1. Scope
TBD
2. Referenced Documents
TBD
3. Terminology
TBD
4. Summary of Test Method
TBD
5. Significance of Use
TBD
6. Apparatus (General Description)

6.1 The test engine is a Ford, spark ignition, four stroke, 4-cylinder gasoline turbocharged direct injection (GTDI) engine with a displacement of 2.0 L. Features of this engine include variable camshaft timing, dual overhead camshafts driven by a timing chain, four valves per cylinder and electronic direct fuel injection. It is based on the Ford Motor Co. 2012 Explorer engine with a displacement of 2.0 L.
6.2 Configure the test stand to accept a Ford 2.0L GTDI engine. All special equipment necessary for conducting this test is listed herein.
6.3 Use the appropriate air conditioning apparatus to control the temperature, pressure, and humidity of the Inlet air to meet the requirements in Table 4.
6.4 Use an appropriate fuel supply system (Figure 1**Error! Reference source not found.**).

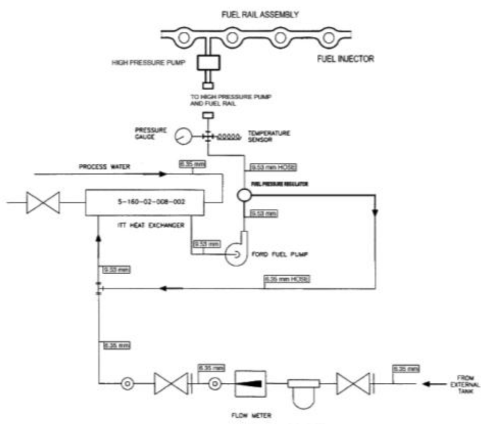


Figure 1. Fuel Supply System

6.5 The control and data acquisition system shall meet the requirements listed in Annex A3.
6.6 Coolant Conditioning Equipment
6.7 **Engine cooling system** – Use coolant inlet and outlet from the supplier shown in A9.2. Typical plumbing for the external coolant system is shown in Figures A2.2 and A2.3. Use coolant flow meter with and accuracy of +1%.
6.8 **Oil System Components**— All oil system components in the engine are production configuration with the exception of the modified oil pan (Figure A2.1) and oil filter housing (figures A2.16 and A2.17)
6.9 Oil Temperature Control – Oil temperature is controlled using the production oil cooler. Process water is run through water side of the oil cooler. Oil temperature thermocouples locations are shown in figure A2.15 and A2.16
6.10
6.11 Dynamometer - Use Midwest dynamometer model 1014A. The dynamometer can be purchased from the vendor shown in Annex X
6.12 Instrumentation
6.12.1 Temperatures - Temperature measurement locations for the six required temperatures are specified. Use thermocouples that are calibratable to 0.5 °C. Use only OEM temperature sensors for EEC inputs.

Comment [FM1]: Inserted instrumentation section from Ron

6.12.1.1 All thermocouples, except the intake-air thermocouple, shall be premium and sheathed. The intake-air thermocouple may be an open-tip type. The diameter and length of the thermocouples shall be 3 mm by 100 mm. Thermocouples, wires, and extension wires should be matched to perform in accordance with the special limits of error as defined in ANSI MC96.1.
6.12.1.2 Engine Coolant Inlet—Install the sensor in the coolant inlet on the engine (OHTVH-008-1) perpendicular to the run. Install sensor with the tip in the center of the stream of flow. (See Fig. A2.2).
6.12.1.3 Engine Coolant Outlet—Install the sensor in the coolantoutlet on the engine (OHTVH-009-1) perpendicular to the run. Install sensor with the tip in the center of the stream of flow. (See Fig. A2.2).
6.12.1.4 Engine Oil Inlet—Install the tip of the sensor at the center of the flow stream in the external oil filter adapter (see Fig. A2.16) through the hole for the oil pressure switch (not used). Install a tee to accept this temperature sensor and attach the oil pressure line.
6.12.1.5 Engine Oil Outlet—Install the tip of the sensor at the center of the cross fitting attached to the side opposite from the engine oil inlet temperature sensor on the oil filter adaptor. The adapter needs to be modified with a 1/8 NPT hole to access the oil passage (see Fig. A2.16).
6.12.1.6 Intake Air—Install the tip of the thermocouple midstream in the air cleaner box downstream of the filter (see Fig. A2.12). Insertion depth shall be (37 ± 2) mm.
6.12.1.7 Fuel – Install the sensor in the fuel line before the high pressure pump.
6.12.1.7.1 Air Charge – Install the sensor in the intercooler outlet tube 25+2 mm downstream from the MAPT sensor. (See fig A2.13)
6.12.1.8 Pre-intercooler – install a sensor in the tube between the turbocharger and the intercooler.
6.12.1.9 Exhaust – install a sensor 140+12 mm downstream on the exhaust flange (see Fig. A2.8)
6.12.1.10 Calibration—Calibrate all thermocouples prior to a reference oil test. The temperature measurement system shall indicate within ± 0.5 °C of the laboratory calibration standard. The calibration standard shall be traceable to NIST.
6.12.2 Pressures - Pressure measurement for each of the eight required parameters is detailed in the following sections. This allows reasonable opportunity for adaptation of existing test stand instrumentation. However, the accuracy and resolution of the pressure measurement sensors and the complete pressure measurement system shall be ??? Replace pressure sensors that are part of the EEC system with only Ford specified equipment.
NOTE 5—Tubing between the pressure tap locations and the final pressure sensors should incorporate condensate traps, as indicated by good engineering practice. This is particularly important in applications where low air pressures are transmitted by means of lines which pass through low-lying trenches between the test stand and the instrument console.
6.12.2.1 Manifold Absolute Pressure (MAP) – measure the manifold absolute pressure at the port downstream of the throttlebody on the front side of the intake manifold (See Fig 2.13)
6.12.2.2 Engine Oil - measure oil pump pressure in the external oil filter adapter (see Fig. A2.16) through the hole for the oil pressure switch (not used). Install a tee to accept the temperature sensor and attach the oil pressure line.
6.12.2.3 Engine Coolant Pressure—Measure engine coolant pressure at the top of the coolant reservoir as shown in Fig. A2.3.
6.12.2.4 Fuel – measure fuel pressure in the lower pressure fuel line at the exit of the stand fuel pump.
6.12.2.5 Crankcase – measure crankcase pressure at the dummy PCV valve in the cylinder block oil separator.
6.12.2.6 Exhaust Back Pressure - measure the exhaust back pressure with the exhaust gas sampling probe located 76+12 mm downstream of the exhaust flange (see Fig. A2.8). A sensor capable of absolute or gage measurement corrected with barometric pressure reading is recommended. Install a condensate trap between the probe and sensor to accumulate water present in the exhaust gas.
6.12.2.7 Inlet Air – measure inlet air pressure in the air cleaner box downstream of the air filter. (See Fig A2.12)
6.12.2.8 Pre-Intercooler – measure the pre-intercooler pressure with the exhaust gas sampling probe located 155+25 mm downstream of the turbocharger flange (See Fig 2.13)
6.12.2.9 Post-Intercooler - measure the post-intercooler pressure with the exhaust gas sampling probe located downstream of the intercooler and at least 305 mm upstream of the MAPT sensor. (See Fig 2.13)
6.12.2.10 Cylinder Head – measure cylinder head pressure at the oil gallery plug on the left sideof the cylinder head next to the belt tensioner.
6.12.2.11 Calibration—Calibrate all pressure measurement sensors prior to a reference oil test. The MAP pressure measurement system shall indicate within 0.1 kPa of the laboratory calibration standard. All other pressure measurement systems shall conform to ???? The calibration standard shall be traceable to NIST

6.12.3 Flow Rates - Flow rate measurement for each of the four required parameters is detailed in the following subsections. With the exception of the engine coolant, measurement equipment is not specified for a given parameter. This allows reasonable opportunity for adaptation of existing test stand instrumentation.
6.12.3.1 Engine Coolant—Determine the engine coolant flow rate using a flowmeter with an accuracy of +1% (see Fig. A2.3) Flowmeter is available from the supplier in X. Take precautions to prevent air pockets from forming in the linesto the pressure sensor. Transparent lines or bleed lines, or both, are beneficial in this application. Ensure that the manufacturer's required for orientation and straight sections of pipe are installed immediately up and down stream of the flowmeter.
6.12.3.2 Fuel – measure fuel flow in kg/hr on the low pressure fuel system before the high pressure engine fuel pump.
6.12.3.3 Calibration—Calibrate the flowmeters used in the measurement of both the engine coolant flow rate and blowby heat exchanger coolant flow prior to a reference oil test. Calibrate the flowmeters as installed in the system at the test stand with test fluid. Calibrate the flowmeters with a turbine flowmeter or by a volume/time method at Stage 1 and 2 operating conditions.
6.12.4 Speed
6.12.5 Torque
6.13 The control and data acquisition system shall meet the requirements listed in Annex 3.
6.14 Combustion Analysis Equipment AVL IndiSmart Gigabit 612. Details of system setup are shown in Appendix C

Comment [FM2]: Need description of Speed and Torque

7. Apparatus (The Test Engine)

7.1 LSPI Test Engine—The test engine parts are available from the Ford Motor Co. (A1.1, use parts list .xls). A detailed listing of all parts is given in Annex (A1, use parts list .xl).
7.2 Required New Engine Parts— A new shortblock is required when initially referencing a stand and engine combination. This shortblock will be used for as many tests as needed as long as it remains within service limits and is able to be referenced. New crush washers and necessary gaskets are required whenever the engine/shortblock is disassembled, ie for pretest measurements or repair. New camshafts and buckets are required when first building a head. New valves are required when rebuilding a head. Required new parts are listed in Annex X
7.3 Reusable Engine Parts— The cylinder head can be used on subsequent shortblocks as long as it remains within the service limits in the work shop manual. The parts listed in Annex A1.2, A1.6 and A1.7 can be used for multiple tests as long as they are in good condition and meet the service limits in the work shop manual.
7.4 Specially Fabricated Engine Parts—The following subsections detail the specially fabricated engine parts required in this test method:
7.4.1 Inlet Air System (see Fig. A2.12) Inlet air system can be fabricated but must use the stock 2012 Explorer air cleaner assembly (A1.6) and MAF sensor. Install the fresh air tube, air cleaner assembly, and new air filter. Modify the air cleaner assembly to accept fittings for inlet air temperature thermocouple and pressure tap as shown in Fig. A2.12. Use the 2012 Explorer fresh air tubes or fresh air tubes can be fabricated but must be 1,040 + 25 mm from the MAF sensor to the turbocharger inlet.
7.4.2 Oil Pan – Modify the stock 2012 Explorer oil pan to add an oil drain plug in one of the locations shown in Fig. A2.1.
7.4.3 Cylinder Head – A modified cylinder head must be used that allows for installation of in cylinder pressure sensors. This assembly can be purchased from the supplier listed in Annex X.
7.4.4 Pressure Sensor Tubes – 3/8" OD steel tubing must be installed into the pressure sensor sleeves in the cylinder head to allow for installation of the in cylinder pressure sensors.
7.4.5 Valve Cover – The stock valve cover must be modified to allow the pressure sensor tubes to protrude through the cover. The location where the tubes protrude through the cover must be sealed to prevent oil from leaking through the penetrations.
7.4.6 Coolant Supply Manifold – a coolant inlet purchased from the supplier in A9.2 is used in place of the stock coolant inlet, to accept the coolant in thermocouple. (Fig A2.2)
7.4.7 Coolant Return Manifold - a coolant outlet purchased from the supplier in A9.2 is used in place of the stock thermostat housing, to accept the coolant out thermocouple and provide a coolant return from the turbocharger. (Fig A2.2)
7.5 Special Engine Measurement and Assembly Equipment—Items routinely used in laboratory and workshop are not included. Use any special tools or equipment shown in the 2012 Explorer service manual for assembly. A list of

Comment [FM3]: *Update figure to show pressure sensor and TC in correct locations*

Comment [FM4]: *Greg to send picture.of LZ modified oil pan - complete*

Comment [FM5]: Add o-ring p/n and valve seal.

these tools is shown in Annex A1.8. Complete any assembly instructions not detailed in Section 7 according to the instructions in the 2012 Explorer Service Manual.
7.5.1 Piston Ring Positioner—Use the piston ring positioner to locate the piston rings from the cylinder block deck surface by 38 mm. This allows the compression rings to be positioned in a consistent location in the cylinder bore for the ring gap measurement. Fabricate the positioner according to the details shown in Fig. A2.19.
7.5.2 Engine Service Tools—A complete list of special tools for the test engine is shown in Annex A1.8. The tools are available from a Ford dealership. These are designed to aid in performing several service items, in addition to the following specific service items that require special tools to perform the functions indicated (if not self-explanatory).
7.6 Engine Installation on the Test Stand—Functions that are to be performed in a specific manner or at a specific time in the assembly process are noted.
7.6.1 Mounting the Engine on the Test Stand—Mount the engine on the test stand so that the flywheel friction face is (0.0 ± 0.5)° from vertical. Two motor mounts are used (Quicksilver part# 6628-A or equivalent) (X2.1.33) at the rear of the engine (Fig A2.5). Use a rubber mount at the front of the engine attached to the front cover mount. An example is shown in Figure A2.4. A drawing showing an example of a rear mount support can be found in Figure A2.6. The engine must be at (0.0 ± 0.5)° role angle.
7.6.2 Flywheel: The flywheel bolts get lightly coated with Loctite 565 to prevent any oil from seeping out of the holes. Torque the flywheel to 108-115 Nm. The flywheel is obtained from the supplier in A9.2
7.6.3 Clutch and pressure plate - The clutch, pressure plate and spacer are obtained from the supplier in A9.2. Put the flat side on the clutch toward the engine. The spacer goes between the flywheel and pressure plate. Torque the pressure plate bolts to 25-33 Nm. The clutch and pressure plate are replaced with every new engine.
7.6.4 Driveline: The driveline is greased every test. Driveline specifications:
Driveline Degree: 1.5 +/- .5 degrees
595 ± 13 mm installed length from flange to flange
1410 series flanges
2.75" pilot
3.75" bolt circle
3.50" x .083" stub and slip

7.7 Exhaust System
7.7.1 A typical exhaust system, and fittings for backpressure probe, O2 sensors and thermocouple are illustrated in Figs. A2.8. Exhaust components should be constructed of either solid or bellows pipe/tubing. Other type flexible pipe is not acceptable.
7.7.2 The backpressure probe can be used until they become unserviceable. If the existing probes are not cracked, brittle, or deformed, clean the outer surface and clear all port holes. Check the probes for possible internal obstruction and reinstall the probes in the exhaust pipe. Stainless steel probes are generally serviceable for several tests; mild steel probes tend to become brittle after one test. Exhaust gas is noxious. (Warning—Any leaks in the connections to the sample probe will result in erroneous readings and incorrect air-fuel ratio adjustment.)
7.8 Fuel Management System:
7.8.1 Fuel Injectors - Inspect the O-rings to ensure they are in good condition and will not allow fuel leaks, replace if necessary. Install the fuel injectors into the fuel rail and into the cylinder head.
7.9 Powertrain Control Module: The engine uses a PCM provided by Ford Motor Company to run this test. The PCM contains a calibration developed for this test. The PCM calibration number is U502-HBBJ0-v1-7-VEP-371.VBF.
(1) The PCM power shall come from a battery (13.5 ± 1.5) V or a power supply that does not interrupt/interfere with proper PCM operation. Connect the PCM battery/power supply to the engine wire harness with an appropriate gage wire of the shortest practical length so as to maintain a dc voltage of (12 to 15) V and minimize PCM electrical noise problems. Ground the PCM ground wire to the engine. From the same ground point, run a minimum two gage wire back to the battery negative to prevent interruption/interference of the PCM operation. The power supply can also be used for the Lambda measuring devices.
7.10 Spark Plugs—Install new Motorcraft CYFS-12-Y2 spark plugs. Spark plugs come pre-gapped. Torque the spark plugs to 9 to 12 N·m. Do not use anti-seize compounds on spark plug threads.
7.11 Crankcase Ventilation System— The crankcase ventilation system is vent to the atmosphere through the port in the valve cover and is not to be connected to the inlet.
7.12 Water to Air Turbocharger Intercooler - Use water to air intercooler (A9.5) capable of achieving the required air charge temperature (Tables 5-8) and an average system pressure loss less than 3 kPa.

Comment [FM6]: Add ring positioner figure to annex - complete

Comment [FM7]: Add figures for front and rear engine mounts

Comment [FM8]: *List specific part numbers from driveshaft manufacturer*

Comment [FM9]: *Check actual pressure drop.*

7.12.1 When cleaning the intercooler as part of normal maintenance, the air side of the intercooler must be spray cleaned with Stoddard solvent, rinsed with hot water and left to air dry. Use commercial Aqua Safe descaler to clean the water side.

7.13 Intercooler Tubing: Fabricate the inlet air system with 51 mm ID stainless steel tubing from the turbocharger to the intercooler and 64 mm ID stainless steel tubing from the intercooler to the throttle body. The tubing length is not specified but should be the appropriate length achieve the required air charge temperature (Tables 5-8) and an average system pressure loss less than 3 kPa. Locate the MAPT sensor 305±25 mm from the intake surface of the throttle body and the intake air charge temperature thermocouple 1 inch downstream from the MAPT sensor. The post-intercooler turbo boost pressure measurement probe should be placed a minimum of 305 mm upstream from the MAPT sensor. The pre- intercooler turbo boost pressure measurement probe should be placed at 155 ±25 mm from the turbocharger outlet. The measurements can be seen in Figure A2.13 and typical installation is shown in Figure A2.14.

Comment [FM10]: *Check actual pressure drop.*

7.14 External Hose Replacement—Inspect all external hoses used on the test stand and replace any hoses that have become unserviceable. Check for internal wall separations that could cause flow restrictions. Check all connections to ensure security.

7.15 Wiring Harness—There are two wiring harnesses used on the test stand, a dynamometer harness that connects to the stand power and PCM and an engine harness. Obtain the dynamometer wiring harness and engine wiring harness from the supplier listed in A9.2. Diagrams of these wire harnesses are shown in Figures A2.20 and A2.21 identifying connections.

Comment [FM11]: *Ron to create drawings for figures*

7.16 Electronic Throttle Controller: Throttle is controlled using simulated accelerator pedal position signals. The dyno wiring harness is supplied with an Accelerator Pedal Position jumper cable with un-terminated pigtail leads. The test laboratory must connect two voltage command signals, Acc Pos Sensor 1 and Acc Pos Sensor 2, to the Accelerator Pedal Position jumper cable. The voltage control ranges for each signal are shown in Table 1.The wiring schematic and pin-out description for this connection is shown in Figure 2. Accelerator Position Wiring Schematic. The voltage signals must be run through a voltage isolator otherwise interference will occur between the lab DAC system and the engine ECU and throttle control will be erratic.

Table 1. Accelerator Position Sensor Control Ranges

Command Signal	Operating Range	Min Signal (Idle)	Max Signal (WOT)
Acc Pos Sensor 1	0-5.0 VDC	0.75 VDC (15%)	4.25 VDC (85%)
Acc Pos Sensor 2	0-2.5 VDC	0.375 VDC (15%)	2.125 VDC (85%)
Note: Acc Pos Senor 2 should always equal 50% of Acc Pos Sensor 1.			

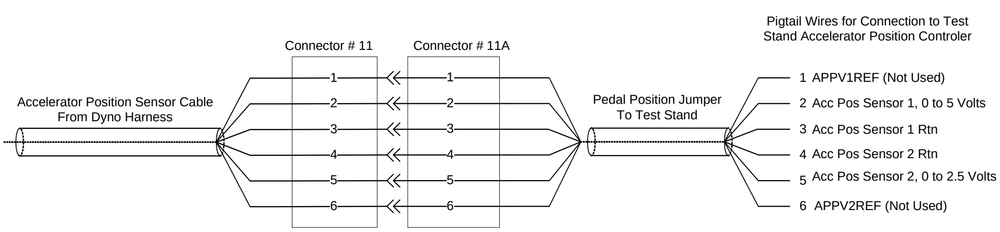


Figure 2. Accelerator Position Wiring Schematic

7.17 Water Pump, Water Pump Drive—Install the water pump and pulley, the crankshaft pulley, and tensioner according to the 2012 Explorer service manual. These are the only components needed to drive the water pump. All other production front end accessory drive components do not need to be installed. The engine cannot be used to drive any external engine accessory other than the water pump. Pull back tensioner and install water pump drive belt as shown in Figure 3. Ensure that there is a minimum contact angle of 20° between the drive belt and the water pump pulley.

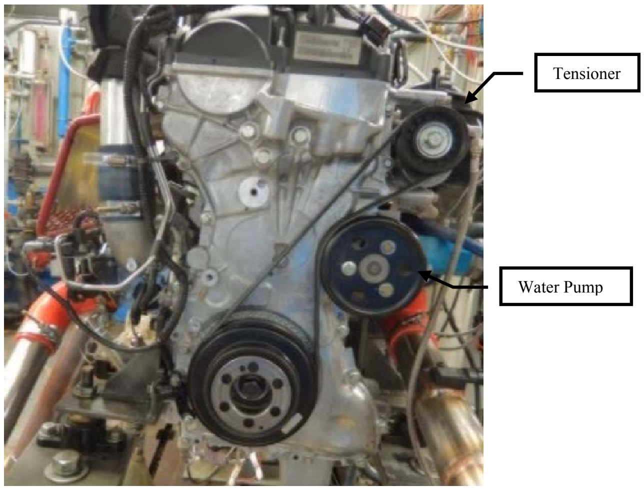


Figure 3 Water Pump Drive Arrangement

7.18 Cylinder block oil separator - Install a dummy PCV valve (PCV valve with the internal components removed) in oil separator on the side of the engine block. This is the location to measure crankcase pressure.
7.19 Engine Vacuum System – install the engine vacuum system as shown in Figure A2.20

7

Comment [FM12]: *Update to show annotations*

8. Engine Preparation

8.1 Engine Disassembly - disassemble the engine according to the 2.0L Ecoboost disassembly procedures in the Ford 2012 Explorer Shop Manual. Note the position of all the engine components to insure they are returned to the same positions when the engine is reassembled.
8.2 Engine Measurements – Record the following engine measurements
8.2.1 Piston and bore measurements are shown in Table 2.
8.2.1.1 Record the piston to bore clearances at the top, 2nd and 3rd ring lands and the piston skirt as shown in figure A2.17. Use bore ladder shown in figure A2.18 to determine bore diameter positions. Measure the bore in both the longitudinal and transverse directions. To determining the piston to bore clearance, calculate the difference between the particular piston diameter location and the average bore diameter for both the transverse and longitudinal directions.
8.2.1.2 Record ring side clearances for the upper and lower compression rings (UCR, LCR). For determining ring side clearance take 4 measurements 90 degrees apart. Either check clearance with a thickness gauge or measuring the difference between the thickness of the ring and the height of the corresponding groove.
8.2.1.3 Measure the ring gap for the top and 2nd oil rings using the piston ring positioner to locate the piston rings from the cylinder block deck surface by 38 mm. The piston ring positioned tool is shown in figure A2.17.
8.2.2 Measure cylinder head dimension shown in Table 3. For determining the valve stem to guide clearance measure the diameter of the valve stem at 38 mm from the tip of the valve and the valve guide at 19.5 mm from the top of the valve guide.

Comment [FM13]: Side clearance measurement method is still TBD

Comment [FM14]: Added Ring Gap measurement description

Table 2. Cylinder Bore and Piston Measurements

FLSPI Cylinder Bore and Piston Measurement Record

Block # / Run # : ______ Date: ______

Test Number: ______ Tech: ______

Cylinder Bore Measurements w/o Stress Plate

Finish Target: (9- 13 Ra) µin
Bore Gauge Set: 87.5 mm

Piston to Wall Clearance: (.0225 - .0475) mm
Cylinder Cross HatchTarget: (25°-35°) Deg

Cylinder bore diameter and surfiace finish

Cylinder Number	Location	Longitudinal Diameter (mm)	Transverse Diameter (mm)	Surface Finish (µin)
	Top			
1	Middle			
	Bottom			
	Average			
	Top			
2	Middle			
	Bottom			
	Average			
	Top			
3	Middle			
	Bottom			
	Average			
	Top			
4	Middle			
	Bottom			
	Average			

Use bore ladder

Piston to Bore Clearance

Cylinder Number	Location	Piston Diameter		Piston Clearance	
		Longitudinal (mm)	Transverse (mm)	Longitudinal (mm)	Transverse (mm)
	Top land				
1	2nd land				
	3rd land				
	Skirt				
	Top land				
2	2nd land				
	3rd land				
	Skirt				
	Top land				
3	2nd land				
	3rd land				
	Skirt				
	Top land				
4	2nd land				
	3rd land				
	Skirt				

Top land= ring land above upper compression ring
2nd land= ring land between upper and lower compression rings
3rd land= ring land between lower compression and oil rings
Skirt= 13-15 mm up from the bottom of the piston skirt

Ring Gap

Cylinder Number	Top Ring	Second Ring
Gap 1		
Gap 2		
Gap 3		
Gap 4		

Cross Hatch Measurement

Cylinder Number	Meas #1 (degrees)	Meas #2 (degrees)	AVG Cross Hatch (degrees)
1			
2			
3			
4			

Ring side clearance

Cylinder Number	Location	Clearance		Clearance	
		0 (mm)	90 (mm)	180 (mm)	270 (mm)
	UCR				
1	LCR				
	UCR				
2	LCR				
	UCR				
3	LCR				
	UCR				
4	LCR				

Ring thickenss and groove height for side clearance calculation

Cylinder Number	Location	0 (mm)	90 (mm)	180 (mm)	270 (mm)
	UCR Thickness				

Table 3. Head Measurements

FLSPI HEAD DATA SHEET

HEAD # ____________

HEAD RUN # ____________

DATE: ____________

Engine # ____________

Test # ____________

Instrument Cntrl # (Valve Guide) ____________

Instrument Cntrl # (Valve Stem) ____________

	Valve Guide Diameter (5.51) mm	Valve Stem Diameter (5.5) mm	Clearance (0.03-0.07) mm
1A Intake			
1B Intake			
2A Intake			
2B Intake			
3A Intake			
3B Intake			
4A Intake			
4B Intake			

	Valve Guide Diameter (5.51) mm	Valve Stem Diameter (5.5) mm	Clearance (0.03-0.07) mm
1A Exhaust			
1B Exhaust			
2A Exhaust			
2B Exhaust			
3A Exhaust			
3B Exhaust			
4A Exhaust			
4B Exhaust			

Instrument Cntrl # (Length) ____________

Instrument Cntrl # (Tension) ____________

	SPRING FREE LENGTH (47mm)	SPRING TENSION (kg@28.5 mm)
1A Intake		
1B Intake		
2A Intake		
2B Intake		
3A Intake		
3B Intake		
4A Intake		
4B Intake		

	SPRING FREE LENGTH (47mm)	SPRING TENSION (@28.5 mm)
1A Exhaust		
1B Exhaust		
2A Exhaust		
2B Exhaust		
3A Exhaust		
3B Exhaust		
4A Exhaust		
4B Exhaust		

Instrument Cntrl # (Lash) ____________

Intake Valve Lash Measurement (.19 - .31) mm	
1F	
1R	
2F	
2R	
3F	
3R	
4F	
4R	

Exhaust Valve Lash Measurement (.30 - .42) mm	
1F	
1R	
2F	
2R	
3F	
3R	
4F	
4R	

Head Flatness: ____________

Initials: ____________

Table 4 Crank Measurements

FLSPI Engine Measurment Record

Engine Number: **Date:**

Test Number: LF

Instrument Cntrl # (*Journal*) **Instrument Cntrl # (*Bearing*)**

Bore Gauge set to 51.986mm

Main Bearing Journals (mm)				
Diameter: (51.978mm - 52.002mm)				
Journal Number	Horizontal Diameter	Vertical Diameter	Bearing Inside Diameter	Clearance .027mm - .052mm
1				
2				
3				
4				
5				

Instrument Cntrl # (*Journal*) **Instrument Cntrl # (*Bearing*)**

Bore Gauge set to 51.986mm

Rod Bearing Journals (mm)				
Diameter: (51.978mm - 52.002mm)				
Journal Number	Horizontal Diameter	Vertical Diameter	Bearing Inside Diameter	Clearance .027mm - .052mm
1				
2				
3				
4				

Instrument Cntrl # (Endplay)

Crankshaft End Play (0.22 mm - 0.45 mm) ______________

8.2.3 Compression Ratio – Measure compression ratio using Whistler P/N KAE-A0250-E

8.3 Engine Assembly – Assemble the engine according to the 2.0L Ecoboost assembly procedures in the 2012 Explorer Shop Manual, except as noted in section 7. Insure all components (ie, pistons, rings, bearings, etc) are put back in the same positions as were originally assembled from the factory.
8.4 Engine Installation on Test Stand - install the engine onto the stand using the equipment shown in section 7. Install all engine components external to the longblock according to the 2.0L Ecoboost assembly procedures in the 2012 Explorer Shop Manual, where applicable. Connect the engine to all external laboratory systems identified in section 6, per laboratory procedures.
8.5 Pressure Sensor Installation - once the sensor tubes and modified valve cover are installed (see section 7.4.4 and 7.4.5), install pressure sensors into the pressure sensor tube using the sensor installation tool shown in Table A1.8 and torque sensors to 1.5 Nm.
8.6 New Engine Break In - Once a new engine has been installed on the test stand, perform the break-in procedure shown in Table 5. LSPI Break-In Procedure**Error! Reference source not found.**, using oil TMC 220.

Table 5. LSPI Break-In Procedure

Step	Speed (RPM)	Load (N-m)	Time per stage (Hr:Min)	Total Time (Hr:Min)
Charge engine with 4200 grams of new oil and new oil filter				
1	Idle	0	0:30	0:30
Oil Change 1 -Shut engine down and drain used oil and remove oil filter. Allow oil to drain for 20 minutes. Install new oil filter and add 4200 grams of new oil.				
Start engine and let idle for 5 minutes				
2	1500	38	0:30	1:00
3	2000	72	0:30	1:30
4	2500	111	0:30	2:00
5	3000	135	0:30	2:30
6	3000	150	3:15	5:45
7	2000	72	0:15	6:00
8	3250	155	0:15	6:15
9	3500	155	0:15	6:30
10	3750	155	0:15	6:45
11	4000	155	1:15	8:00
Bring engine to idle for 5 minutes then shut down				
Oil Change 2- Drain used oil and remove oil filter. Allow oil to drain for 20 minutes. Install new oil filter and add 4200 grams of new oil.				
Run one full test per section 12.3 for additional break in. After test is complete drain the oil, remove the oil filter, and proceed to section 12.1.				

- The controlled parameters during break in are listed in Table 6. All other controls are left wide open/free flowing. The engine does not produce enough heat in the early steps to reach all target temperatures. All controlled parameters are expected to be on target at the beginning of Step 4.

Table 6. Sequence CW Break-in Controlled Parameters

Break In Controlled Parameters	
Coolant Out Temp.	85 degC
Oil Gallery Temp.	100 degC
Inlet Air Pressure	0.05kPa
Air Charge Temp.	37 deg C
Inlet Air Temp.	30 degC
Humidity	11.4 g/kg

12. Calibration

Comment [FM15]: Contents of this section are TBD

13. Test Procedure

13.1 Oil Flush Procedure – For each new test, perform two oil flushes using test oil as detailed below.

1. Charge engine with 4200 grams of new oil and install a new oil filter.
2. Warm Up - Start engine and operate at Idle (900 rpm) for two minutes.
3. Ramp to 2000RPM and 70 N-m within two minutes. Control to warm up conditions listed in Table 7. Maintain conditions for 15 minutes (including ramp time).
4. Ramp to idle within two minutes. Hold at idle conditions for two minutes (including ramp time).
5. Shut down engine.
6. Drain engine oil for 15 minutes.
7. Repeat for second flush.

Table 7. Warm Up Conditions

Controlled Parameter	Set Point	Units
Coolant Out Temperature	95	degC
Oil Gallery Temperature	95	degC
Air Charge Temperature	43	degC
Inlet Air Temperature	30	DegC
Inlet Air Pressure	0.05	kPaA
Exhaust Back Pressure	104	kPaA
Humidity	11.4	g/kg

13.2 Test Start/Oil Seasoning Procedure:

1. Charge engine with 4200 grams of test oil and install new oil filter.
2. Warm Up - Start engine and operate at Idle (900 rpm) for two minutes
3. Ramp to 2000RPM and 100 Nm in 60 seconds. Control to warm up conditions listed in Table 7. Run at these conditions for 15 minutes.
4. Ramp to 1750RPM and 269 Nm in 60 seconds.
5. Hold at 1750RPM, 269 Nm and control to test condition temperatures for 60 minutes.
6. Ramp to cool down conditions shown in Table 8**Error! Reference source not found.**. Maintain conditions for 15 minutes (including ramp times).

Table 8. Cool Down Conditions

Controlled Parameter	Set Point	Units	Ramp times (min)
Engine Speed	2000	RPM	1
Engine Load	50	Nm	1
Coolant Out Temp	45	degC	15
Oil Gallery	45	degC	15
Inlet Air Temp	30	degC	N/A
Air Charge	30	degC	N/A
Inlet Air Pressure	0.05	kPaA	N/A
Exhaust Back Pressure	104	kPaA	N/A
Humidity	11.4	g/kg	N/A

7. Ramp to idle and hold for 2 minutes.
8. Shut down engine for a minimum of 10 minutes. Take oil dip and inspect engine and stand.
9. Restart Engine to Start Cycle 1

13.3 Test Cycle – The following test cycle procedure is conducted four times for one complete test.

1. Warm Up - Start engine and operate at Idle (900 rpm) for two minutes.
2. Ramp to 2000RPM and 100 Nm in 60 seconds. Control to warm up conditions listed in Table 7. Run at these conditions for 15 minutes.
3. Ramp to test conditions listed in Table 9.

Table 9. Test Conditions

Test Conditions			
Controlled Parameter	**Set Point**	**Units**	**Ramp times (min)**
Speed	1750 ±15	RPM	1
Load	269±2	Nm	1
Coolant Out Temperature	95±0.5	degC	< 20
Oil Gallery Temperature	95±0.5	degC	< 20
Air Charge Temperature	43±0.5	degC	< 20
Inlet Air Temperature	30±0.5	degC	< 20
Fuel Temperature	30	degC	NA
Back Pressure	104 +/-2	kPaA	NA
Inlet Air Pressure	0.05 +/-.02	kPaG	NA
Humidity	11.4 +/-1	g/kg	NA

4. Hold until the following conditions are true:
   - Coolant Out Temp: 95 ± 0.5 degC
   - Oil Gallery Temp: 95 ± 0.5 degC
   - Inlet Air Temp: 30 ± 0.5 degC
   - Air Charge Temp: 43 ± 0.5 degC

   All the above temperatures should be met within a maximum of 20 minutes. If not, perform soft shut down and fix any issue preventing the test conditions from being met before trying again.
5. Once test conditions are met, allow engine to stabilize for five minutes.
6. After five minute stabilization, begin recording combustion analysis data using AVL Indicom for 175,000 combustion cycles.
7. Ramp to cool down conditions shown in Table 8. Maintain conditions for 15 minutes (including ramp times).
8. Ramp to idle and hold for 2 minutes.
9. Shut down for a minimum of 10 minutes. Take oil dip and inspect engine and stand

13.4 End of Test. Make sure everything is turned off:
- Fuel off
- Coolant pressure off
- Chilled water off

13.5 Record the operation and canbus data listed in Table 10. Recorded Test Points at a rate of 1/sec.

Table 10. Recorded Test Points

	TEST POINT	UNITS
Controlled	Engine Speed	rpm
	Engine Load	Nm
	Coolant Out Temp	deg C
	Oil Gallery Temp	deg C
	Air Charge Temp	deg C
	Inlet Air Temp	deg C
	Inlet Air Press	kPaG
	Exhaust Press	kPaA
	Fuel Temp	deg C
	Humidity	g/kg
Monitored	Fuel Flow	kg/hr
	Inlet Manifold Pressure	kPaA
	Boost Pressure	kPaA
	Barometric Pressure	kPaA
	Oil Gallery Pressure	kPaG
	Oil Head Pressure	kPaG
	Oil Filter In Temp	deg C
	Exhaust temp	deg C
	Crank Case Pressure	kPaG
	Fuel Pressure	kPaG
	Power	kW
	Pre-Intercooler Air Pressure	kPaA
	Ambient Temperature	degC
	Coolant In Temperature	degC
	Lambda	unitless
PCM CAN BUS Channels	Ignition Timing Advance for #1 Cylinder	Deg CA
	Absolute Throttle Position	%
	Engine Coolant Temperature	Deg C
	Inlet Air Temperature	Deg C
	Equivalence Ratio (Lambda)	unitless
	Absolute Load Value	%
	Intake Manifold Absolute Pressure	kPa
	Fuel Rail Pressure	kPa
	Accelerator Pedal Position	%
	Boost Absolute Pressure - Raw Value	kPa
	Turbocharger Wastegate Duty Cycle	%
	Actual Intake (A) Camshaft Position	Deg
	Actual Exhaust (B) Camshaft Position	Deg
	Intake (A) Camshaft Position Actuator Duty Cycle	%
	Exhaust (B) Camshaft Position Actuator Duty Cycle	%
	Charge Air Cooler Temperature	Deg C
	Cylinder 1 Knock/Combustion Performance Counter	Count
	Cylinder 2 Knock/Combustion Performance Counter	Count

	Cylinder 3 Knock/Combustion Performance Counter	Count
	Cylinder 4 Knock/Combustion Performance Counter	Count

13.6 At the end of each 175,000 cycle run, report the following data from the AVL Indicom combustion analysis software for each engine cycle.

- PMAX
- CA02
- PMAXV
- PMINV
- KP_INT

This data will be used to determine the number of LSPI events for each test run according to the method described in section 13.

Appendix A. Determination of Test Results

Steps for calculating LSPI triggers adjustment for distribution Skewness and kurtosis:

I. Remove Invalid Cycles

Prior to performing the PP and MFB2 LSPI calculations described in this document, remove all invalid combustion cycles from both the PP and MFB2 data set. Use the following criteria to identify invalid cycles.

1. Remove all cycles with a MFB2 < -30 degrees
2. Remove all cycles with a PP < 20 bar.

Comment [FM16]: Add PMINV requirement

Remove the entire cycle, including PP and MFB2 values, for any cycle that meets the conditions given above. These cycles are considered invalid and are not counted as LSPI cycles.

II. Remove PP LSPI cycles – (Individually for each cylinder)

1. Remove obvious outliers. The mathematical method of estimating quantiles decreases in accuracy the further from normality so obvious outliers should be eliminated prior to applying the method.
   a. Remove PP > 90 (I think we all agree that likely anything over 90 is a LSPI)
2. Determine the following statistics on the remaining results. I am assuming that there are built in functions for each of these. If not, I can provide them but we may want to reconsider this approach because the follow steps become increasing more complicated.
   a. Median
   b. Standard deviation (s)
   c. Skewness (S)
   d. Kurtosis (K)
3. Determine the number of standard deviations for our distributions subject to Skewness and kurtosis corresponding to the 5 that is appropriate for a valid normal distribution.
   a. Simultaneously solve for *B*, *C* and *D* in the following three equations (where *S* and *K* are Skewness and Kurtosis, respectively, from Step 2):

$$1 = B^2 + 2C^2 + 6BD + 15D^2$$

$$S = 8C^3 + 6B^2C + 72BCD + 270CD^2$$

$$K = 3B^4 + 60B^2C^2 + 60C^4 + 60B^3D + 936BC^2D + 630B^2D^2 + 4500C^2D^2 + 3780BD^3 + 10395D^4 - 3$$

Where S = Skewness and K = Kurtosis.

   b. Then calculate *F*, an estimate of the quantile corresponding to *Z* = 5.

$$F = -C + BZ + CZ^2 + DZ^3$$

or

$$F = -C + B(5) + C(5^2) + D(5^3)$$

F will generally be on the order of 5 to 10 on the first iteration and 5 to 7 on the last iteration.

4. Those cycles with PP > Median +*F* s (where s is the standard deviation) are outliers (LSPI) and should be omitted.
5. If no outliers are found in Step 2, count the LSPI and the process is complete, else return to Step 2. The total number of outliers is from Steps 1a and 4.

III. Remove MFB02 LSPI Cycles – (individually for each cylinder)

1. Remove obvious outliers. The mathematical method of estimating quantiles decreases in accuracy the further from normality so obvious outliers should be eliminated prior to applying the method.

   a. Remove MFB02 < 0 (I think we all agree that likely anything under 0 is a LSPI)
2. Determine the following statistics on the remaining results. I am assuming that there are built in functions for each of these. If not, I can provide them but we may want to reconsider this approach because the follow steps become increasing more complicated.
   a. Median
   b. Standard deviation (s)
   c. Skewness (S)
   d. Kurtosis (K)
3. Determine the number of standard deviations for our distributions subject to Skewness and kurtosis corresponding to the -5 that is appropriate for a valid normal distribution.
   a. Simultaneously solve for *B*, *C* and *D* in the following three equations (where *S* and *K* are Skewness and Kurtosis, respectively, from Step 2):

$$1 = B^2 + 2C^2 + 6BD + 15D^2$$
$$S = 8C^3 + 6B^2C + 72BCD + 270CD^2$$
$$K = 3B^4 + 60B^2C^2 + 60C^4 + 60B^3D + 936BC^2D + 630B^2D^2 + 4500C^2D^2 + 3780BD^3 + 10395D^4 - 3$$

Where S = Skewness and K = Kurtosis.
   b. Then calculate *F*, an estimate of the quantile corresponding to *Z* = -5.

$$F = -C + BZ + CZ^2 + DZ^3$$
$$or$$
$$F = -C + B(-5) + C(-5)^2 + D(-5)^3$$

F will generally be on the order of -4 to -10 on the first iteration and -4 to -7 on the last iteration.
4. Those cycles with MFB02 < Median +*F* s (where s is the standard deviation) are outliers (LSPI) and should be omitted.
5. If no outliers are found in step 2, count the LSPI and the process is complete, else return to Step 2. The total number of outliers is from Steps 1a and 4.

IV. <u>Report LSPI Cycles</u>

Report the following data for each cylinder
1. Total number of combined LSPI cycles (containing both a PP and MFB2 LSPI trigger)
2. Total number of LSPI cycles containing only a PP trigger
3. Total number of LSPI cycles containing only a MFB2 trigger
4. Number of Invalid Cycles
5. Skewness, Kurtosis, and F values for each iteration of the PP and MFB2 analysis

Appendix B. PCM CANBUS Parameter IDs

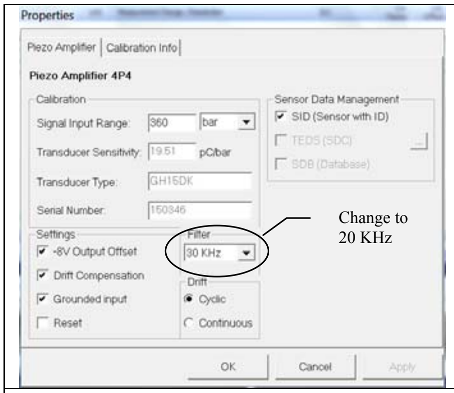
B.1. CAN Bus Data –Set up the data acquisition software to record the following Parameter IDs from the engine's PCM:

Table 11 PCM CANBUS Parameter IDs

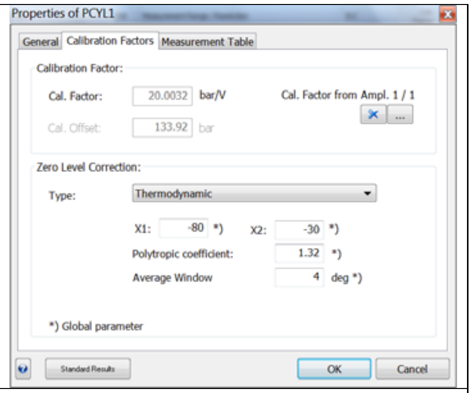
Mode	PID Number (Hex)	Parameter Description	Type	Bytes	Scale	Offset	Minimum	Maximum	Units
1	0E	Ignition Timing Advance for #1 Cylinder	Unsigned Numeric	1	0.5	-64	-64	63.5	Deg
1	11	Absolute Throttle Position	Unsigned Numeric	1	0.392156862745	0	0	100	%
1	05	Engine Coolant Temperature	Unsigned Numeric	1	1	-40	-40	215	Deg C
1	0F	Intake Air Temperature	Unsigned Numeric	1	1	-40	-40	215	Deg C
1	34	Equivalence Ratio (Lambda)	Unsigned Numeric	2	0.000030518044	0	0	2	unitless
1	43	Absolute Load Value	Unsigned Numeric	2	0.392156862745	0	0	25700	%
1	0B	Intake Manifold Absolute Pressure	Unsigned Numeric	1	1	0	0	255	kPa
1	23	Fuel Rail Pressure	Unsigned Numeric	2	10	0	0	655350	kPa
1	49	Accelerator Pedal Position	Unsigned Numeric	1	0.392156862745	0	0	100	%
22	033E	Boost Absolute Pressure - Raw Value	Unsigned Numeric	2	0.007629394531	0	0	499.992370605469	kPa
22	0462	Turbocharger Wastegate Duty Cycle	Unsigned Numeric	2	0.003051757813	0	0	199.996948274955	%
22	0318	Actual Intake (A) Camshaft Position	Signed Numeric	2	0.0625	0	-2048	2047.9375	Deg
22	0319	Actual Exhaust (B) Camshaft Position	Signed Numeric	2	0.0625	0	-2048	2047.9375	Deg
22	0316	Intake (A) Camshaft Position Actuator Duty Cycle	Unsigned Numeric	2	0.003051757813	0	0	199.996948242188	%
22	0317	Exhaust (B) Camshaft Position Actuator Duty Cycle	Unsigned Numeric	2	0.003051757813	0	0	199.996948242188	%
22	0461	Charge Air Cooler Temperature	Signed Numeric	2	0.015625	0	-512	511.984375	Deg C
22	05AC	Cylinder 1 Pre-Ignition Counter	Unsigned Numeric	1	1	0	0	255	Count
22	05AD	Cylinder 2 Pre-Ignition Counter	Unsigned Numeric	1	1	0	0	255	Count
22	05AE	Cylinder 3 Pre-Ignition Counter	Unsigned Numeric	1	1	0	0	255	Count
22	05AF	Cylinder 4 Pre-Ignition Counter	Unsigned Numeric	1	1	0	0	255	Count

Appendix C. AVL Indicom Settings

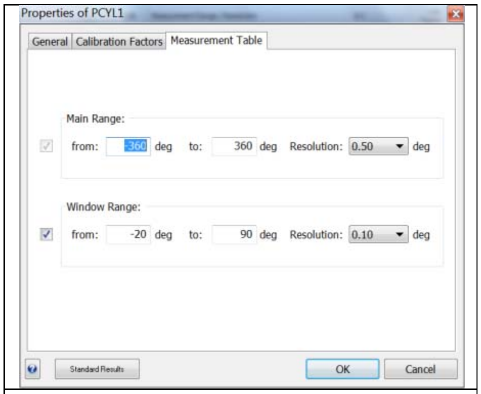
Amplifier and Pressure Sensor Settings (accessed through the “Sensor” menu)



Amplifier Settings



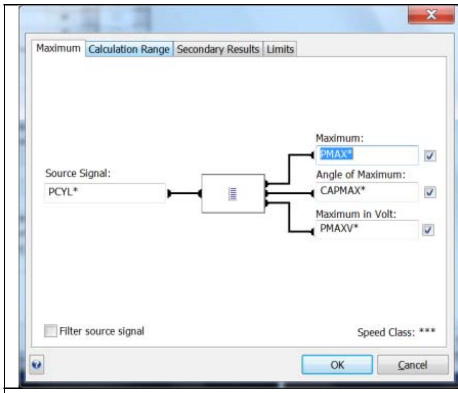
Pressure Sensor Settings

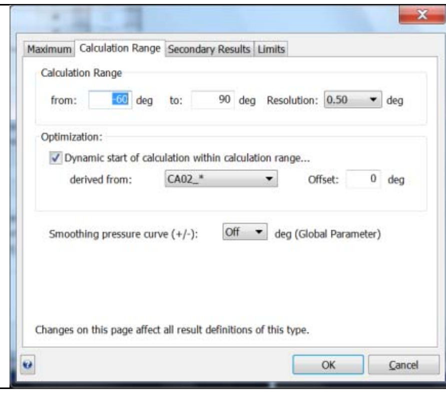


Pressure Sensor Settings

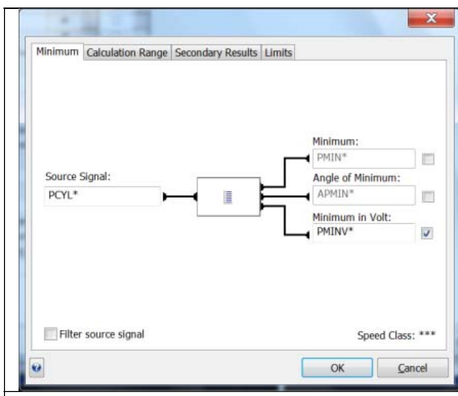
A.

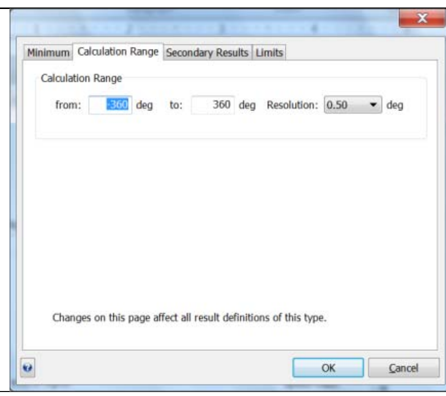
Standard Results Settings



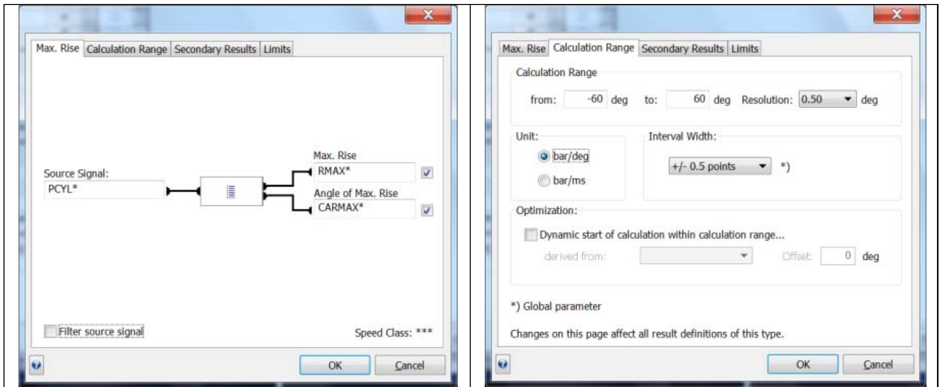


PCYL MAX Settings

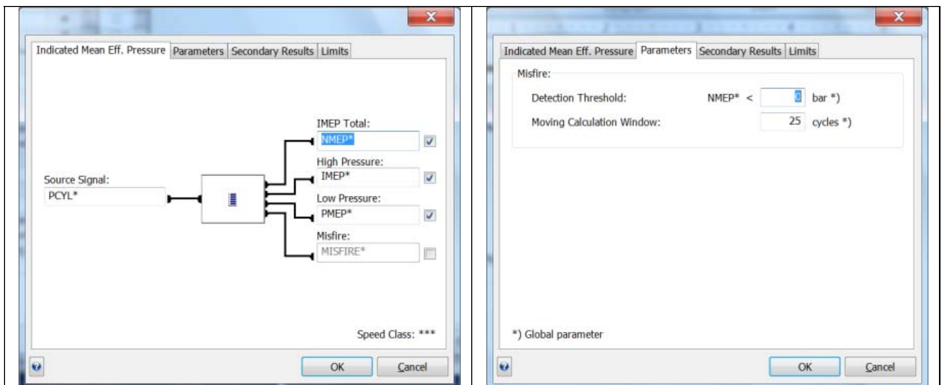




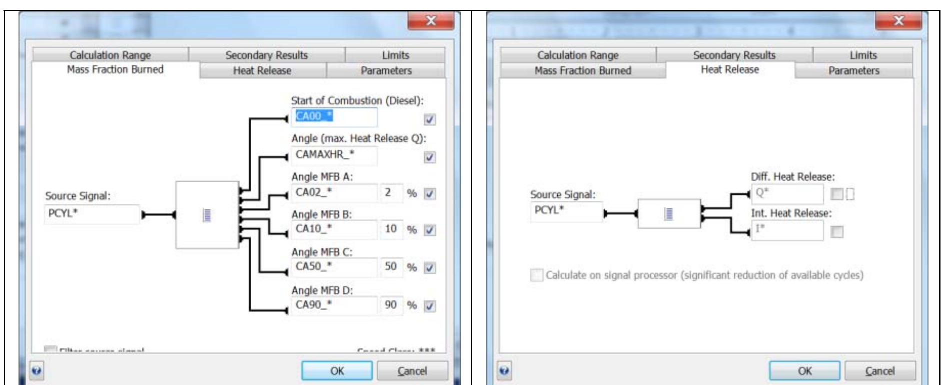
PCYL MIN Settings



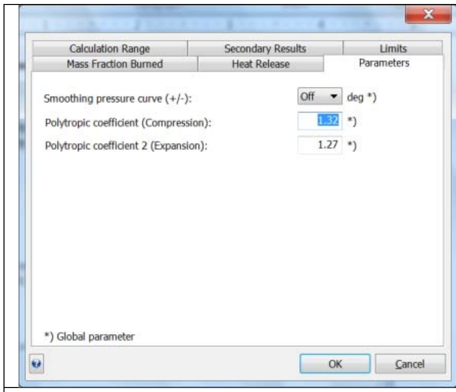
PCYL Max Rise Settings

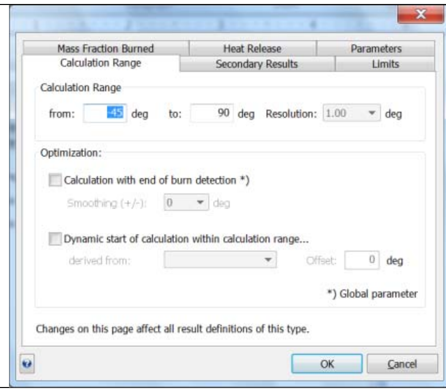


PCYL IMEP Settings

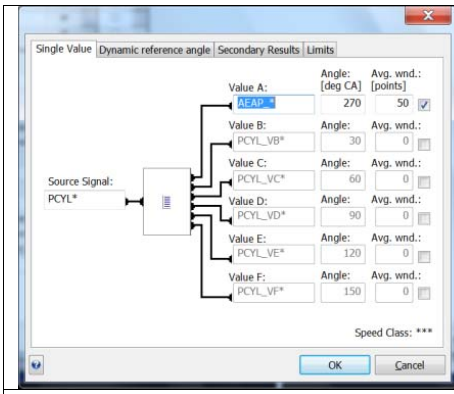


PCYL Heat Release Settings

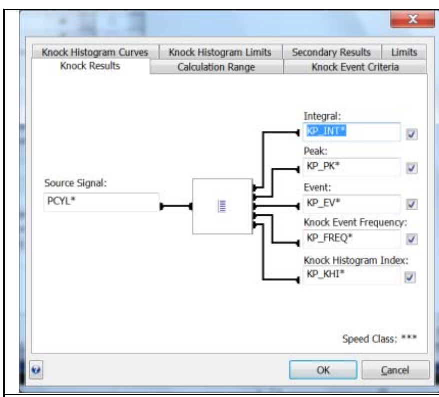


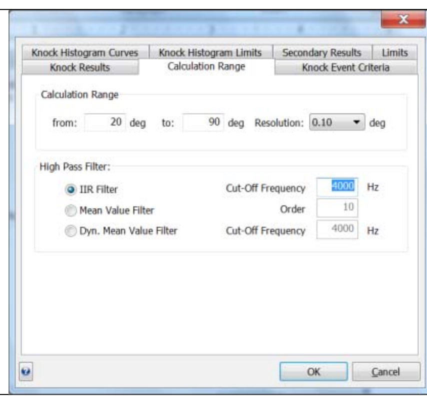


PCYL Heat Release Settings

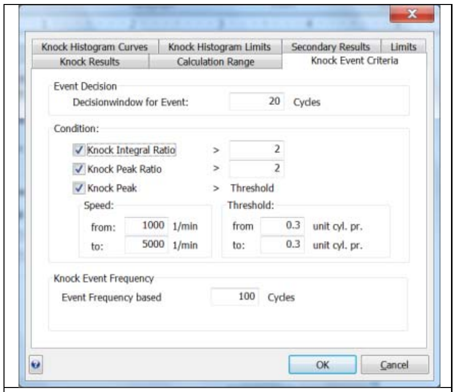


PCYL Single Value Settings

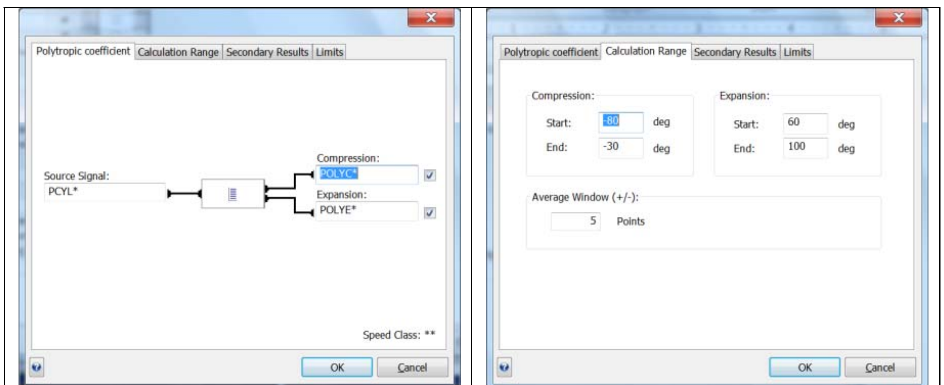




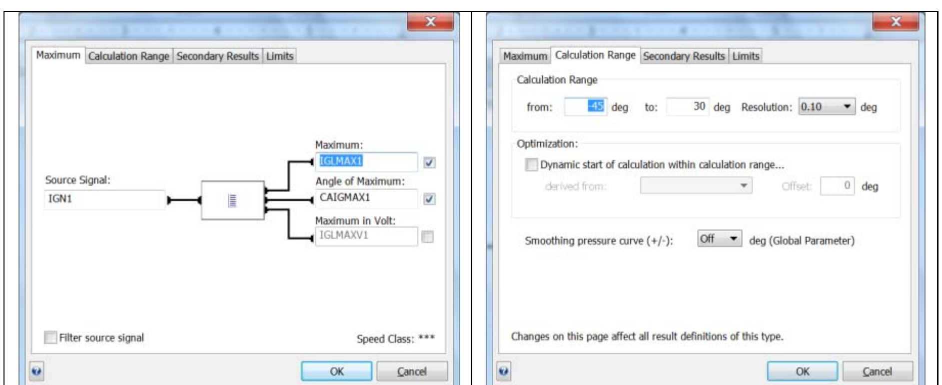
PCYL Knock (Cylinder Pressure) Settings



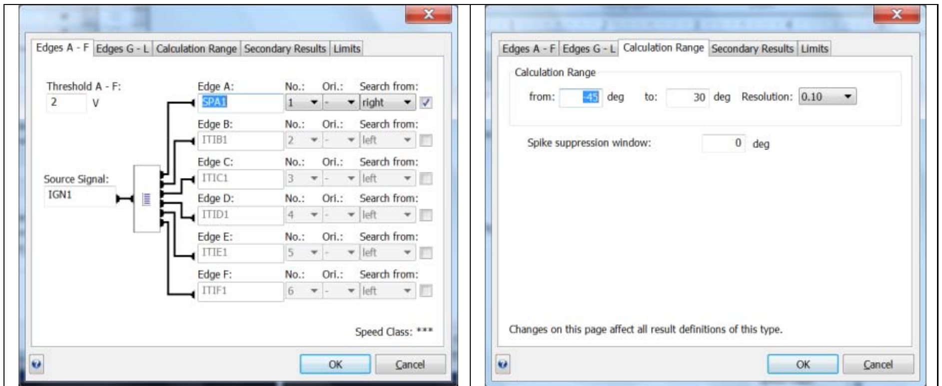
PCYL Knock (Cylinder Pressure) Settings



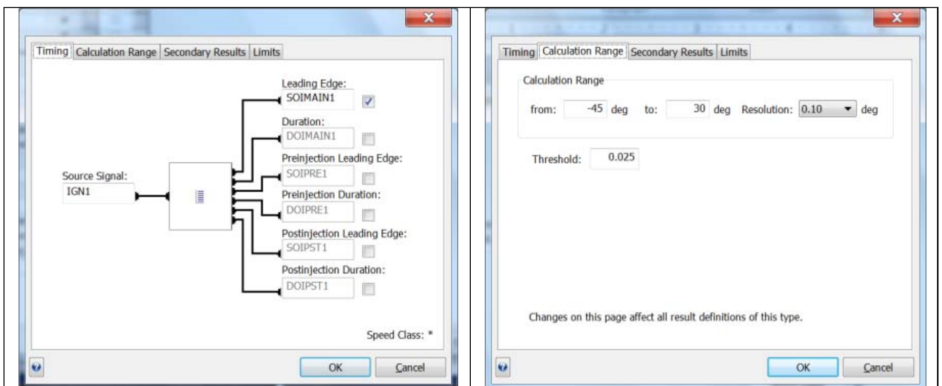
PCYL Polytrophic Coefficient Settings



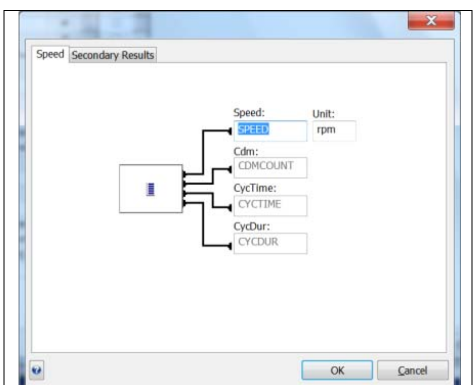
IGN1 MAX Settings



IGN1 Edge Detection Settings



IGN1 Timing Settings



Speed Settings

Channels To Report

- PMAX*
- CA02*
- PMAXV*
- PMINV*
- KP_INT*

Annex

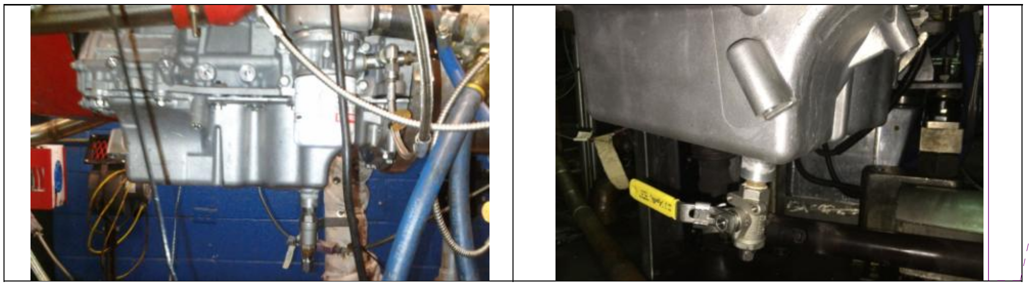
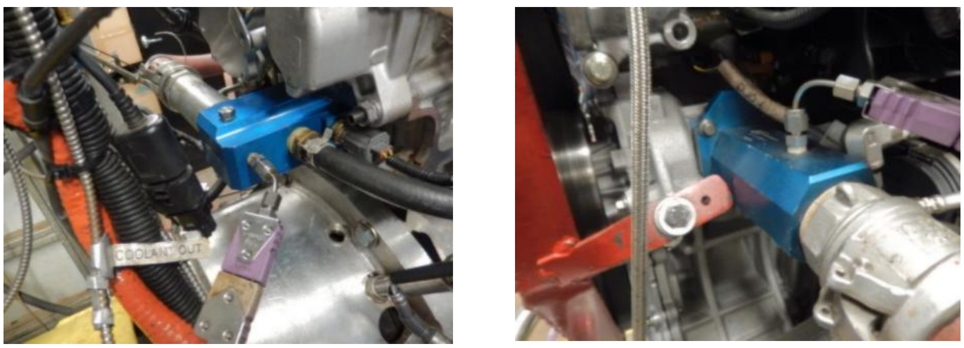
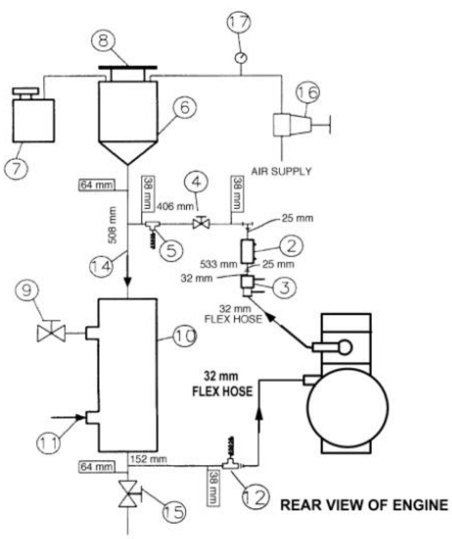


Figure A2.1 Oil Pan Drain Locations

Comment [FM17]: LZ Oil Pan Picture Added



Coolant in and out connections and thermocouple locations
FIG. A2.2



NOTE 1—Observe temperature sensor locations in thermostat housing and at water pump inlet.
NOTE 2—Components of Engine Cooling System—
(1) Thermostat housing with temperature sensor
(2) Sight glass
(3) Flowmeter
(4) Flow control valve
(5) Optional temperature control sensor
(6) Fabricated coolant reservoir
(7) Constant full expansion tank
(8) Pressure radiator cap (MOTORCRAFT RS40 P/N D2YY-8100-A)
(9) Process water control valve (regulated by temperature controller with three remote set points)
(10) Heat exchanger (ITT Standard P/N 5-030-06-048-001 TYP.)
(11) Process water supply (shell side)
(12) Tee with temperature sensor for coolant inlet; located (300 to 400) mm upstream of pump inlet at the block face
(13) Water pump inlet with temperature sensor
(14) Engine coolant (tube side)
(15) Coolant system drain valve
(16) Coolant pressure regulator
(17) Coolant pressure gage
(18) External coolant pump

FIG. A2.3 Typical Engine Cooling System Schematic (cont.)

Figure A2.4: Motor Mount, front

Figure A2.5: Motor Mount, rear

Comment [FM18]: Figures needed

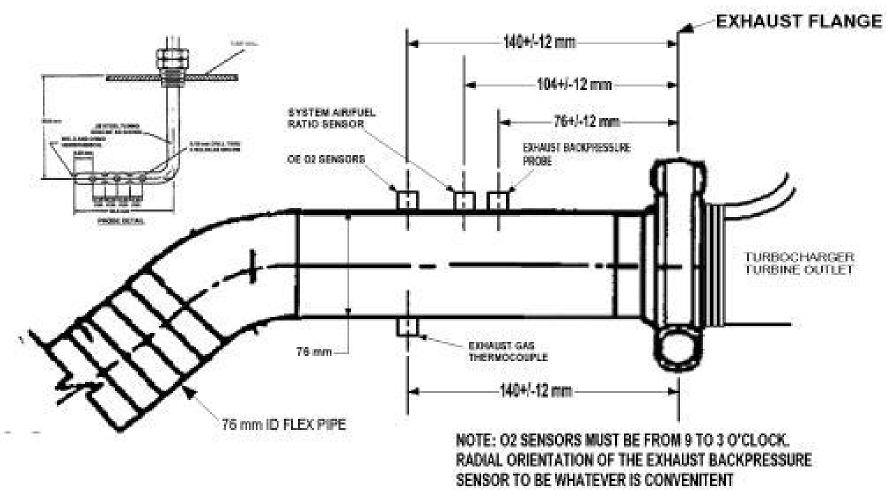


Figure A2.8: Exhaust Measurements and Instrumentation

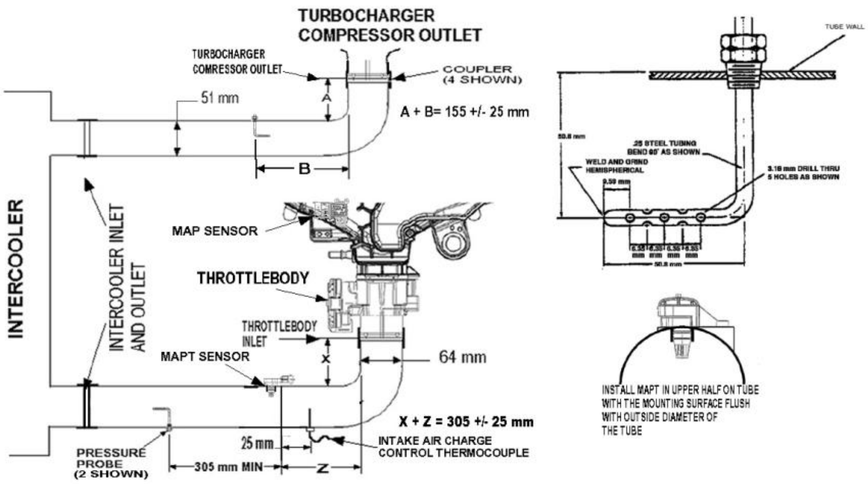


Figure A2.13: Intercooler Tubing Measurements and Instrumentation

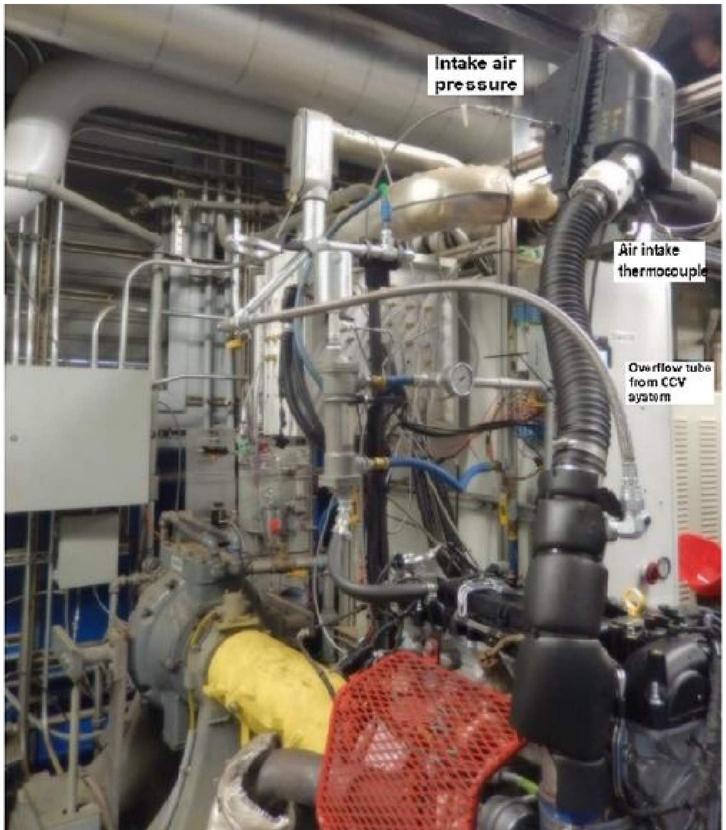


FIG. A2.12 Typical air inlet system

Comment [FM19]: Update to show correct temp and press locations

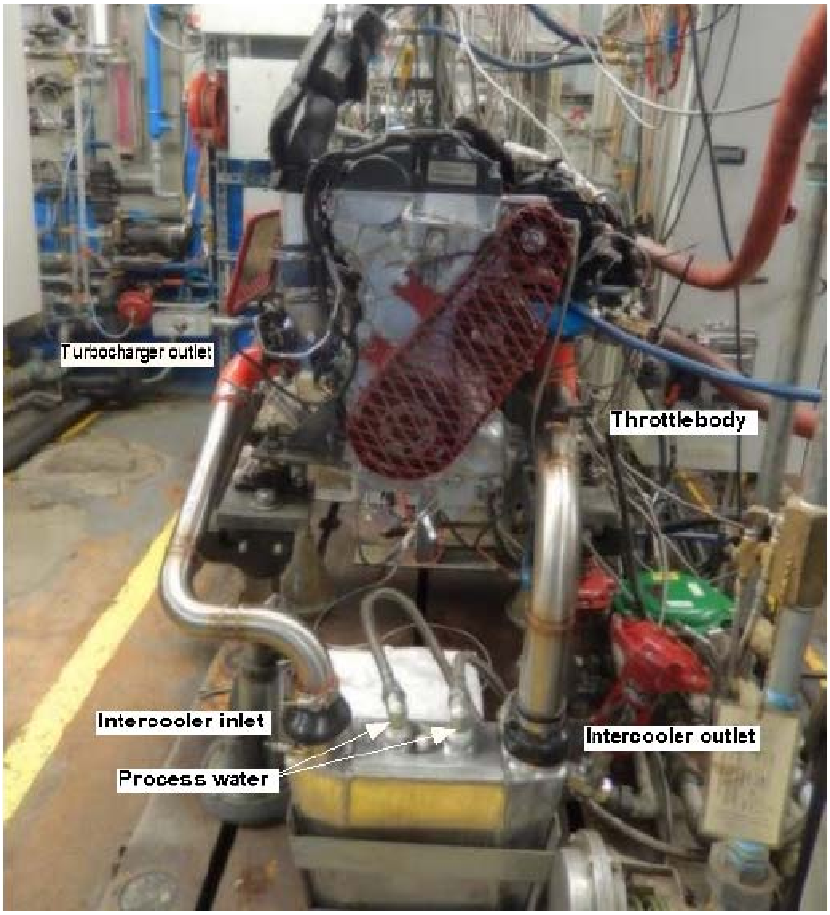


Figure A2.14 Typical intercooler installation

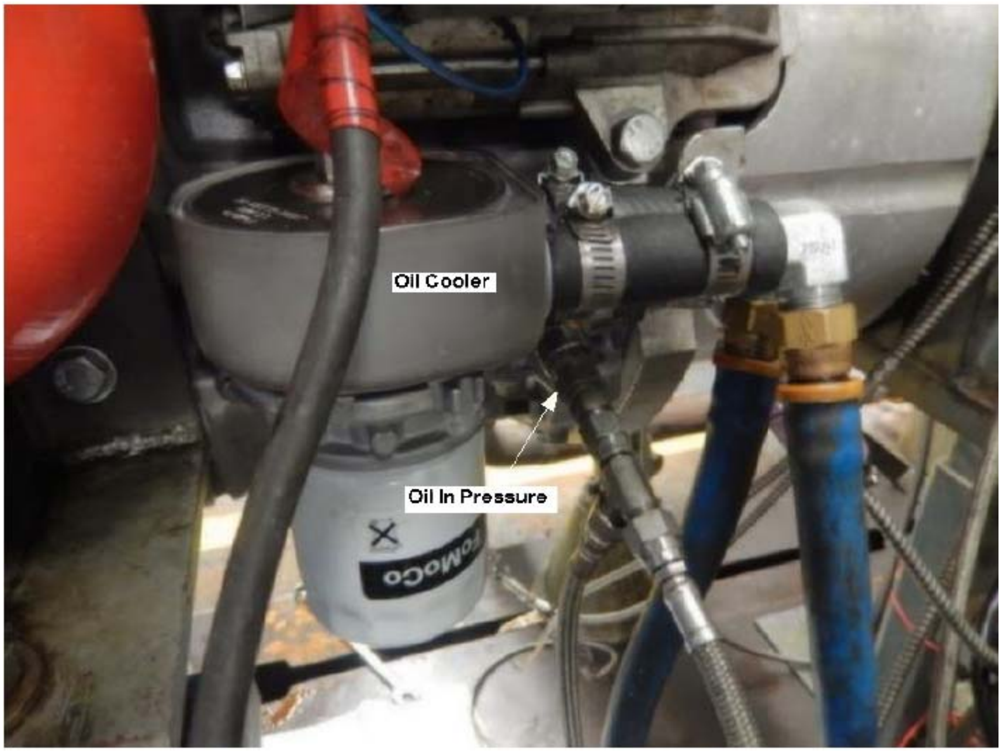
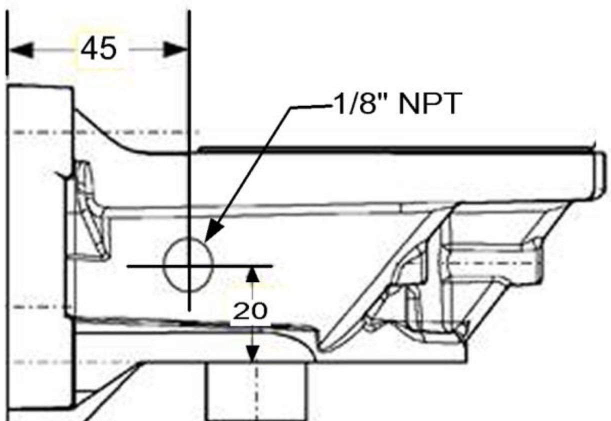
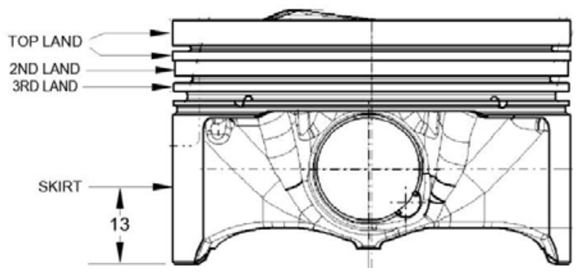


Figure A2.15Oil cooler showing oil gallery pressure location

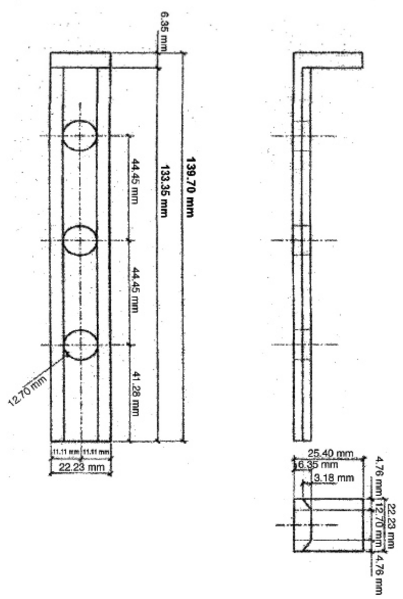
Figure A2.16 Oil cooler showing oil temperature locations



Oil Out temperature location in oil filter adapter
Figure A2.16 Oil cooler showing oil temperature locations

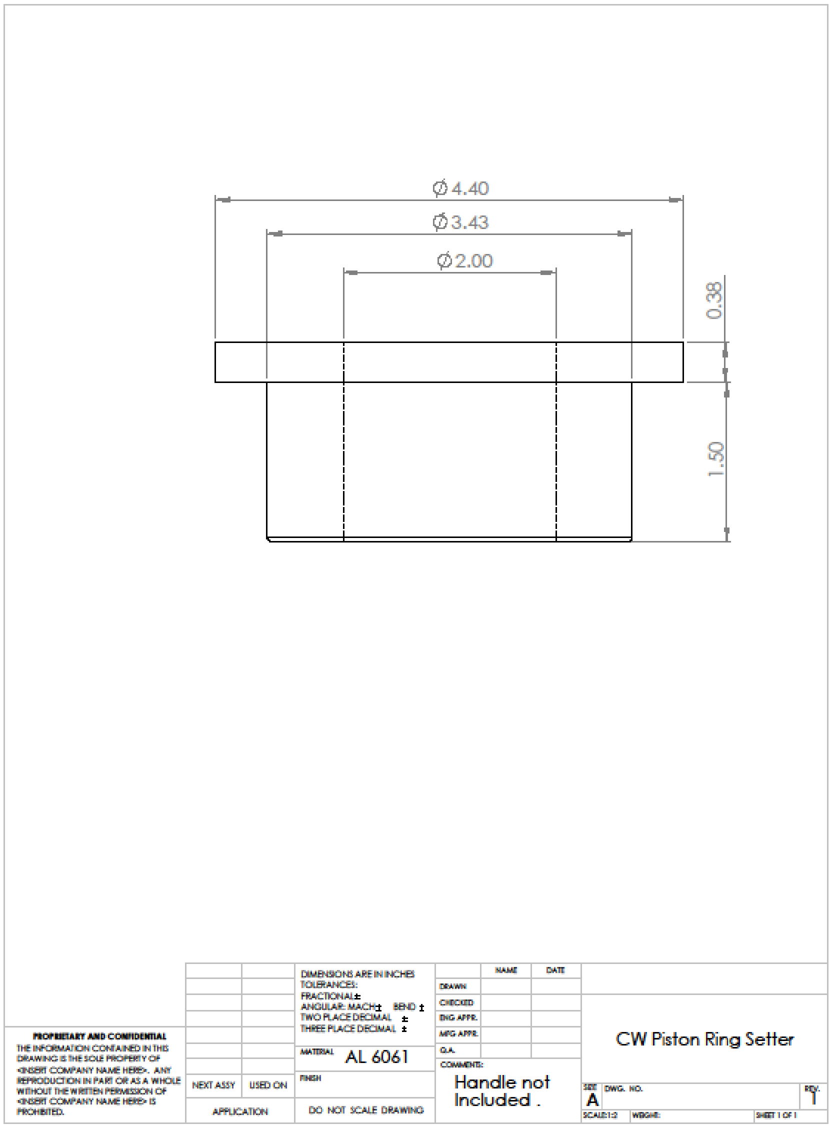


A2.17 Piston diameter measurements



A2.18. Bore Ladder

Comment [FM20]: Added figure for bore ladder



A2.19. Piston Ring Positioner

Comment [FM21]: Added Ring Positioner Figure

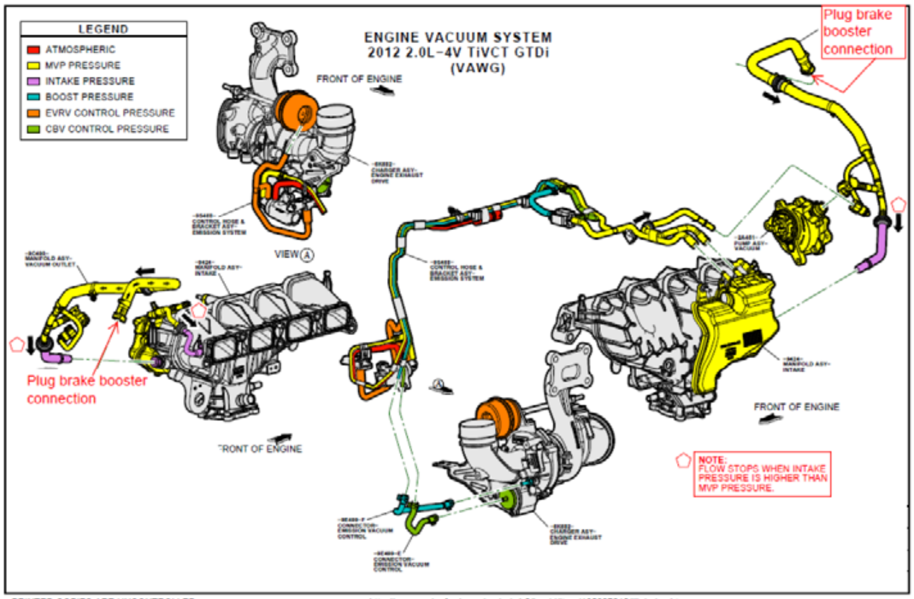


Figure A2.20 Vacuum System

Comment [FM22]: Added reference to this figure in section 7.19

A3. CONTROL AND DATA ACQUISITION REQUIREMENTS

A3.1 *General Description*:

A3.1.1 The data acquisition system shall be capable of logging the operational data in digital format. It is to the advantage of the laboratory that the system be capable of real time plotting of controlled parameters to help assess test validity. The systems shall be capable of calculating real time quality index as this will be monitored throughout the test as designated in A2.5.

A3.1.2 Control capability is not dictated by this procedure. The control system shall be capable of keeping the controlled parameters within the limits specified in Table 9 and maintain the quality index shown in A2.5.

A3.1.3 Design the control and data acquisition system to meet the requirements listed below. Use the recommendations laid out in the Instrumentation Task Force Report and Data Acquisition Task Force Report for any items not addressed in Annex A3.

A3.2 *Digital Recording Frequency*—The maximum allowable time period over which data can be accumulated is one second. This data can be filtered, as described in A3.6, and will be considered a reading.

A3.3 *Steady State Operation*:

A3.3.1 Each test interval of 175,000 engine cycles is conducted at steady state operation Calculate the quality index using values reported to the accuracy levels in Table A3.1.

TABLE A3.1 Accuracy Levels of Data Points to be Used in QI Calculations

Comment [FM23]: TBD

Parameter	Field Length
Speed	
Humidity	
Temperature	
Torque	
Inlet Air Pressure	
Exhaust Backpressure	
Coolant Outlet Pressure	

TABLE A3.2 L and U Constants and Over and Under-Range Values

Parameter	Stages	L	U	Over-Range	Under-Range

Comment [FM24]: TBD

TABLE A3.3 Maximum Allowable Time Constants

Control Parameter	Time Constant, s
Engine speed, r/min	0.5
Torque, Nm	0.7
Engine oil in, °C	0.6
Engine coolant out, °C	0.6
Engine coolant flow, L/min	8.0
Blowby in, °C	0.6
Inlet, air, °C	0.6
Inlet air press, kPa	0.2
Exhaust back pressure, kPa	0.2
Engine coolant pressure	2.0

Comment [FM25]: TBD

A3.3.2 The time intervals between recorded readings shall not exceed 1 second. Data shall be recorded throughout the length of each test interval.

A3.4 *Quality Index*:

TBD

A3.5 *Time Constants*:

A3.5.1 Filtering can be applied to all control parameters. The amount of filtering applied shall not allow time constants to exceed the values listed in Table A2.3. This time constant shall pertain to the entire system, running from the sensor to the display and data acquisition.

A3.5.2 Maximum allowable system time constants for the controlled parameters are shown in Table A3.3