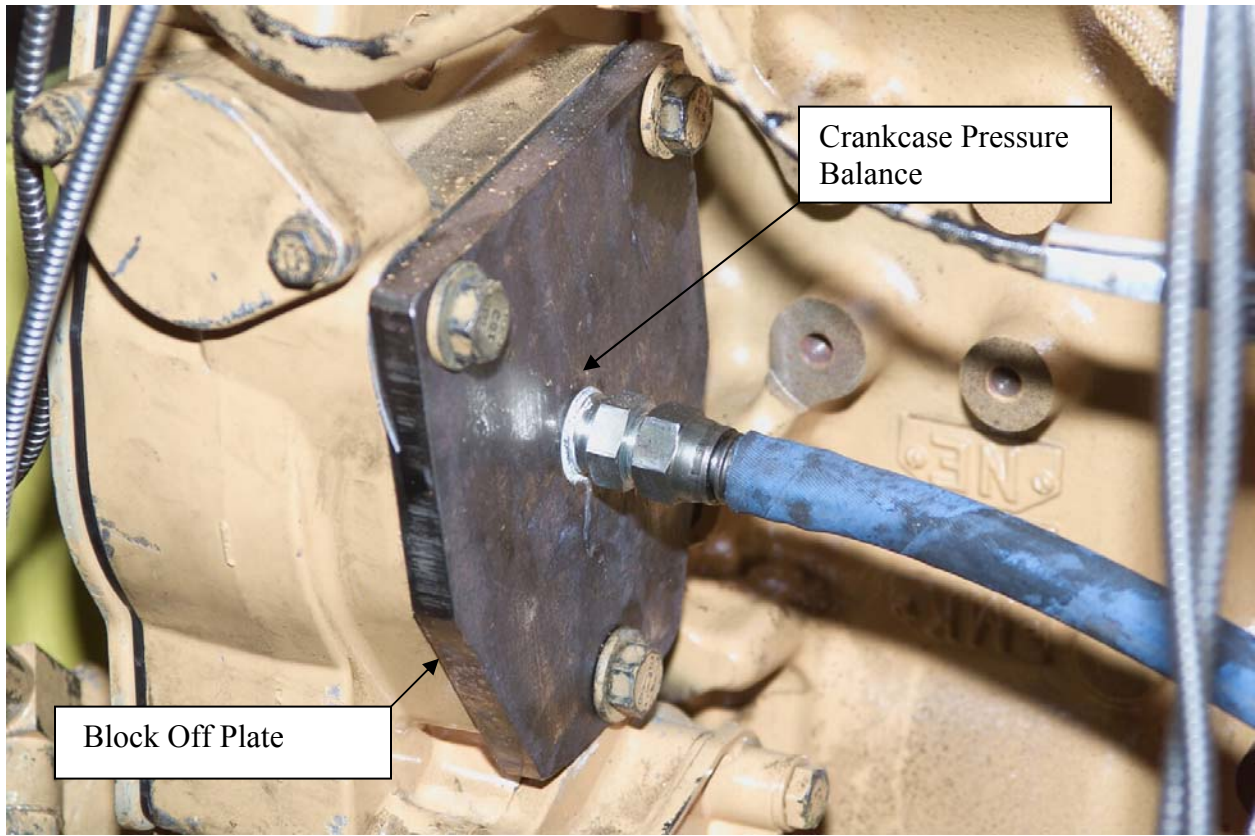
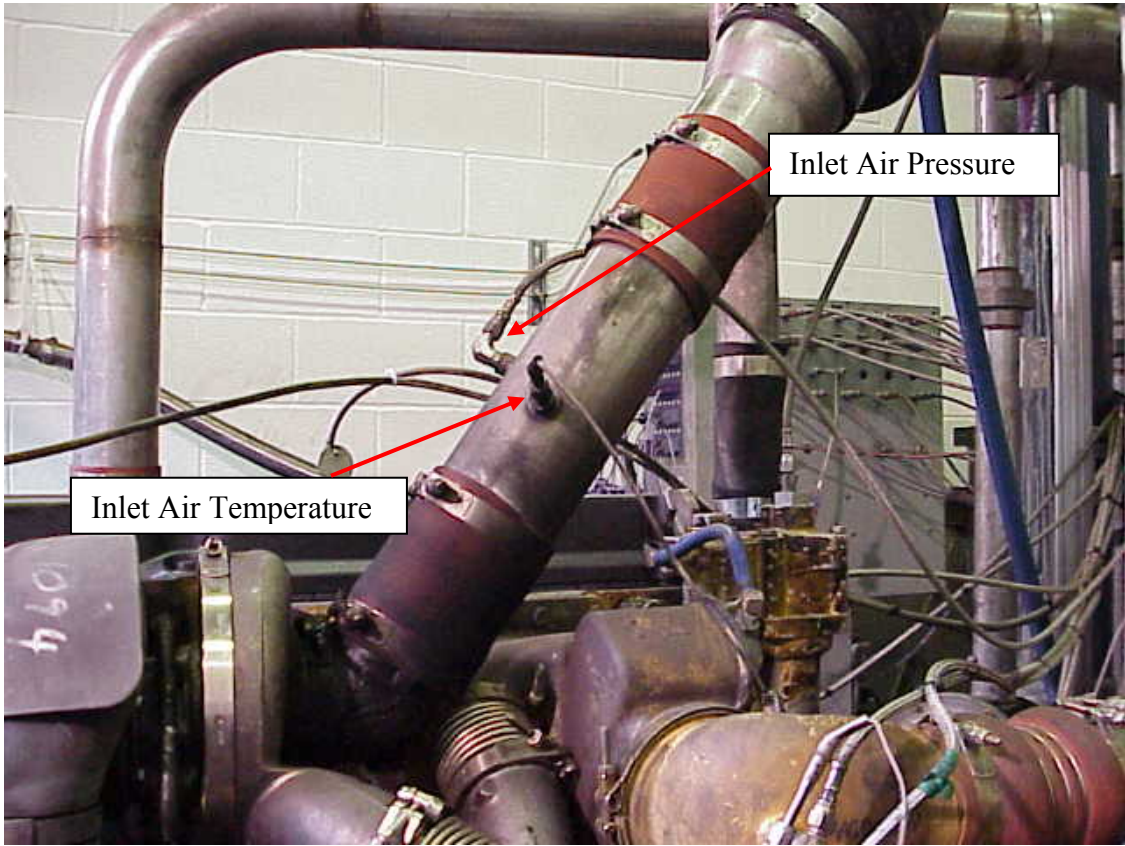


Figure A4.1.4 Auxiliary Oil System Return Port Location

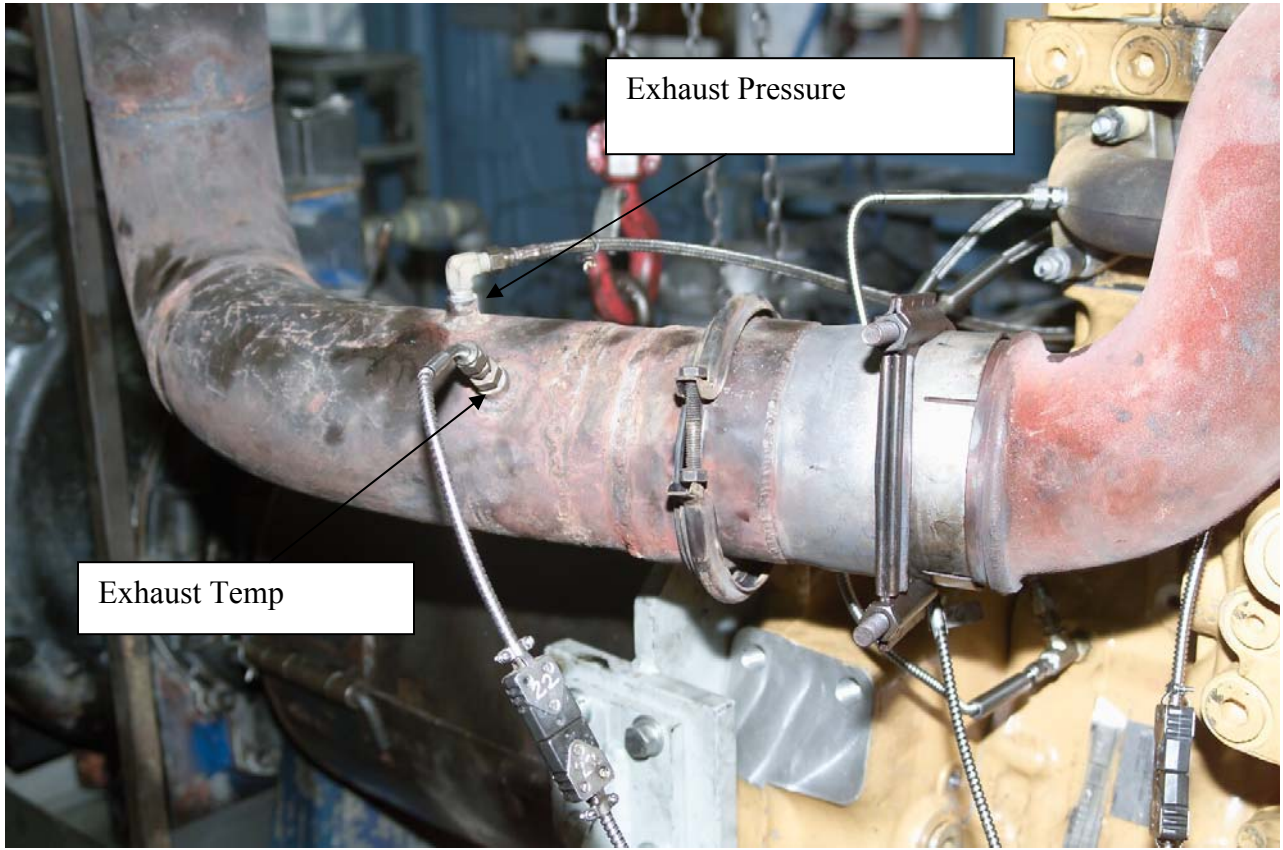




**Fig A4.2**  
**Compressor Block off Plate and Crankcase Pressure Balance Connection**

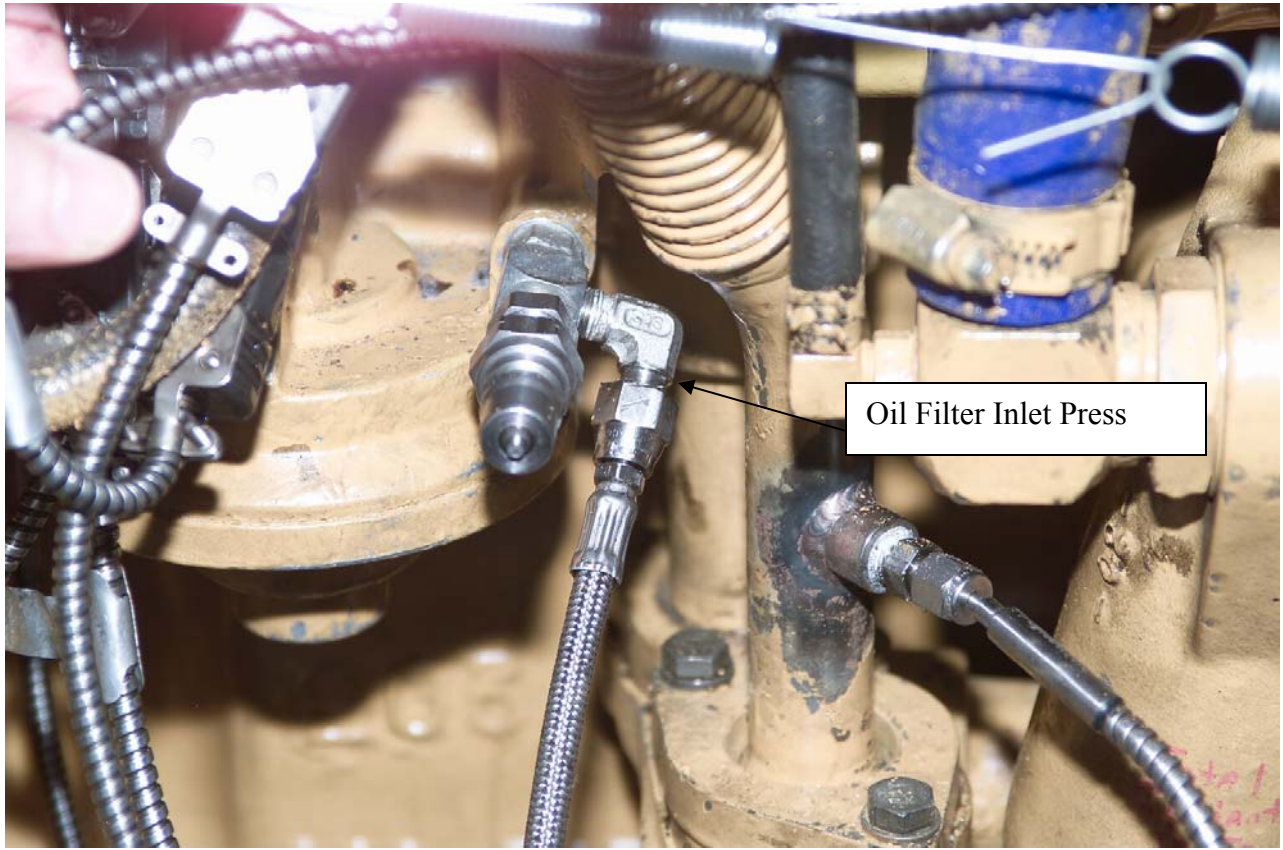


**Fig. A4.3 Inlet Tube**

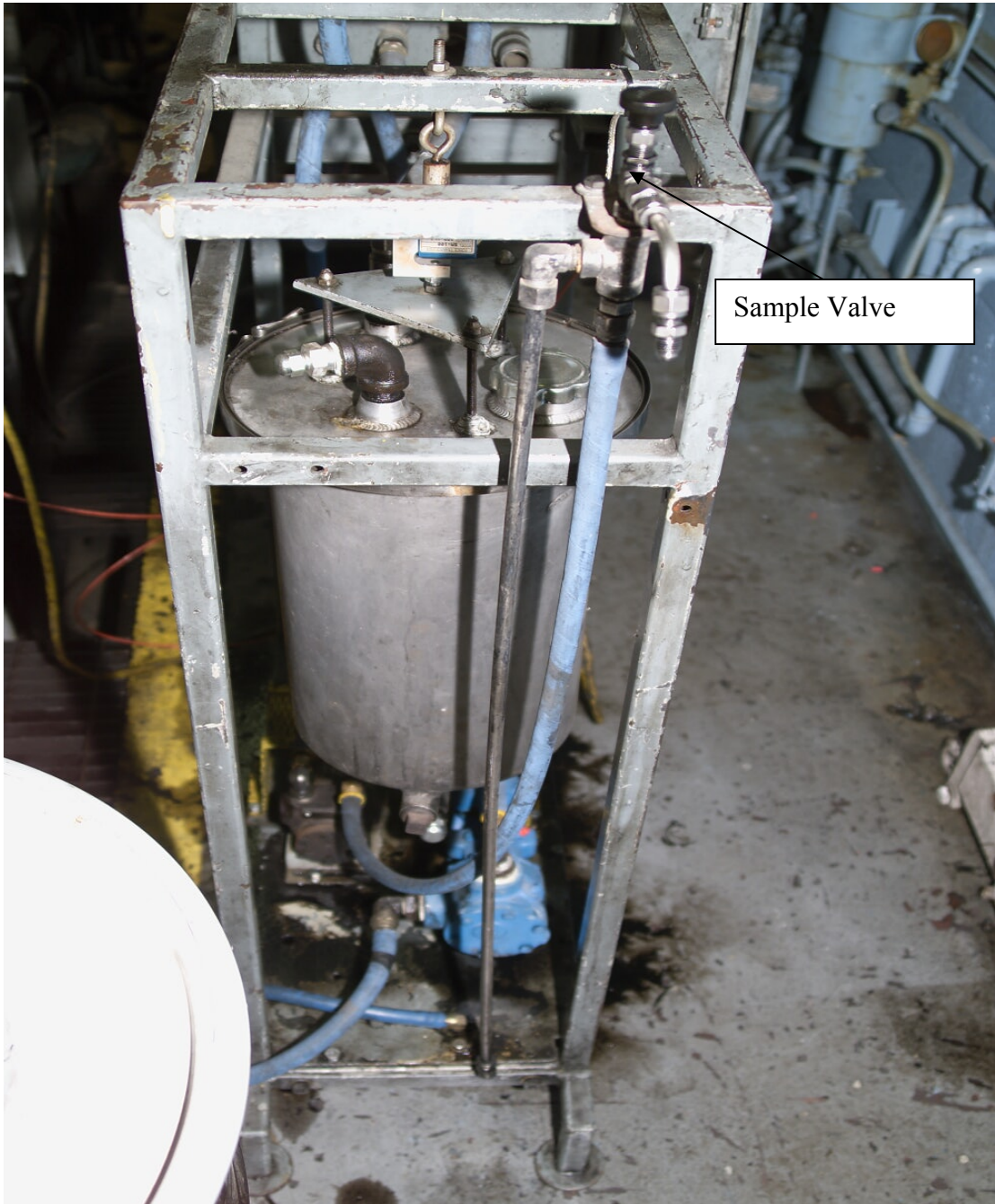


**Fig. A4.4 Exhaust Tube**





**Fig. A4.5 Oil Filter Inlet Pressure Port**

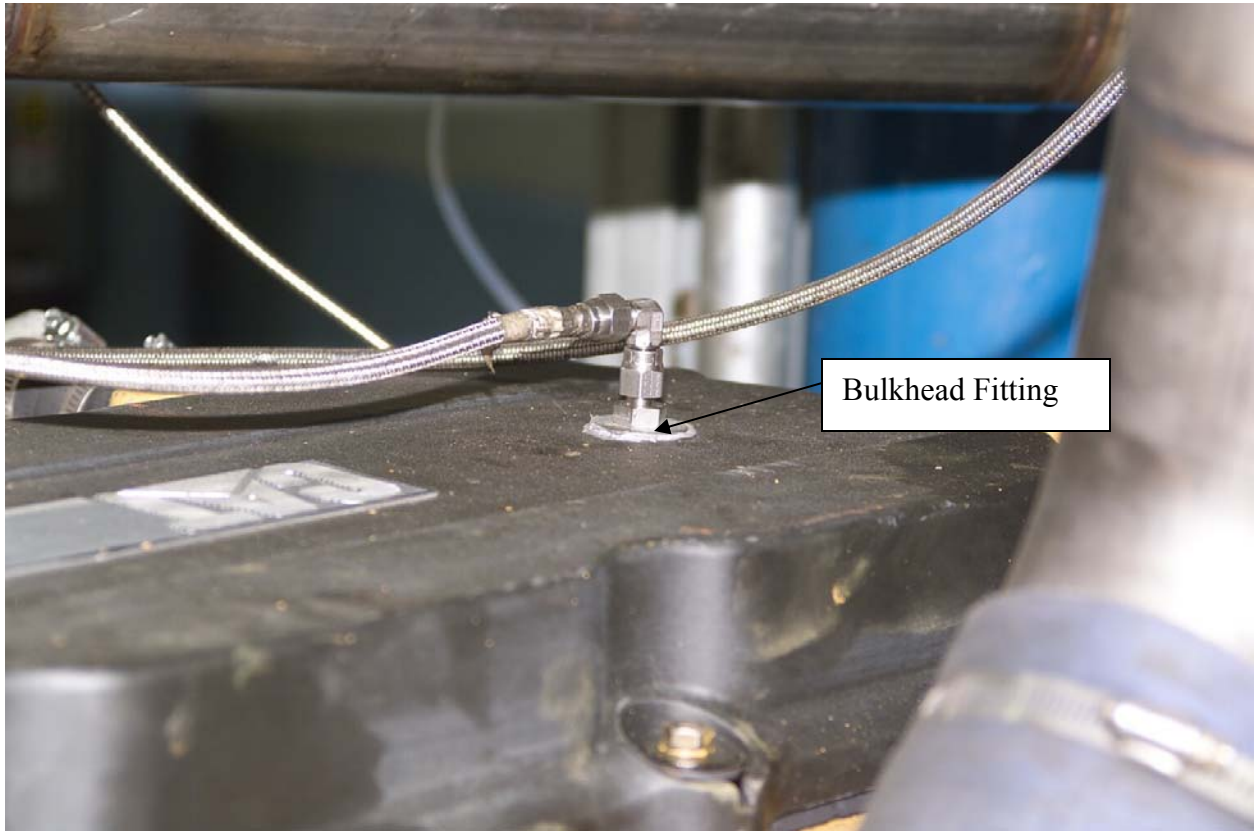


**Fig. A4.6 Oil Weight Cart**

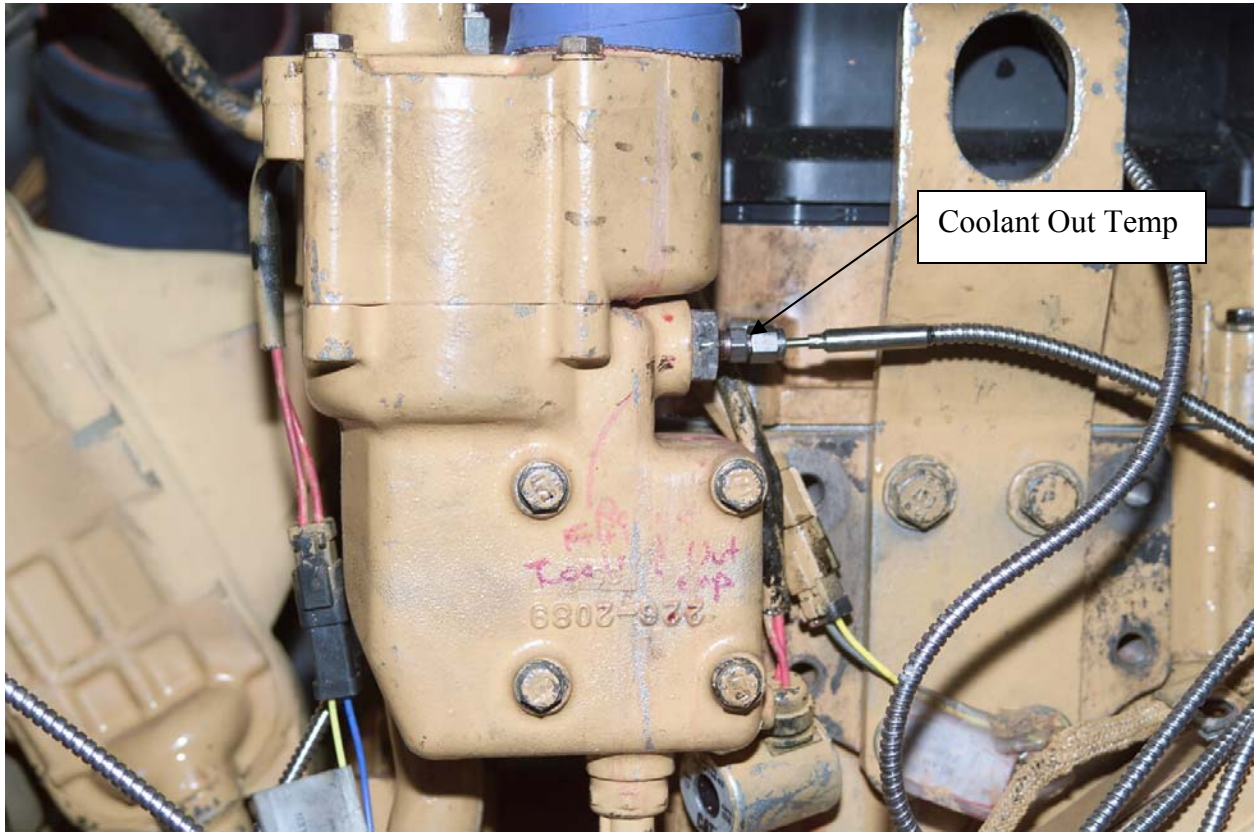




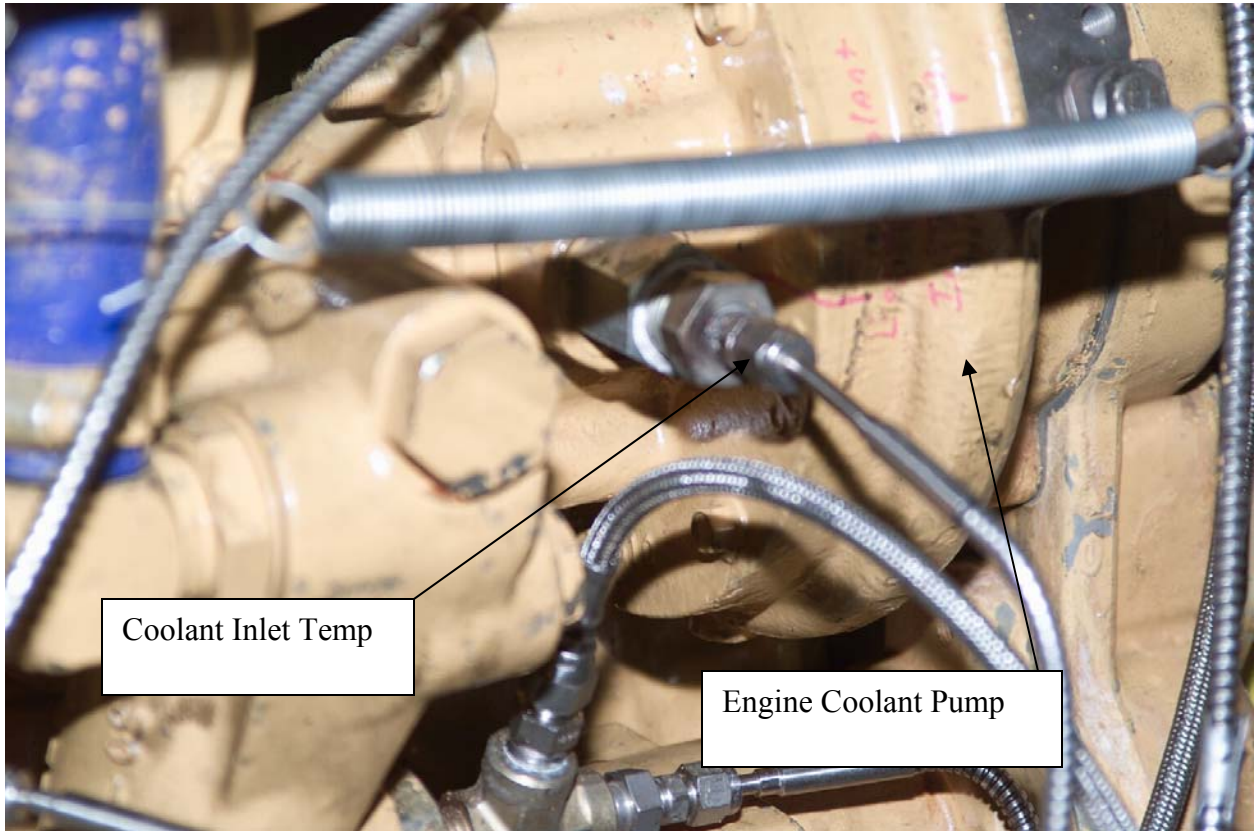




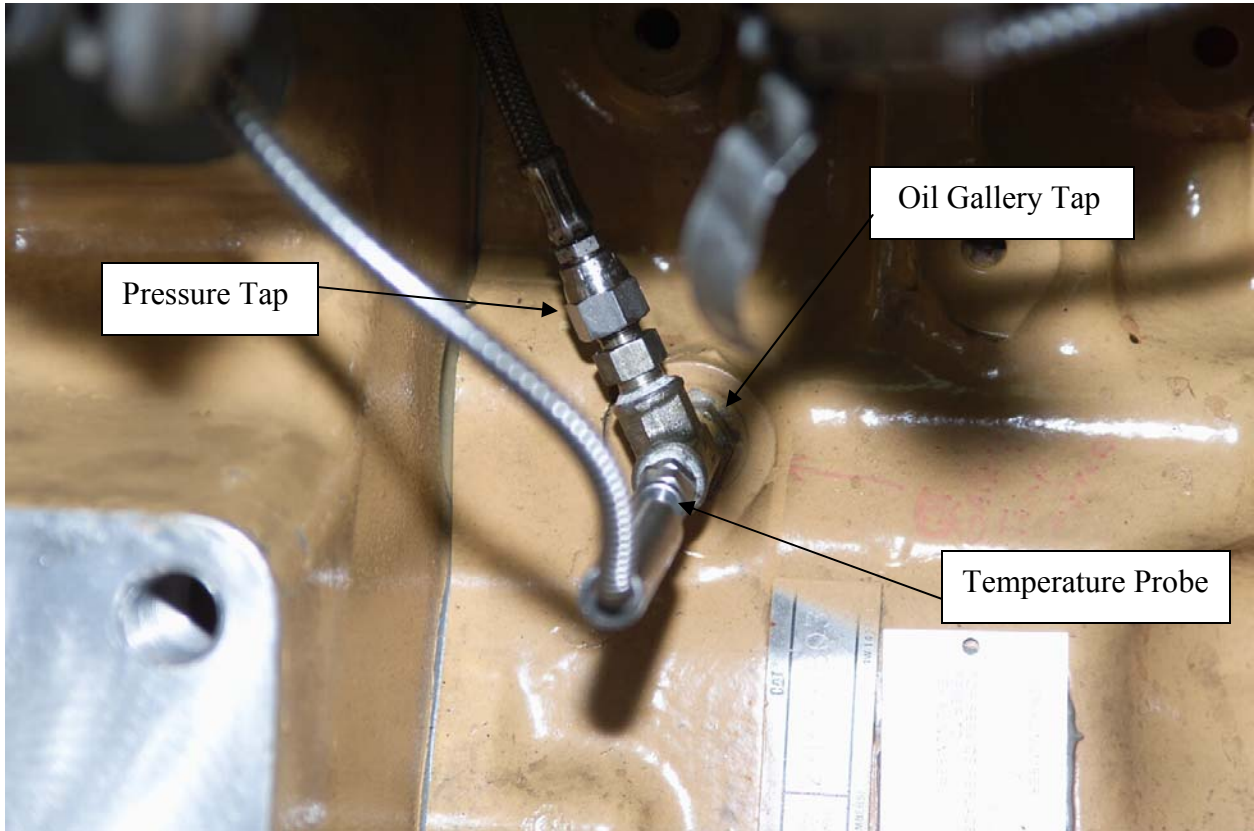
**Fig. A4.8 Crankcase Pressure Connection**



**Fig. A4.9 Coolant Outlet Temperature**

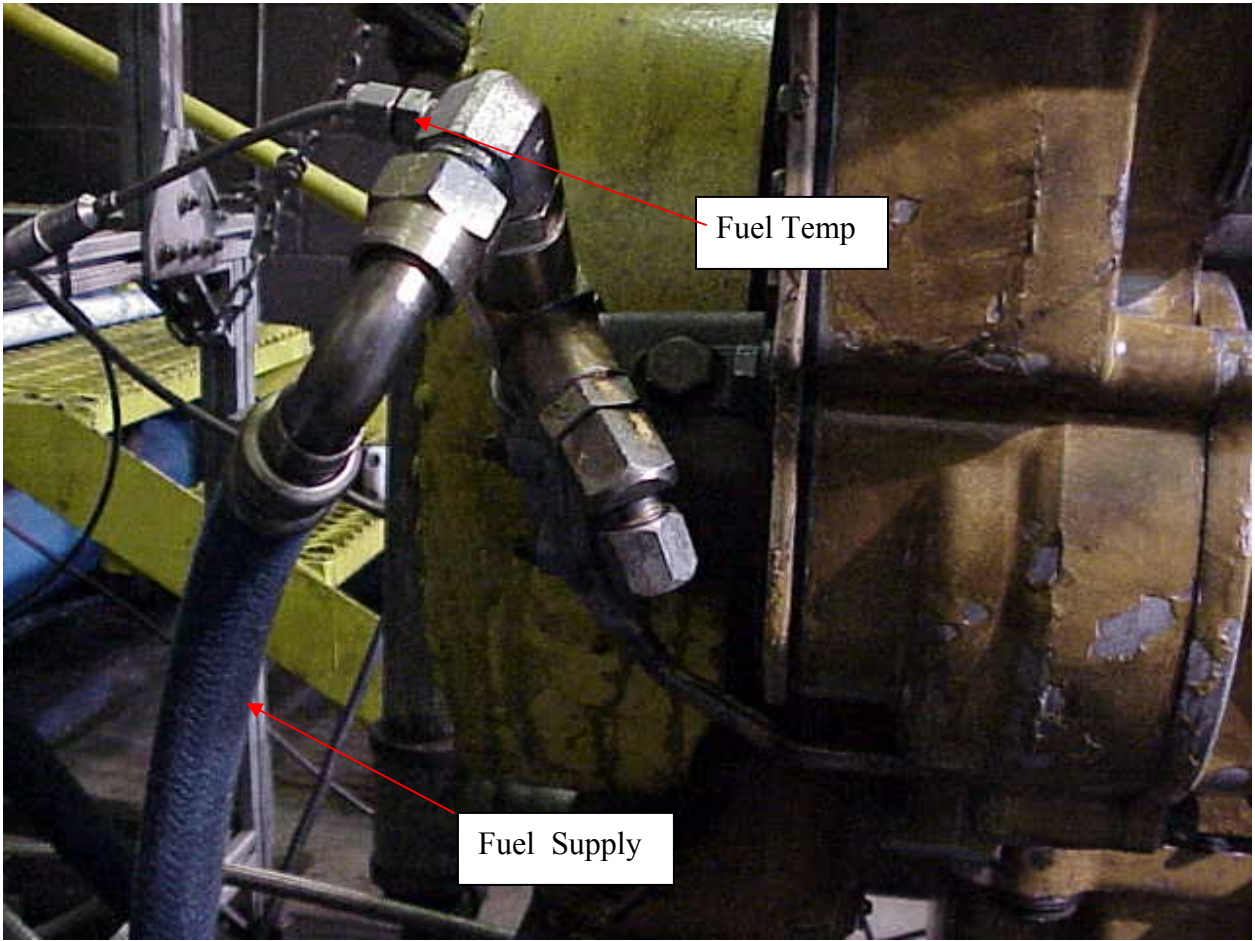


**Fig. A4.10 Coolant to Engine**

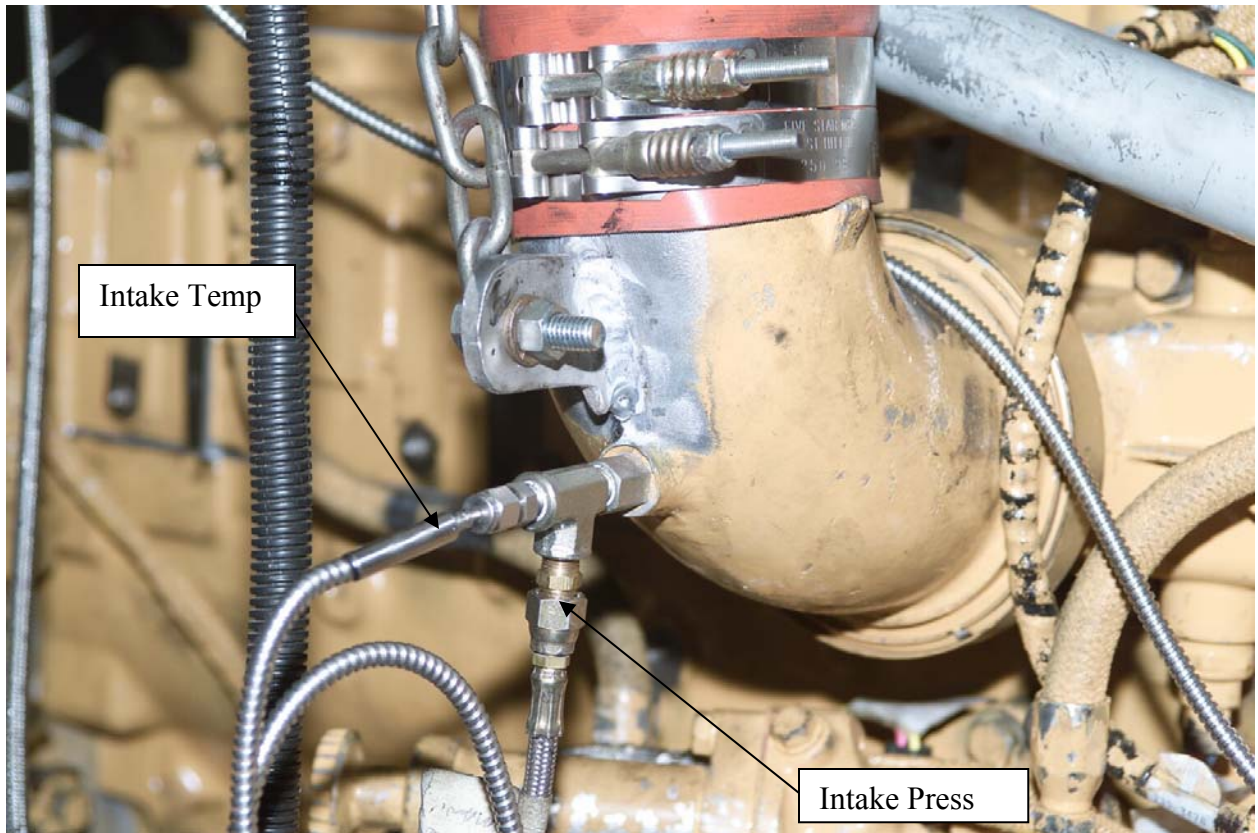


**Fig. A4.11 Oil Gallery Pressure and Temperature**

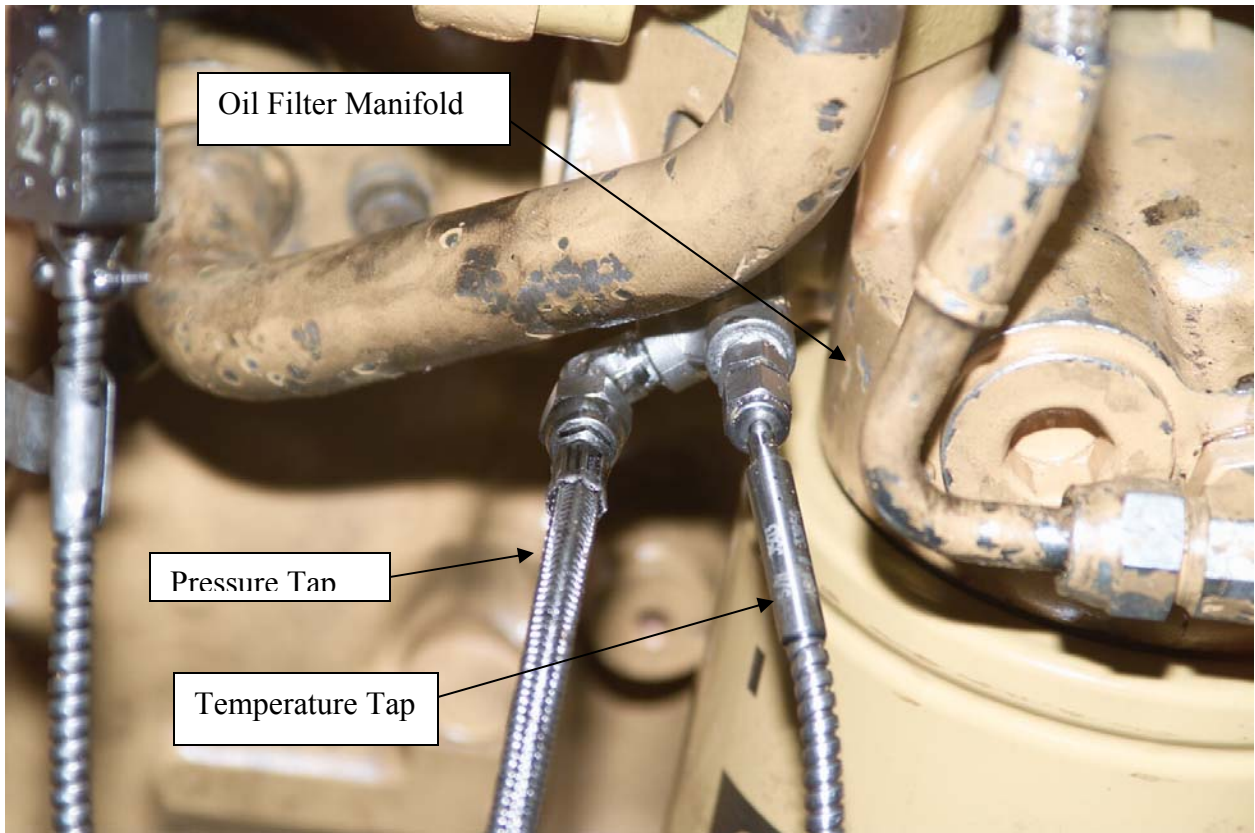




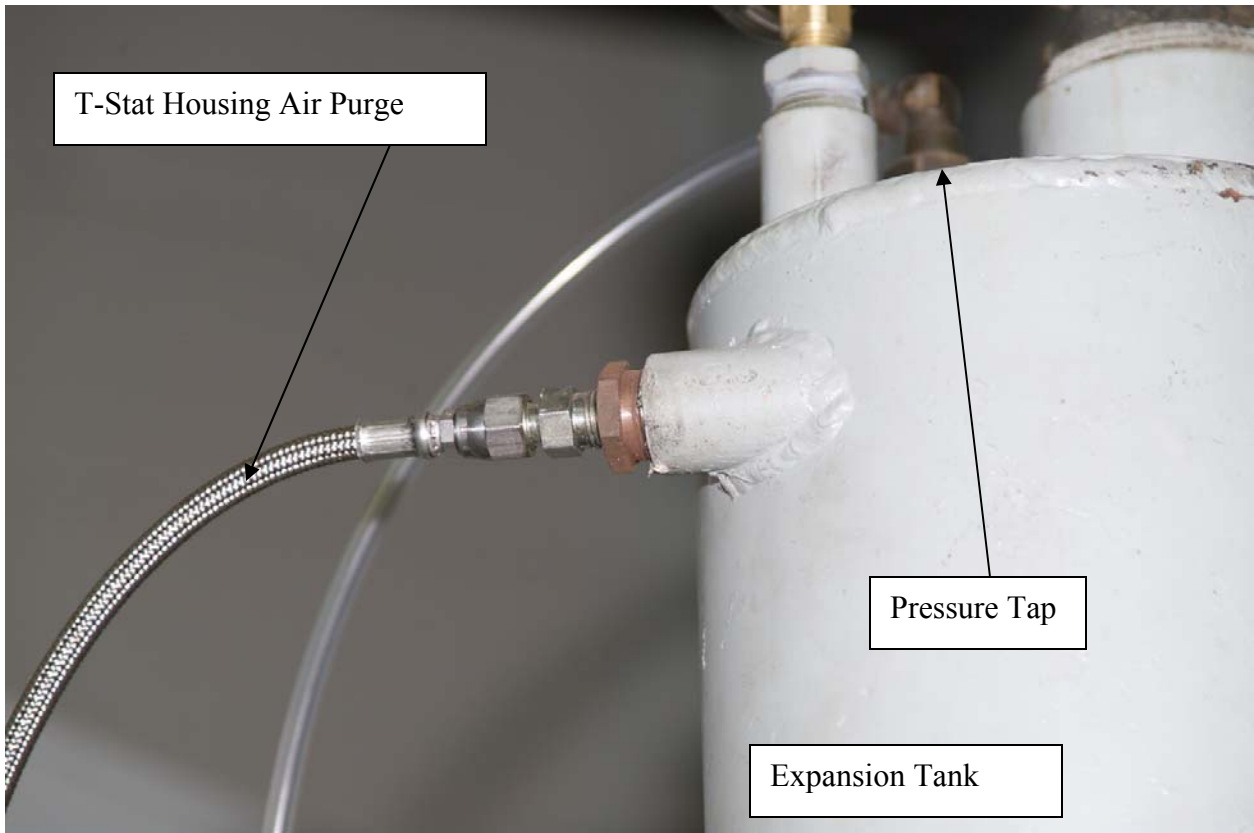
**Fig. A4.12 Fuel to Engine Temperature**



**Fig. A4.13 Intake Manifold Pressure and Temperature**

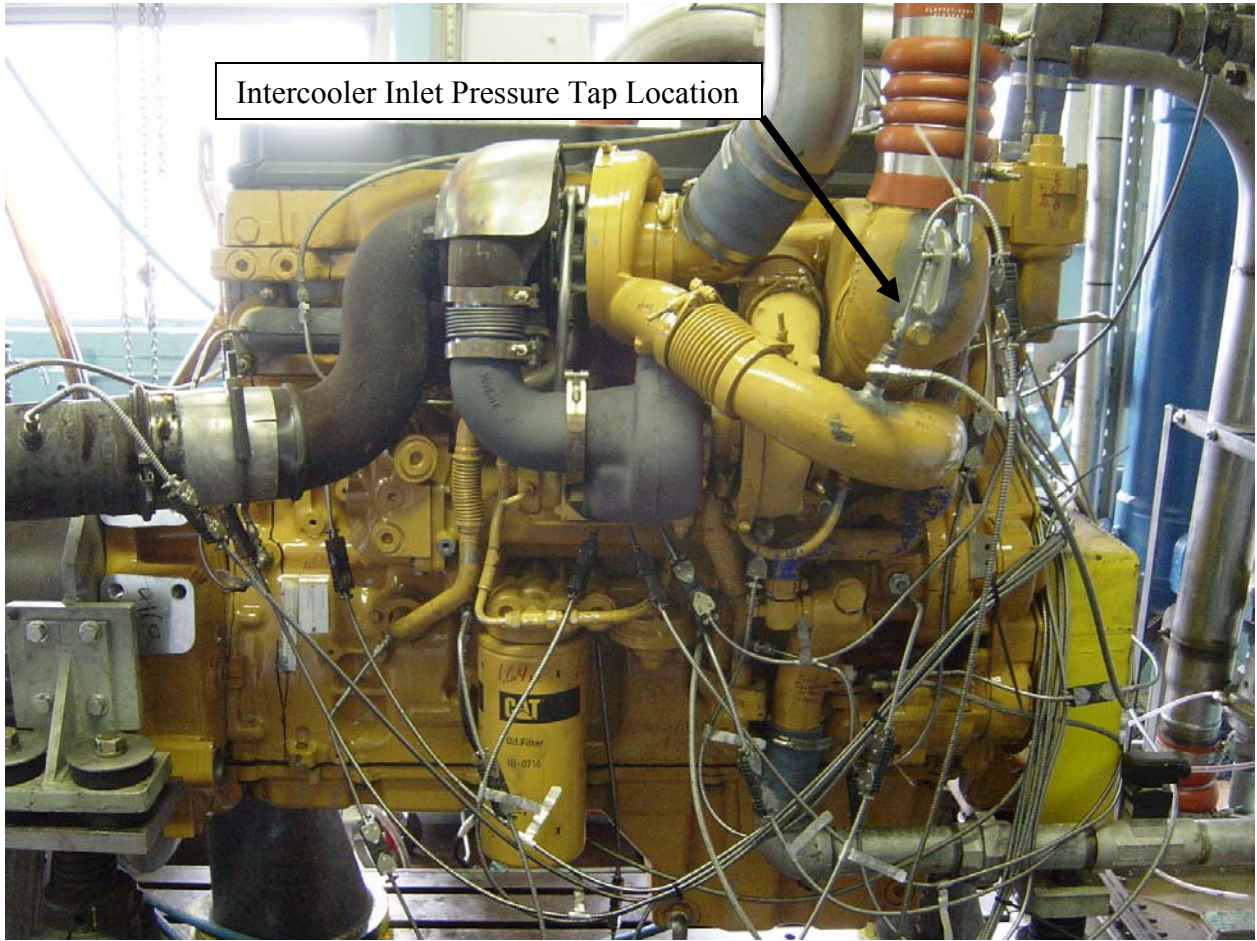


**Fig. A4.14 Oil Filter Out Pressure and Temperature**

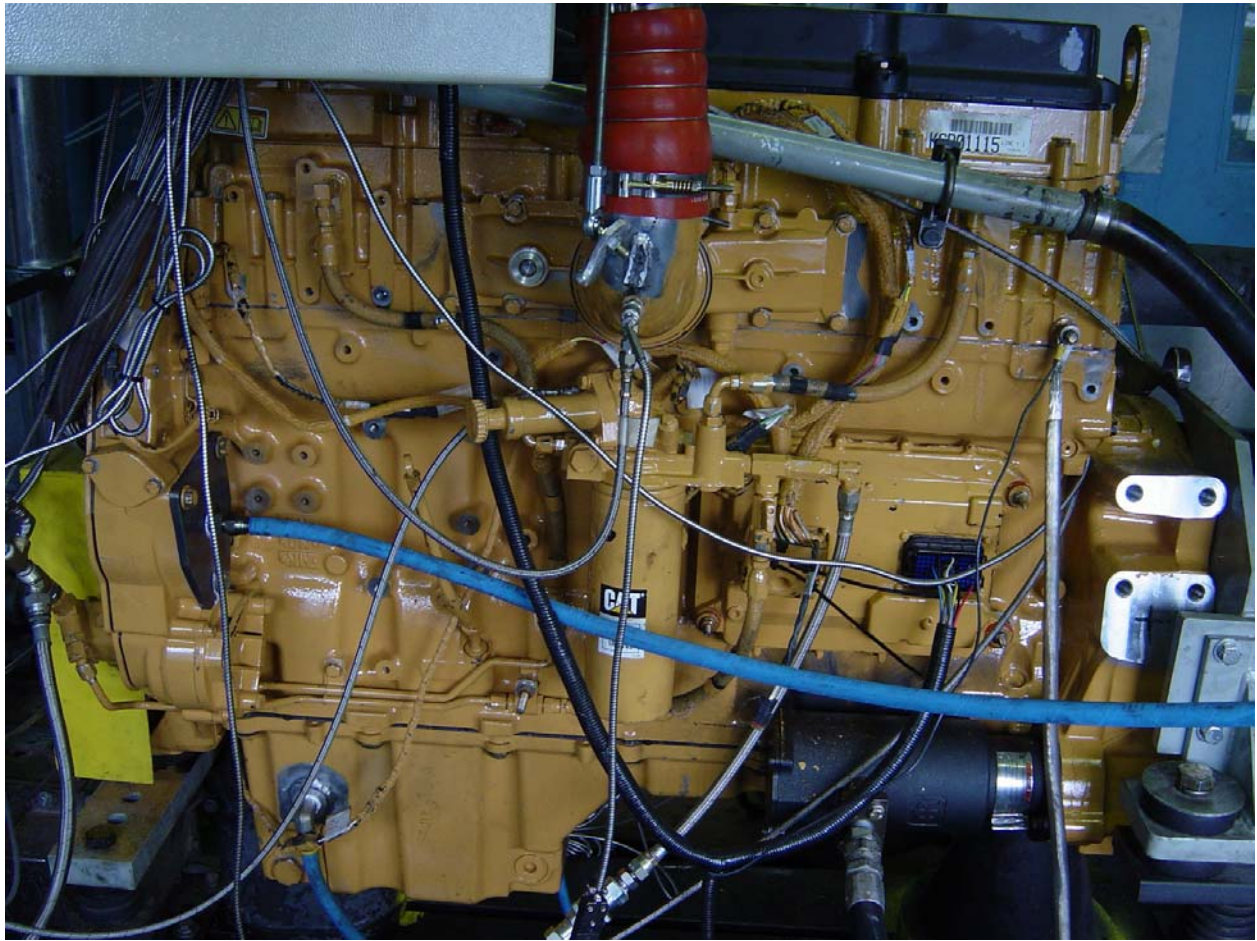


**Fig. A4.15 Cooling System Pressure**



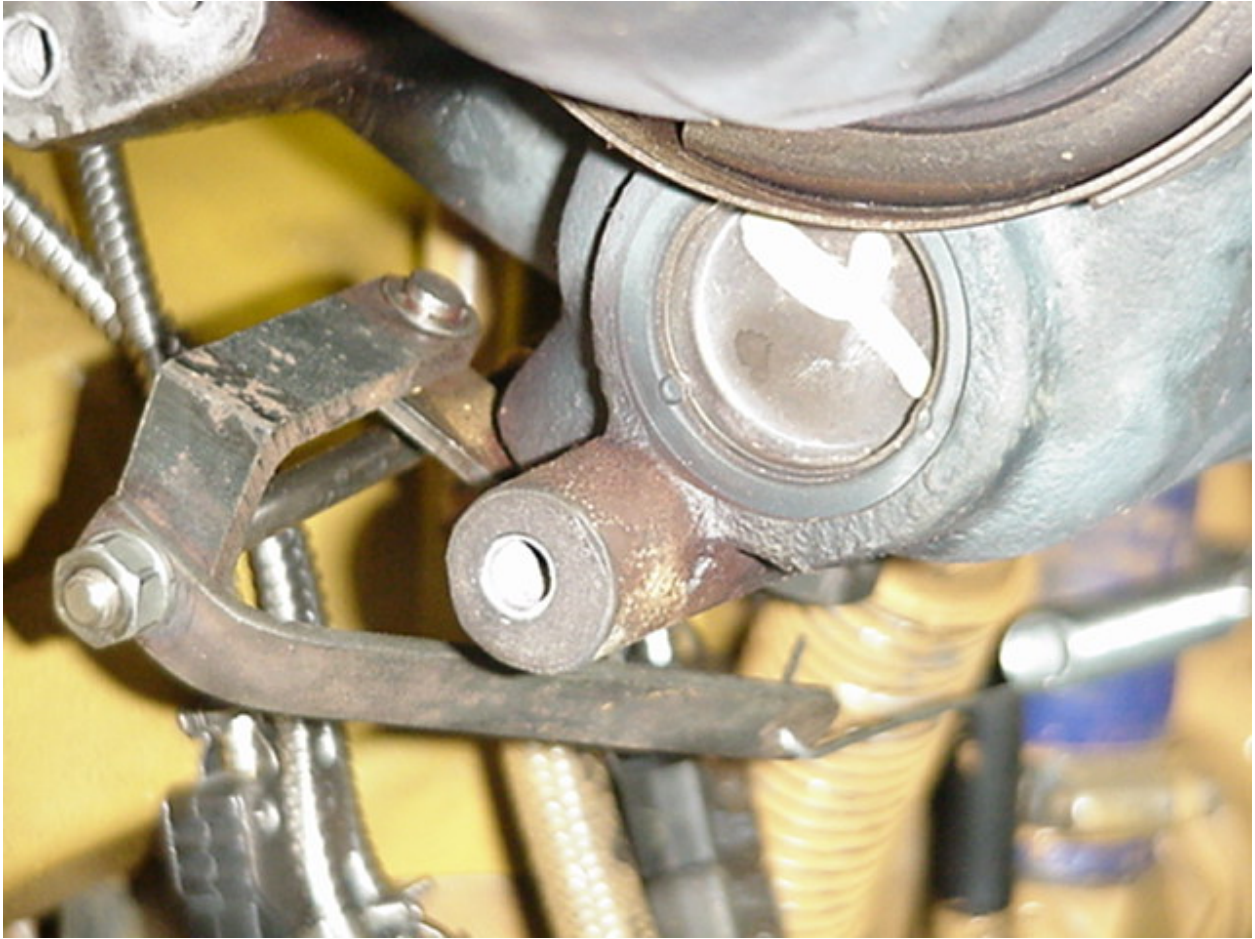


**Fig. A4.16 Right Side of Installed Engine**

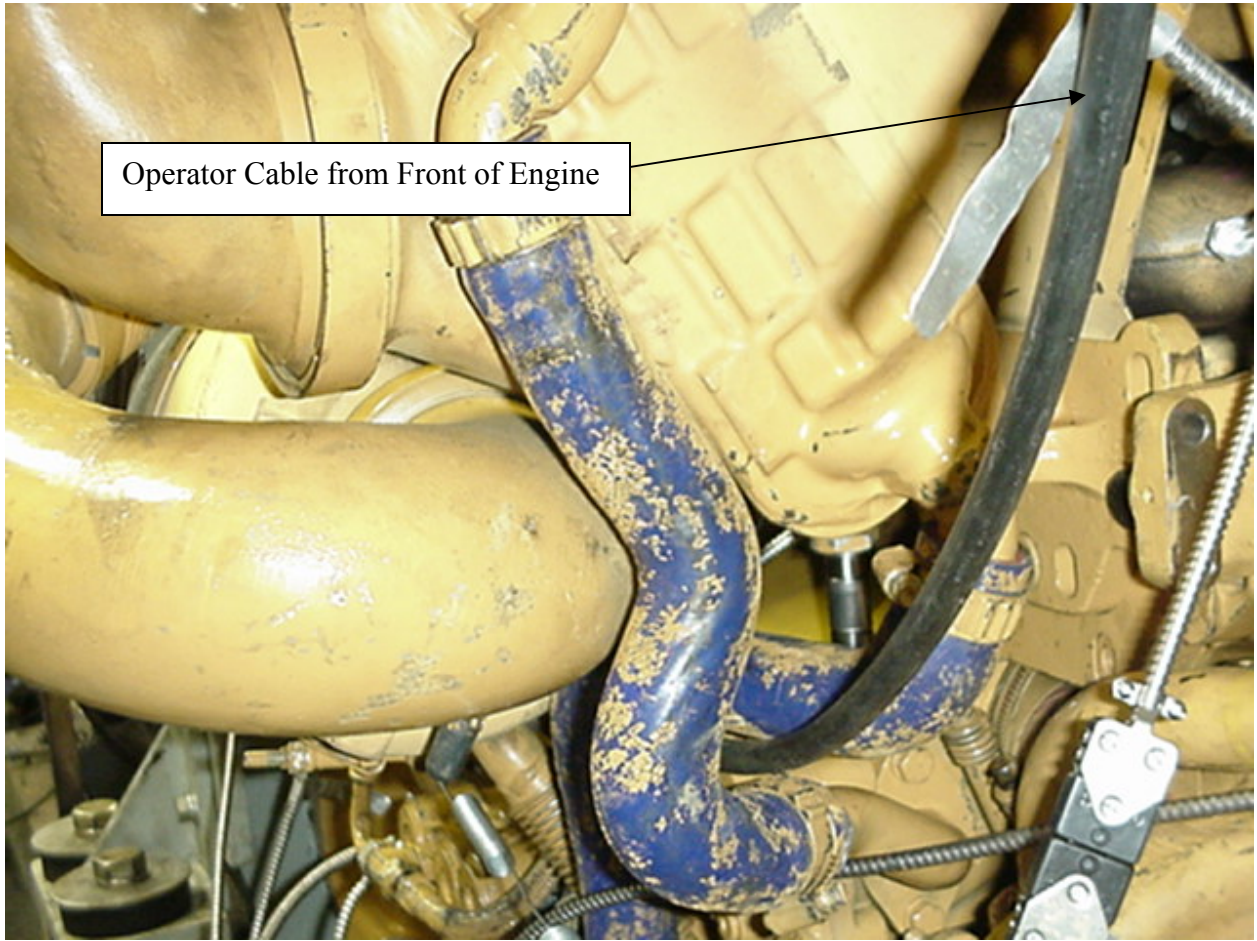


**Fig. A4.17 Left Side of Installed Engine**

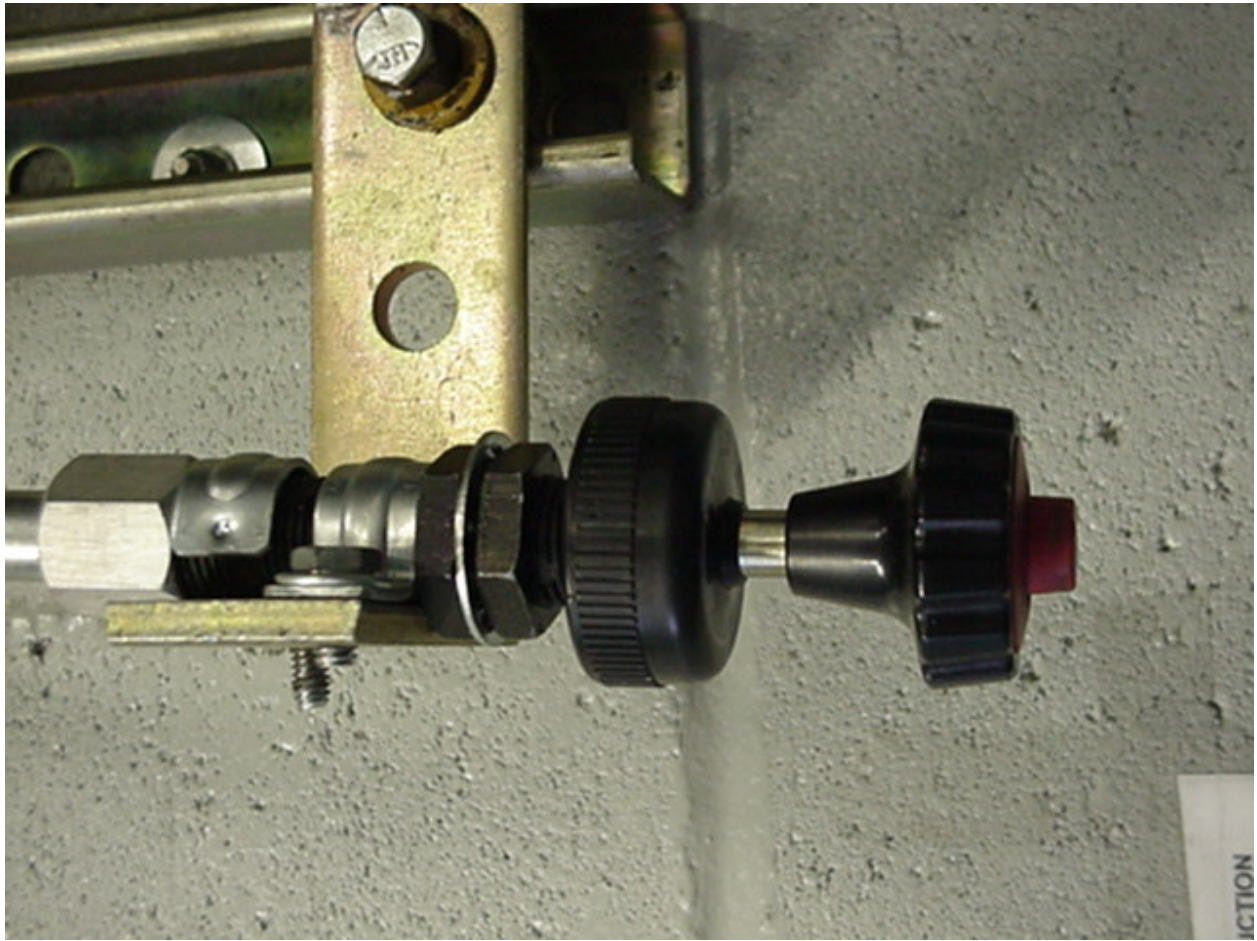




**Fig. A4.18 Turbo Wastegate Control**



**Fig. A4.19 Turbo Wastegate Control Cable**

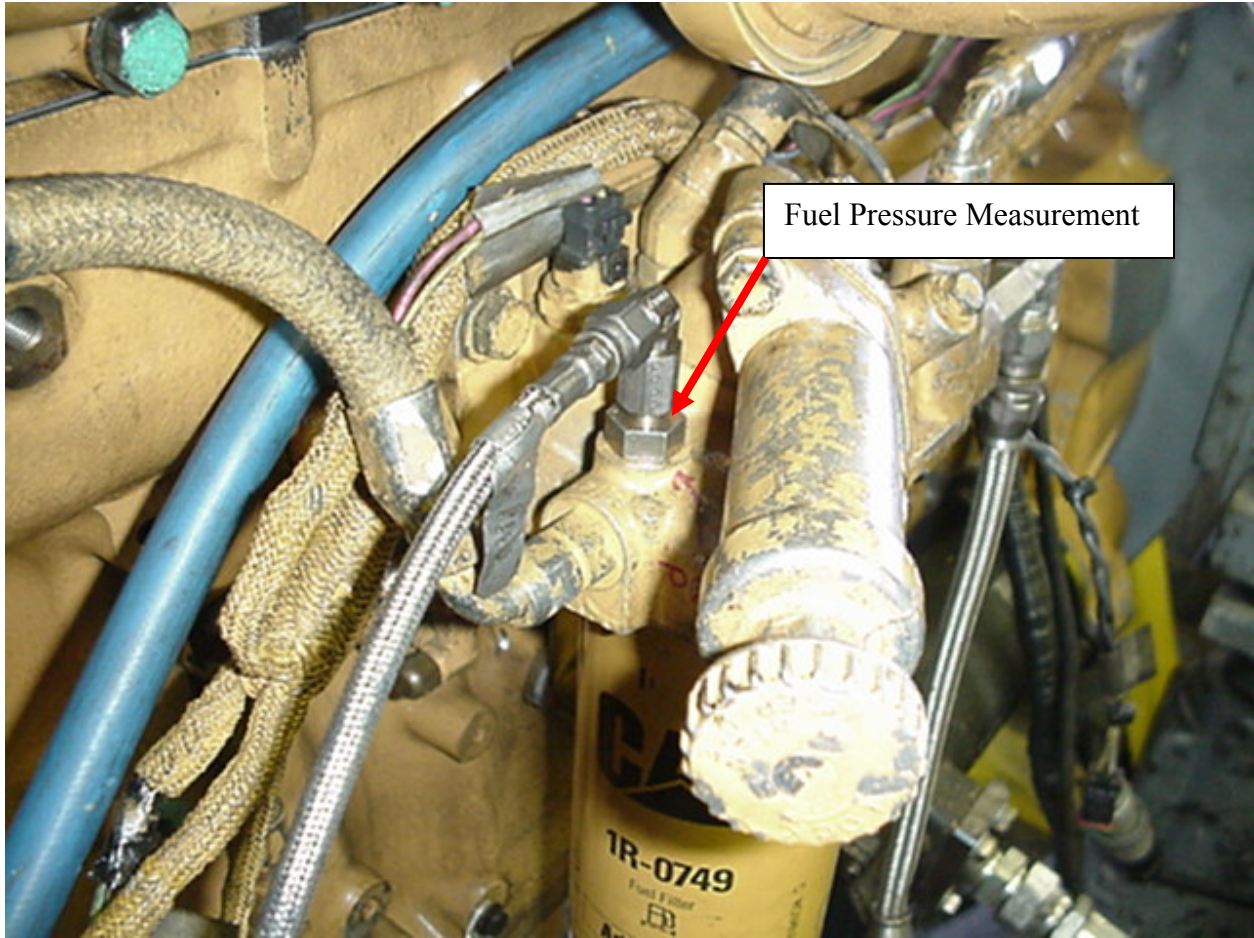


**Fig. A4.20 Turbo Wastegate Control Manual Adjuster**





**Fig. A4.21 Pressurized Oil Fill Location**



**Fig. A4.22 Fuel Pressure Measurement Location**

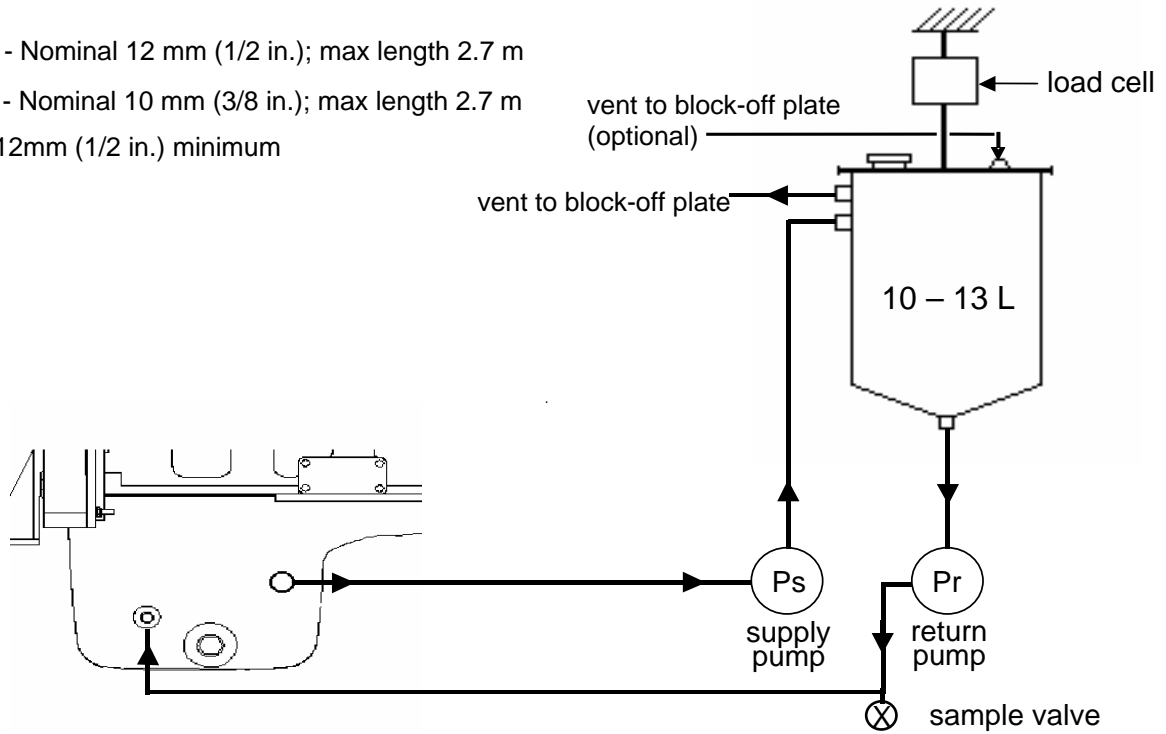
**A5. EXTERNAL OIL SYSTEM**  
**FIG. A5.1 External Oil System**

Hoses:

Supply - Nominal 12 mm (1/2 in.); max length 2.7 m

Return - Nominal 10 mm (3/8 in.); max length 2.7 m

Vent - 12mm (1/2 in.) minimum





## A6. FUEL SPECIFICATIONS

A6.1 See Table A6.1.

**Table A6.1 PC-10 ULSD Fuel Specifications**

Measurement	Specifications	Test Method
<b>Total Sulfur, ppm</b>	<b>7 - 15</b>	<b>D 5453</b>
<b>Gravity, °API</b>	<b>34 – 37</b>	<b>D 4052</b>
<b>Hydrocarbon Composition</b>		
<b>Aromatics % Wt.</b>	<b>26 – 31.5</b>	<b>D 5186</b>
<b>Olefins % Vol.</b>	<b>Report</b>	<b>D 1319</b>
<b>Cetane Index</b>	<b>Report</b>	<b>D 976</b>
<b>Cetane No.</b>	<b>43 – 47</b>	<b>D 613</b>
<b>Copper Strip Corrosion</b>	<b>1 Maximum</b>	<b>D 130</b>
<b>Flash Point, °C</b>	<b>54 Minimum</b>	<b>D 93</b>
<b>Pour Point, °C</b>	<b>-18 Maximum</b>	<b>D 97</b>
<b>Carbon Residue on 10% Residuum, %</b>	<b>0.35 Maximum</b>	<b>D 524 (10% Bottoms)</b>
<b>Water &amp; Sediment, % Vol.</b>	<b>0.05 Maximum</b>	<b>D 2709</b>
<b>Viscosity, cSt @ 40°C</b>	<b>2.0 – 2.6</b>	<b>D 445</b>
<b>Total Acid Number</b>	<b>0.05 Maximum</b>	<b>D 664</b>
<b>Strong Acid Number</b>	<b>0.00 Maximum</b>	<b>D 664</b>
<b>Accelerated Stability</b>	<b>1.5 max</b>	<b>D 2274</b>
<b>Ash, % Wt.</b>	<b>0.005 max</b>	<b>D 482</b>
<b>SLBOCLE, g</b>	<b>3100 min<sup>A</sup></b>	<b>D 6078<sup>A</sup></b>
<b>90% Distillation, °C</b>	<b>293 - 332</b>	<b>D 86</b>

<sup>A</sup>May be altered to be consistent with CARB or ASTM diesel fuel specifications.

**A7. CATERPILLAR SERVICE PUBLICATIONS**

TBD

## 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, and tubing 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.

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 S.I. units. The intent of this test method is to measure all parameters directly in S.I. 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 S.I. units.

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

**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	1 g/min
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
Carbon Dioxide	0.01 %

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

Parameter	Round off to Nearest
Mass Loss	0.1 mg
Oil Consumption	0.1 g
Piston Ratings	0.1 rating unit

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

(1) target

(2) target and range

(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 30.8 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 A8.2:** 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 (range<sub>low</sub> – range<sub>high</sub>). For example, the coolant system pressure is 99 – 107 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.emu.edu/> or they can be obtained in hardcopy format from the TMC.

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## A10. PISTON RATING LOCATIONS

A10.1 Each piston/ring combination is to be rated for ring sticking and sluggish rings as removed from the engine and then again after a solvent rinse. Each piston/ring combination is then to be measured for loss of side clearance. The piston rings are then removed and the pistons rated. See Table A10.1.

**Table A10.1 PISTON RATING LOCATIONS**

Location / Deposit	Special Instructions
Grooves:	
Top Groove Fill	
Intermediate Groove Fill	
“C” Groove Fill	
Groove No. 1	Rate HC, MC, LC & Lacquer
Groove No. 2	Rate HC, LC
Groove No. 3	Rate HC, MC, LC
Lands:	
Top Land Heavy Carbon	
Top Land % Flaked Carbon	
Lands No. 1 – No. 4	Rate HC, LC
Lands No.1 No. 2	Lacquer
Other:	
Undercrown	Rate separately from grooves and lands

**A11. OIL ANALYSES**

A11.1 See Table A11.1

**Table A11.1  
Oil Analysis Schedule**

Analysis, Method	Test Hours											
	0	4	50	100	150	200	250	300	350	400	450	500
Viscosity @ 100°C, D 445	√	√	√	√	√	√	√	√	√	√	√	√
TBN, D 4739	√	√	√	√	√	√	√	√	√	√	√	√
TAN, D 664	√	√	√	√	√	√	√	√	√	√	√	√
Fuel Dilution, D 3524			√				√					√
TGA Soot, D 5967 Annex A4			√				√					√
Oxidation, T-10 Integrated IR	√	√	√	√	√	√	√	√	√	√	√	√
Wear Metals, D 5185 (Al, Cr, Cu, Fe, Pb, Si)	√	√	√	√	√	√	√	√	√	√	√	√

## **A12. DETERMINATION OF OPERATIONAL VALIDITY**

### *A12.1 Quality Index Calculation*

A12.1.1 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.

A12.1.2 Use the U, L, Over Range, and Under Range values shown in Table A12.1 for the QI calculations.

A12.1.3 Round the calculated QI values to the nearest 0.001.

A12.1.4 Report the QI values.

### *A12.2 Averages*

A12.2.1 Calculate the average for control and non-control parameters, and report the values. Note that, with the exception of non-QI and ranged parameters, the averages are not directly used to determine operational validity but may be helpful when an engineering review is required (A12.4).

### *A12.3 Determining Operational Validity*

A12.3.1 QI threshold values for operational validity are shown in Table A12.1. Specifications for non-QI control parameters and ranged parameters are also shown in Table A12.1.

A12.3.1.1 A test with all control parameter QI values greater than or equal to the threshold value and with averages for all non-QI control parameters and all ranged parameters within specifications is operationally valid provided that no other operational deviations exist that may cause the test to be declared invalid.

A12.3.1.2 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 A12.1.

### *A12.4 Engineering Review*

A12.4.1 Perform an engineering review 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.

A12.4.2 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.

A12.4.2 Determine operational validity based upon the engineering review and summarize the decision in the comment section the test report. Supporting documentation may be included at the end of the test report. The final decision regarding operational validity rests with the laboratory.



**TABLE A12.1  
QUALITY INDEX CALCULATION VALUES**

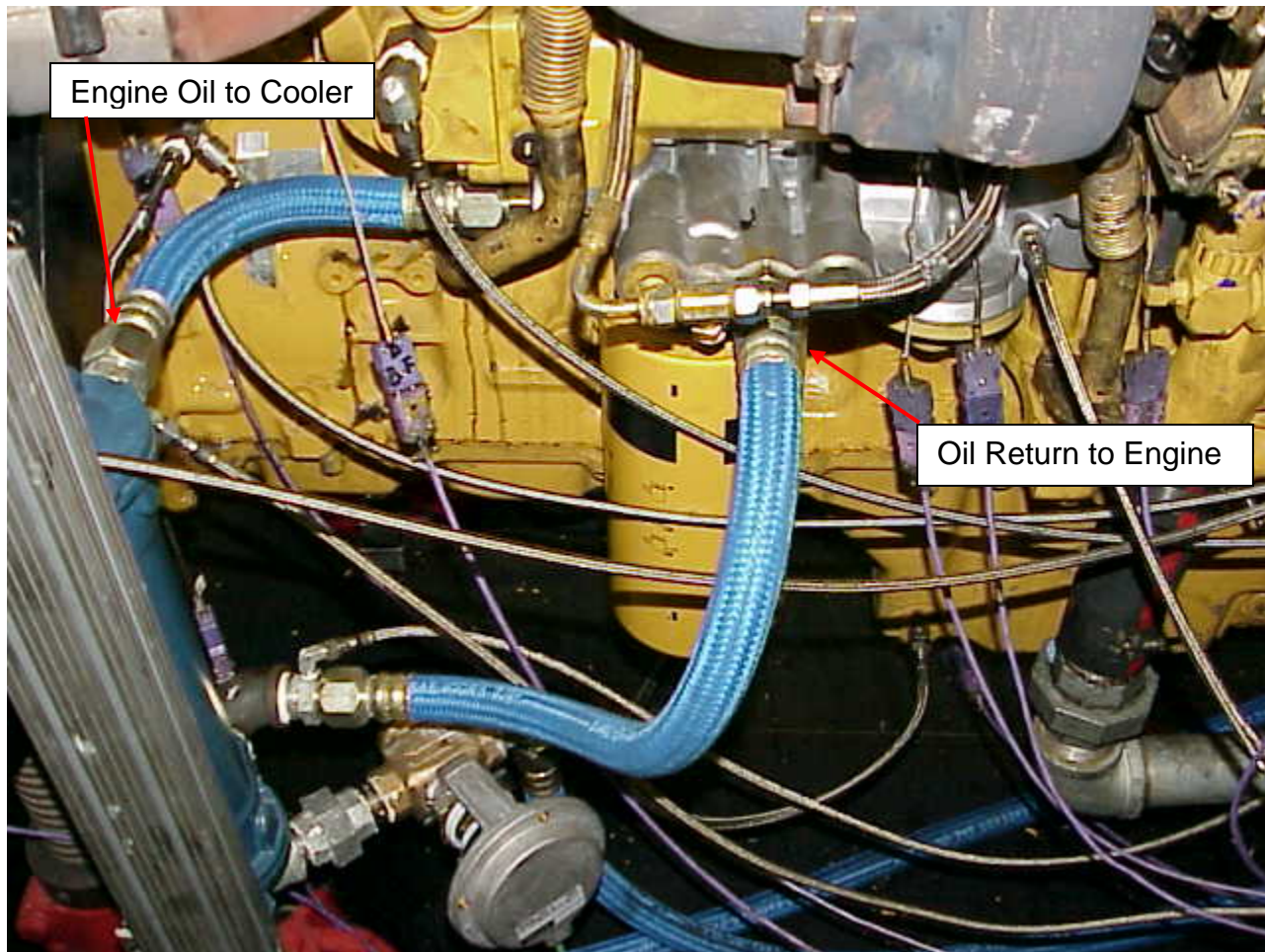
Control Parameter	Units	Quality Index Threshold	Quality Index U & L Values		Over & Under Range Values	
			U	L	High	Low
Speed	r/min	0.000	1802.5	1797.5	1937	1663
Fuel Flow	kg/h	0.000	1203	1197	1364	1036
Inlet Air Temp.	°C	0.000	26	24	79.8	-29.8
Intake Man. Temp.	°C	0.000	40.5	39.5	67.4	12.6
Fuel In Temp.	°C	0.000	40.4	39.6	61.9	18.1
Coolant Out Temp.	°C	0.000	88.4	87.6	109.9	66.1
Oil Gallery Temp.	°C	0.000	98.3	97.7	114.4	81.6
Exhaust Back Press.	kPa	0.000	6.3	5.7	22.4	-10.4
					Over & Under Range Values	
<b>Non-QI Control Parameter</b>	<b>Units</b>		<b>Specification</b>		<b>High</b>	<b>Low</b>
Inlet Air Pressure	KPa		93 ± 1.5		175	11
<b>Ranged Parameter</b>	<b>Units</b>		<b>Range</b>		<b>High</b>	<b>Low</b>
Intake Manifold Pressure	KPa		275 – 285		554	6

## **A13 OIL TEMPERATURE CONTROL SYSTEM**

A13.1 System Details - details of the auxiliary oil heat exchanger setup are shown in Figs. A13.1 through A13.4.

A13.2 Heat Exchanger – use an ITT Standard SSCF heat exchanger, p/n SN5160030014004.

A13.3 Oil Lines and Fittings – Use two No. 16 size lines with a maximum length of 36 in. (total of both lines). Use No. 16 NPT threaded fittings for the line connections. It is recommended that stainless steel braided hose be used for the oil lines.



**Fig A13.1 Remote Oil Heat Exchanger**

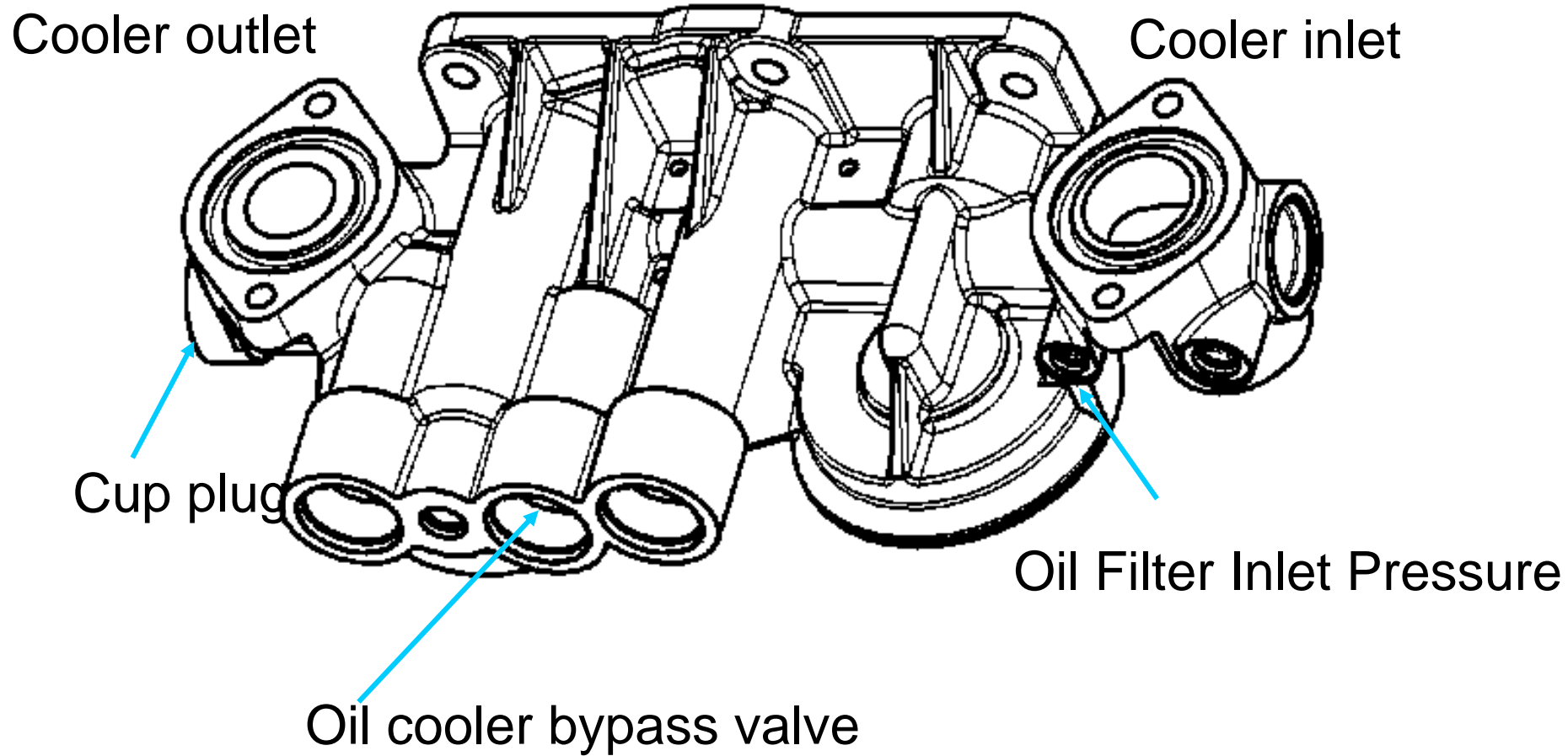
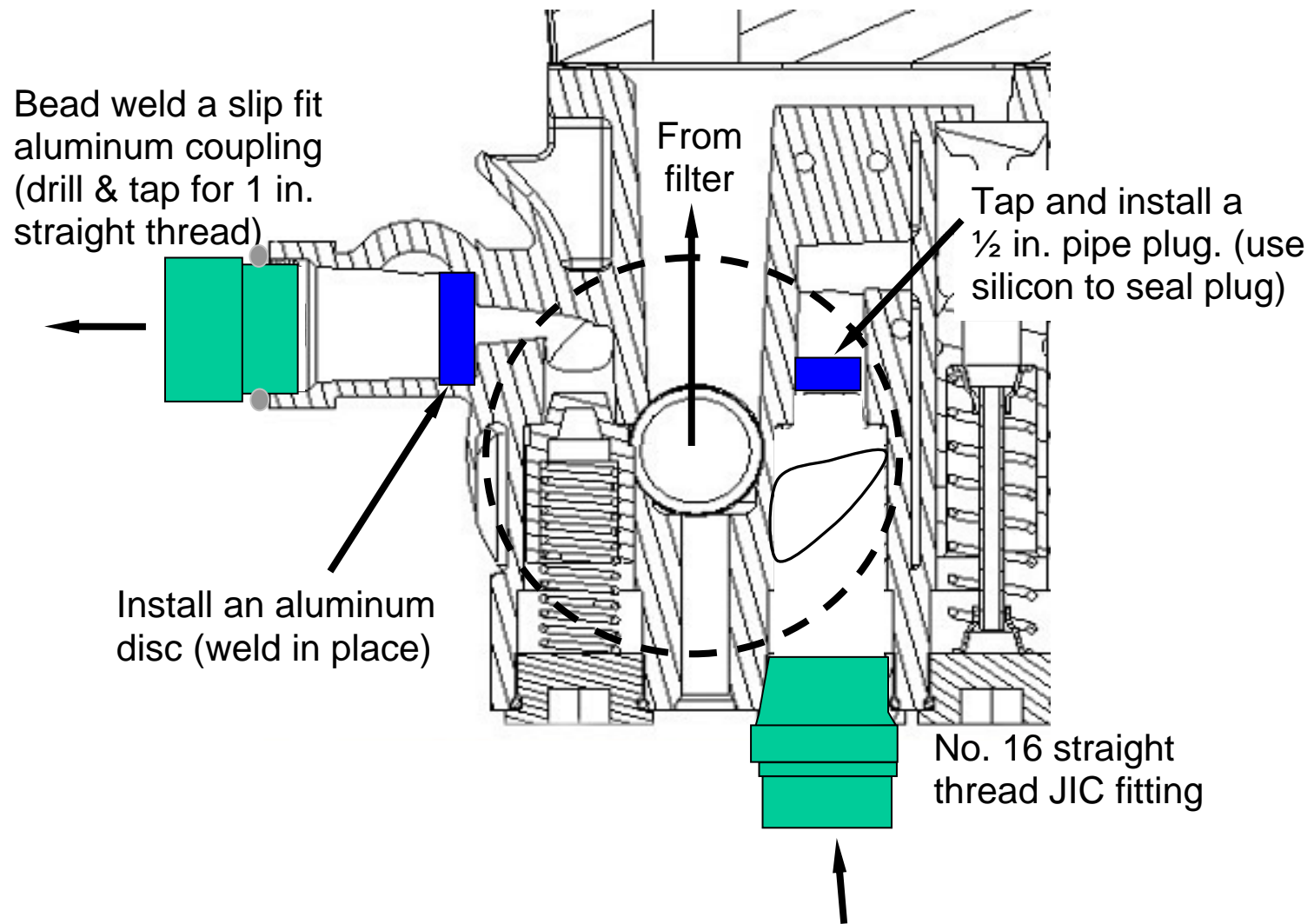
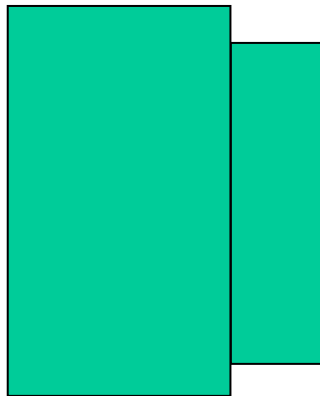


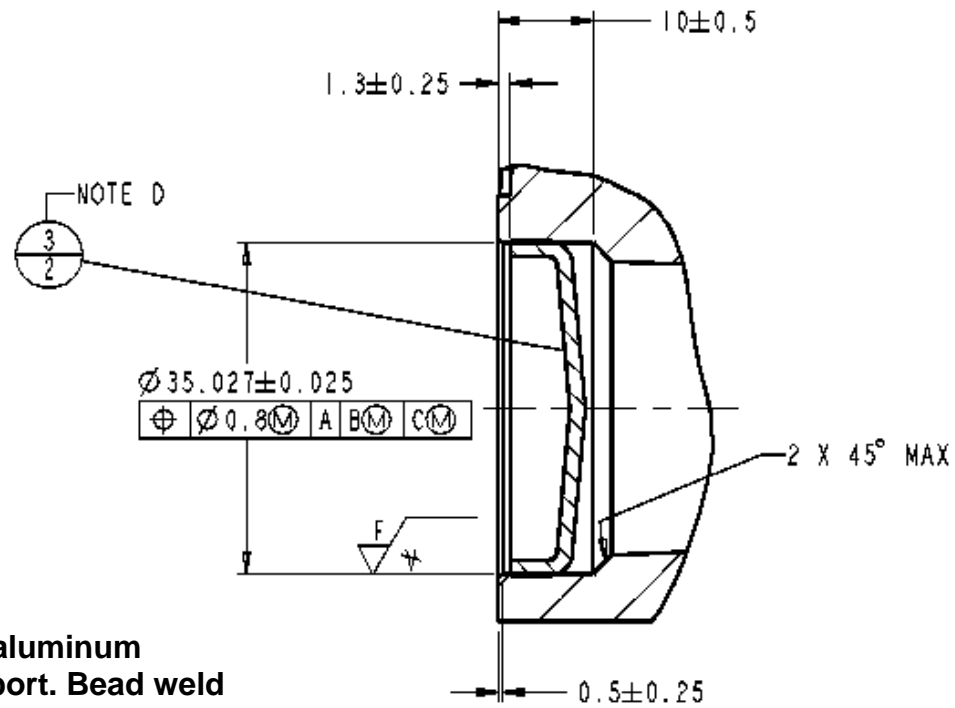
Fig. A13.2 Filter Base (p/n 251-6668) View



**Fig. A13.3 Filter Base Modifications**



Fabricate a 1" straight thread aluminum coupling that will slip into the port. Bead weld the coupling in place.



**DETAIL P**  
 SCALE 2:1  
 SH 2 D-8

Fig A13.4 Details of Cup Plug Feature at Back End of Filter Base

## A14 C13 OUTLIER SCREENING METHODS

### A14.1 Average Top Groove Carbon:

A14.1.1 Calculate the average top groove carbon using all rings and report the data on the appropriate forms.

A14.1.2 For each piston, calculate the top groove carbon relative offset as

$$TGCOffset_{piston} = TGC_{piston} - ATGC - RPTGC_{piston} \quad (A14.1)$$

Where:

$TGC_{piston}$  = top groove carbon for the piston, dem.

ATGC = average top groove carbon from A14.1.1, dem.

$RPTGC_{piston}$  = reference relative top groove carbon profile from Table A14.1

ATGCO is the average of the six  $TGCOffset_{piston}$ 's

Piston = 1,2,3,4,5,6

A14.1.3 If  $\max |TGCOffset_{piston}|/SDTGCO > 1.887$ , the outlier screened average top groove carbon is the average of the top groove carbons for the five pistons for which  $|TGCOffset_{piston}|$  is not maximized plus  $RRPTGC_{piston} / 6$  for the piston where it is maximized

$$\text{where } SDTGCO = \sqrt{\sum_{cylinder=1}^6 (TGCOffset_{cylinder} - ATGCO)^2 / 5} \quad (A14.2)$$

A14.1.4 If  $\max |TGCOffset_{piston}|/SDTGCO \leq 1.887$ , the outlier screened average top groove carbon is identical to the average top groove carbon from A14.1.1.

### A14.2 Average Top Land Carbon:

A14.2.1 Calculate the measured average top land carbon and report the value on the appropriate form.

A14.2.2 Use Practice E178, two-sided test at a 95% significance level, to determine if any of the top land carbon values are outliers. Report the outlier screened average top land carbon on the appropriate form. If no outliers were identified, this value will be identical to the measured value calculated in A14.2.1.

### A15.3 Average Second ring top Carbon:

A14.3.1 Calculate the measured average second ring top carbon and report the value on the appropriate form.

A14.3.2 Use Practice E178, two-sided test at a 95% significance level, to determine if any of the second ring top carbon values are outliers. Report the outlier screened average second ring top carbon on the appropriate form. If no outliers were identified, this value will be identical to the measured value calculated in A14.3.1.

**Table A14.1 – Top Groove Carbon Relative Profiles**

Piston	1	2	3	4	5	6
Relative Profile	5.38	-0.39	-0.71	-3.15	-1.43	0.30

## A15 C13 MERIT RATING CALCULATION

### A15.1 Merit System Components:

A15.1.1 *Anchors* – anchor performance level based on one test.

A15.1.2 *Maximums* – limit of acceptable performance.

A15.1.3 *Minimums* – best achievable result.

A15.1.4 *Weights* – relative contribution to total merit.

**Table A15.1**

Criterion	Top Groove Carbon	Top Land Carbon	Second Ring Top Carbon	Delta Oil Consumption
Weight	300	300	100	300
Maximum	53	35	33	31
Anchor	46	30	22	25
Minimum	30	15	5	10

A15.1.5 *Multipliers* – Using Table A16.1, determine the multiplier for each parameter as follows:

A15.1.5.1 If a result is at the anchor, multiplier is one. (e.g., Top Groove Carbon = 46 yields multiplier=1)

A15.1.5.2 If a result is at or below the minimum, multiplier is two (e.g., Top Groove Carbon = 30 yields multiplier=2)

A15.1.5.3 If a result is at the maximum, multiplier is zero (e.g., Top Groove Carbon = 53 yields multiplier=0)

A15.1.5.4 If a result is between minimum and anchor, linearly interpolate multiplier between 2 and 1. (e.g. Top Groove Carbon = 42 yields multiplier = 1.25)

A15.1.5.5 If a result is between anchor and maximum, linearly interpolate multiplier between 1 and 0. (e.g. Top Groove Carbon = 50 yields multiplier = 0.43)

A15.1.5.6 If a result is above the maximum, linearly extrapolate multiplier on the same line as between 1 and 0. (e.g. Top Groove Carbon = 57 yields multiplier = -0.57)

A15.2 *Calculated Merit Result* – Sum the products of weights and multipliers across the four results. This is the calculated merit result. In equation form:

$$\text{Calculated Merit} = \sum_{i=1}^4 \text{Weight}_i$$

$$x \left\{ \begin{array}{l} \delta(\text{result}_i > \text{anchor}_i) \times (\text{max}_i - \text{result}_i) / (\text{max}_i - \text{anchor}_i) \\ + \delta(\text{min}_i < \text{result}_i \leq \text{anchor}_i) \times [1 + (\text{anchor}_i - \text{result}_i) / (\text{anchor}_i - \text{min}_i)] \\ + \delta(\text{result}_i \leq \text{min}_i) \times 2 \end{array} \right\}$$

where  $\delta(x) = 1$  if  $x$  is true;  $0$  if  $x$  is false

A15.2.1 Report the results of the merit calculations on the appropriate.



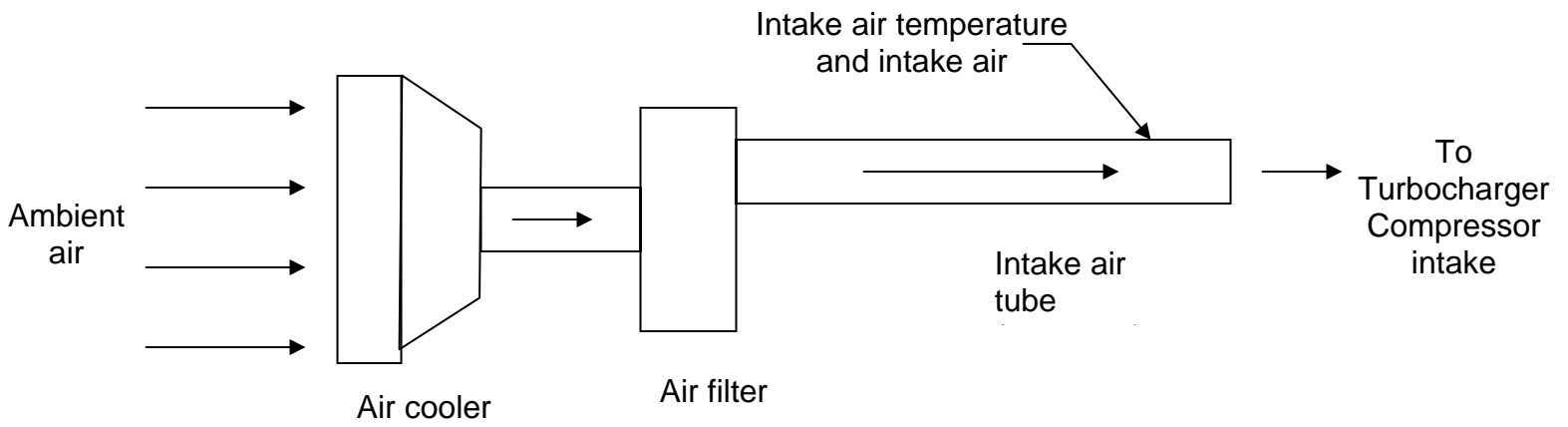
**APPENDIXES**  
**(Non Mandatory Information)**

X1. Typical System Configurations:

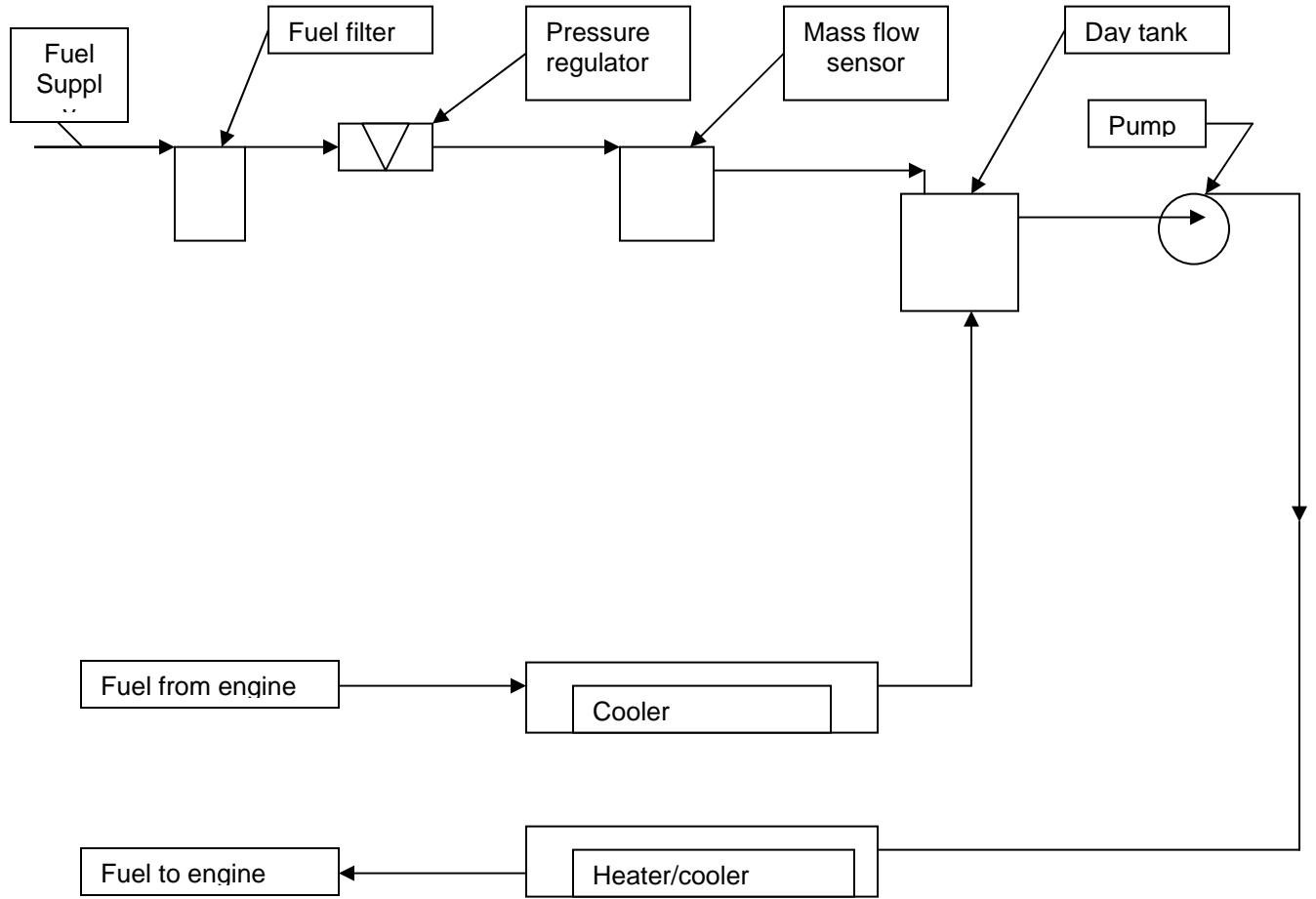
X1.1 Intake Air System (Fig. X1.1)

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

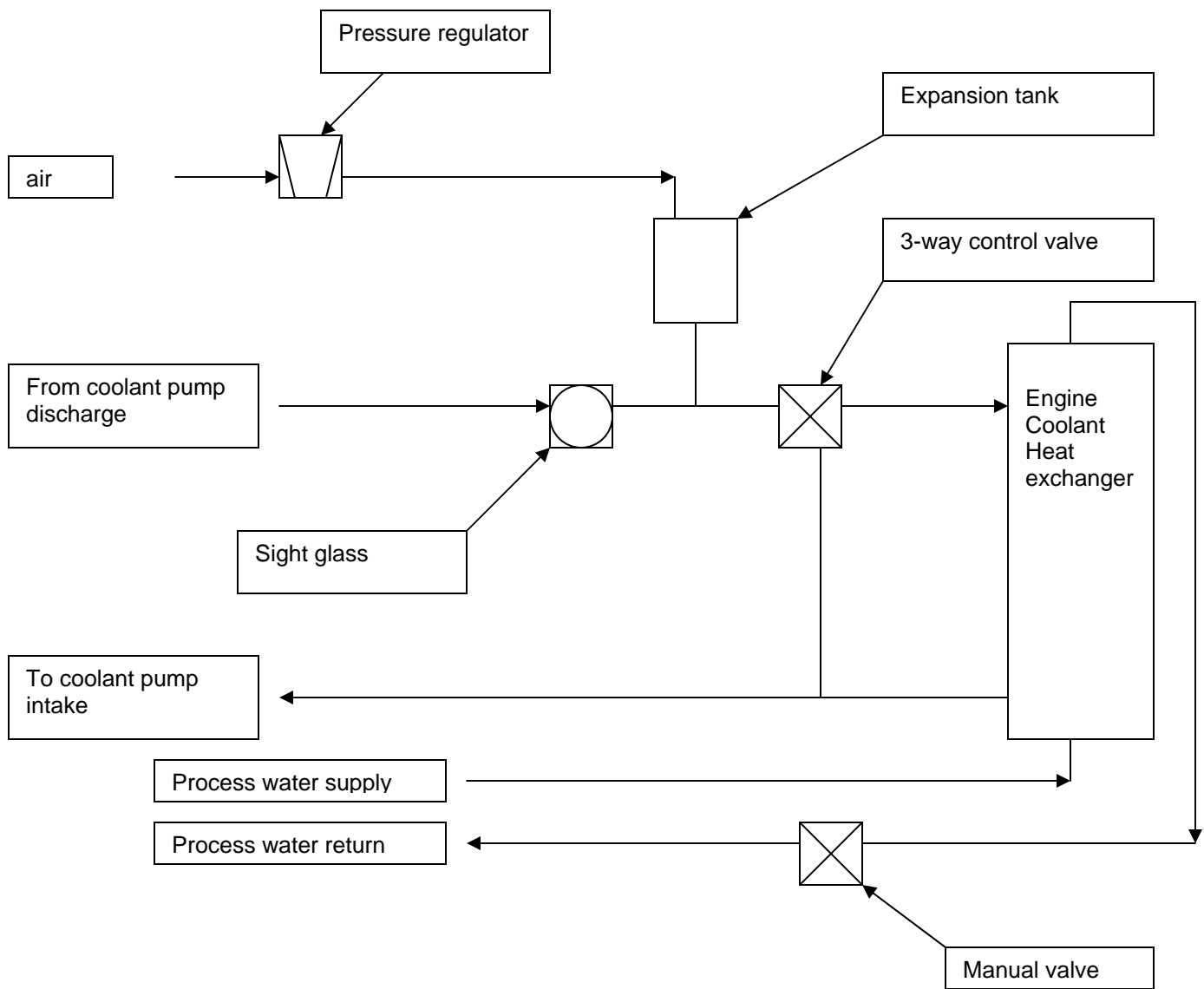
X1.3 Coolant System (Fig X1.3)



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



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



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

## Caterpillar C13 Footnotes

<sup>1</sup> This test method is under the jurisdiction of ASTM Committee D02 on Petroleum Products and Lubricants and is the direct responsibility of Subcommittee D02.0B on Automotive Lubricants. Current edition approved XXX. Published YYYY.

<sup>2</sup> American Society for Testing and Materials takes no position respecting the validity of any patent rights asserted in connection with any item mentioned in this standard. Users of this standard are expressly advised that determination of the validity of any such patent rights, and the risk of infringement of such rights, are entirely their own responsibility.

<sup>3</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.

<sup>4</sup> Annual Book of ASTM Standards, Vol 05.01

<sup>5</sup> Annual Book of ASTM Standards, Vol 05.04

<sup>6</sup> Annual Book of ASTM Standards, Vol 05.02

<sup>7</sup> Annual Book of ASTM Standards, Vol 05.03

<sup>8</sup> Annual Book of ASTM Standards, Vol 14.02

<sup>9</sup> Annual Book of ASTM Standards, Vol 14.03

<sup>10</sup> Available from the Coordinating Research Council, Inc., 219 Perimeter Parkway, Atlanta, Georgia 30346.

<sup>11</sup> Available from Superintendent of Documents, Attn: New Orders, P.O. Box 371954, Pittsburgh, PA 15250-7954. Charge orders may be telephoned to the Government Printing Office order desk at 202-512-1800.

<sup>12</sup> Information available from Caterpillar, Inc. attention Britt Pulley.

<sup>13</sup> Available from ExxonMobil Corporation, 3225 Gallows Road, Fairfax, VA 22037. Phone: (703) 846-3000. Web: [www.exxonmobil.com](http://www.exxonmobil.com).

<sup>14</sup> Available from a Caterpillar parts distributor.

<sup>15</sup> Available from the ASTM Test Monitoring Center, 6555 Penn Avenue, Pittsburgh, PA 15206-4489, Attention: Administrator.

<sup>16</sup> Available from Chevron Philips Chemical Company LP, 10001 Six Pines Drive, Suite 4036B, The Woodlands, TX 77387-4910 Phone: (832) 813-4859, Fax: (832) 813-4907, Email: [fuels@cpchem.com](mailto:fuels@cpchem.com).

<sup>17</sup> Available from ASTM, 100 Barr Harbor Drive, West Conshohocken, PA 19428-2959.

<sup>18</sup> ASTM Test Monitoring Center, 6555 Penn Avenue, Pittsburgh, PA 15206-4489 Phone: (412) 365-1000, Fax: (412) 365-1047.