1. Lubricant Test Monitoring System Control Charts

Test stands and test laboratories are calibrated by the ASTM Test Monitoring Center (TMC). Calibration is in terms of both test severity and precision and is checked by the application of the control charts in the Lubricant Test Monitoring System (LTMS) to operationally valid reference oil test results. The purpose of the control charts is to monitor and track both large abrupt changes and smaller consistent trends in both test severity and precision. The Shewhart charts check for the abrupt changes while the Exponentially Weighted Moving Average (EWMA) charts check for consistent changes and trends over time. The five control charts are listed below:

1. Shewhart Chart for Monitoring Severity
2. Shewhart Chart for Monitoring Precision
3. EWMA Chart for Monitoring Severity
4. EWMA Chart for Monitoring Precision
5. Shewhart Chart of Prediction Error

A. Control Chart Construction

This section outlines the construction of the six control charts that constitute this Lubricant Test Monitoring System. An example is provided in Exhibits I-III.

1. Shewhart Chart for Monitoring Severity

The vertical axis of this control chart represents the standardized calibration test results (Y). These results are plotted against completion date order (integer) which is on the horizontal axis. Y is calculated as follows:

$$Y_i = \frac{T_i - \text{MEAN}}{\text{STANDARD DEVIATION}}$$

T_i = Test result at test order i in appropriate units (see applicable test type in Section 2).

Y_i = Standardized test result at test order i. Standardized test result with the mean and the standard deviation of reference oil (in appropriate units) used in the calibration test.

The following are the control chart limits for the Shewhart chart for monitoring severity (Y plotted against completion date order).

$$0 \pm K$$

K is a constant that determines the chart's estimated false detection rate. The false detection rate is the percentage of time that a plotted result will fall outside the control limits when, in fact, no change in the process has occurred. As K increases, the false detection rate decreases. However, the false detection rate must be balanced with the chart's sensitivity to real changes in the process. This sensitivity is diminished as K increases. K is test type specific.

2. Shewhart Chart for Monitoring Precision

The vertical axis of this control chart represents the standardized calibration test moving ranges (R). These results are plotted against completion date order (integer) which is on the horizontal axis. R is calculated as follows:

$$R_i = \frac{\sqrt{|Y_i - Y_{i-1}|} - 0.969}{0.416}$$

R_i = Standardized test moving range at test order i. (For Sequence VID, $R_1 = 0$)

where: $Y_0=0$

The following is the control chart limit for the Shewhart chart for monitoring precision (R plotted against completion date order).

$0 + K$

K is a constant that determines the chart's estimated false detection rate. Deterioration in precision is signaled by control chart points exceeding the value of K. K is test type specific.

3. Exponentially Weighted Moving Average (EWMA) Chart for Monitoring Severity

The vertical axis of this control chart represents the EWMA of standardized calibration test results (Z). These results are plotted against completion date order (integer) which is on the horizontal axis. Z is calculated as follows:

Z_i = EWMA of the standardized test result at test order i.

Z_i = (LAMBDA) Y_i + (1 - LAMBDA) Z_{i-1}

where: $0 \leq \text{LAMBDA} \leq 1$,

Z_0 = 0 (For T-13, Z_0 = Mean Y_i of first two operationally valid tests. For Sequence VID and C13 Aeration, Z_0 = Mean Y_i of the first three operationally valid tests.)

LAMBDA (λ) is the smoothing constant and must be between 0 and 1. This value determines the amount of weight given to the current and past data points. As LAMBDA decreases, past data points are given more weight and the resulting plot gets smoother. When LAMBDA is set equal to 1, the EWMA chart is equivalent to the Shewhart chart.

The following are the control chart limits for the EWMA chart for monitoring severity (Z plotted against completion date order).

$$0 \pm K\sqrt{\frac{\lambda}{2-\lambda}}$$

K is a constant that determines the chart's estimated false detection rate. K is test type specific.

4. EWMA Chart for Monitoring Precision

The vertical axis of this control chart represents the EWMA of standardized calibration test moving ranges (Q). These results are plotted against completion date order (integer) which is on the horizontal axis. Q is calculated as follows:

Q_i = (LAMBDA) R_i + (1 - LAMBDA) Q_{i-1}

where: $0 \leq \text{LAMBDA} \leq 1$, $Q_0 = 0$ (For Sequence VID, $Q_0 = 0$ and $Q_1 = 0$)

Q_i = EWMA of standardized test moving range results at test order i.

LAMBDA (λ) is the smoothing constant and must be between 0 and 1. The value Q at test order 0, Q_0, must be set equal to 0.

The following is the control chart limit for the EWMA chart for monitoring precision (Q plotted against completion date order).

$$0 \pm K\sqrt{\frac{\lambda}{2-\lambda}}$$

K is a constant that determines the chart's estimated false detection rate. K is test type specific.

5. Shewhart Chart of Prediction Error from EWMA

The vertical axis of this control chart represents the Prediction Error from EWMA of standardized calibration test results (Z). These results are plotted against completion date order, which is on the horizontal axis. e_i is calculated as follows:

$e_i = Y_i - Z_{i-1}$

where: Y_i = Standardized test result at test order *i*.
Z_{i-1}= EWMA of the standardized test result at test order i-1.

The following are the control chart limits for the Prediction Error from the EWMA to determine whether a severity adjustment can be applied (e_i is plotted against completion date order):

± Level 1
± Level 2
± Level 3

Where Limit 1, Limit2, and Limit3 are constants that **c**over situations where test severity can be considered within an acceptable prediction level.

Anytime a Level 3 limit is exceeded an Excessive Influence analysis must be performed. After a Level 3 alarm is exceeded start an additional test on the stand or engine-stand combination (if appropriate) that triggered the alarm. Do not update severity adjustments until after the Excessive Influence analysis is completed.

The following comparison determines whether the value of Y_i is modified to limit its influence on LTMS. Y_{i+1} is the next completed reference in the stand or engine-stand combination after the Level 3 alarm:

i) If $|Y_i - Y_{i+1}| \leq e_i$ Level 3 limit, then Y_i is equal to the value originally determined.

ii) If $Y_i > Z_{i-1}$ and $Y_i - Y_{i+1} > e_i$ Level 3 limit, then let
$Y_i = e_i$ level 3 limit + Z_{i-1}.

iii) If $Y_i \leq Z_{i-1}$ and $Y_i - Y_{i+1} < -e_i$ Level 3 limit, then let
$Y_i = -e_i$ Level 3 limit + Z_{i-1}.

iv) If none of i), ii), or iii) is true, then Y_i is equal to the value originally determined.

Where: i = test that originally triggered Level 3 alarm,
i-1 = test prior to alarm trigger, and
i+1 = test immediately following alarm trigger.

Once the proper Y_i value has been determined, update the charts. Confirm calculations with the TMC. The laboratory and the TMC maintain a record of the modification.

B. Engineering Judgment as Applied to the Interpretation of LTMS Control Charts

The Lubricant Test Monitoring System (LTMS) Shewhart and EWMA control charts, by design, will infrequently produce false indications of the severity and/or precision of a test result. These false indications can occur at the stand, laboratory, and industry levels. One type of false indication is an alarm that is not the result of a real problem but is, rather, an anomaly. A second type of false indication occurs when a real problem exists, yet the control charts remain within acceptable limits. On occasion, when sufficient technical information is available, either type of false indication can be identified as such. In these cases, the ASTM Test Monitoring Center (TMC), through the application of engineering judgment, may determine that a deviation from normal LTMS actions is warranted. The following points describe the process by which engineering judgment is applied by the TMC:

1. The TMC determines if the potential exists for the application of engineering judgment in the interpretation of control charts.

2. When it is determined that the potential exists for the application of engineering judgment, all subsequent investigation proceeds under the assumption that the current control chart indications are correct.

3. When an engineering investigation is commenced, it is incumbent on the affected lab(s) to prepare necessary technical information in concert with the TMC.

4. The ACC Monitoring Agency will be notified that an engineering investigation involving control chart interpretation has commenced.

5. The TMC may solicit relevant input from outside sources, such as the Test Developer, Surveillance Panel Chairman, O&H Subpanel Leader and the ACC Monitoring Agency. In all cases, the confidentially of the affected lab(s) will be appropriately maintained.

6. If, in the judgment of the TMC, a deviation from normal LTMS actions is warranted, this judgment will be documented in writing along with a summary of the relevant technical information considered in making the judgment. The affected lab(s) and the ACC Monitoring Agency will receive copies of this document.

7. If, in the judgment of the TMC, normal LTMS action should be followed by the affected lab(s), no special documentation is required.

8. The application of engineering judgment in the interpretation of LTMS control charts is handled on a case-by-case basis. The TMC does not consider any prior judgment rendered to be precedent setting.

- Exceed EWMA test stand chart action limit for precision (critical parameters only)

  – Remove test stand from the system. Notify the TMC. Correct test stand precision problem. Follow requirements for entry of a new test stand into the system.

- Exceed Shewhart test stand chart action limit for precision (critical parameters only)

  – Conduct an additional calibration test.

- Exceed Shewhart laboratory chart action limit for precision (critical parameters only)

  – Notify TMC for guidance.

- Exceed EWMA laboratory chart action limit for severity (all parameters)

  – Calculate test laboratory Severity Adjustment (SA) for each parameter that exceeds the action limit. Use the current laboratory EWMA (Z_i) as follows:

HRS:	SA = $(-Z_i)$ x (7.701)
APV:	SA = $(-Z_i)$ x (0.220)
WPD:	SA = $(-Z_i)$ x (0.658)
VIS60:	SA =0.5* HRS SA
PVIS	SA= 0.000000

  – Confirm calculation with the TMC.

- Exceed EWMA test stand chart action limit for severity (critical parameters only)

  – Notify the TMC. If the direction of the test stand is deemed different from that of the laboratory, conduct an additional calibration test in the identified test stand. If this limit is still exceeded after the additional calibration test, then remove the test stand from the system, notify the TMC, correct test stand severity problem, and follow requirements for entry of a new test stand into the system.

- Exceed Shewhart test stand chart action limit for severity (critical parameters only)

  – Conduct an additional calibration test.

3. Control Charts

In Section 1 of the LTMS, the construction of the control charts that constitute the Lubricant Test Monitoring System is outlined. The constants used for the construction of the control charts for the Sequence IIIGB, and the response necessary in the case of control chart limit alarms, are depicted below.

LUBRICANT TEST MONITORING SYSTEM CONSTANTS

		Severity		
		EWMA		Shewhart
Chart Level	Limit Type	LAMBDA	K	K
Lab	Action	0.2	1.65	--
Industry	Warning	0.2	2.24	--
	Action	0.2	2.88	--

The following are the steps that must be taken in the case of exceeding control chart limits. The steps are listed in order of priority, although charts should be studied simultaneously to determine the cause(s) of a problem. In the case of multiple alarms, contact the TMC for guidance.

- Exceed EWMA laboratory chart action limit for severity

  – Calculate test laboratory Severity Adjustment (SA) for each parameter that exceeds the limit. Use the current laboratory EWMA (Z_i) as follows:

    PHOS: $SA = (-Z_i) \times (2.33)$*

    * standard deviation based on RMSE of oils 434, 435 & 438

  – Confirm calculation with the TMC.
  – *Note that Sequence IIIGB laboratory severity adjustments are only updated following an acceptable stand calibration test.*

The following industry issues are handled by the TMC and do not require individual laboratory action.

- Exceed EWMA industry chart action limit

  – TMC to notify test developer, surveillance panel chairman, and ACC Monitoring Agency. Meeting of the TMC, test developer, and the surveillance panel required to determine course of action.

- Exceed EWMA industry chart warning limit

  – TMC to notify test developer, surveillance panel chairman, and ACC Monitoring Agency. Coordination of TMC, test developer, and surveillance panel chairman required to discuss potential problem.

15. C13 LTMS Requirements

The following are the specific C13 calibration test requirements.

A. Reference Oils and Parameters

The critical parameters are Top Groove Carbon, Top Land Carbon, Oil Consumption Delta, and Second Ring Top Carbon. The reference oils required for test stand and test laboratory calibration are reference oils accepted by the ASTM C13 Surveillance Panel. The mean and standard deviation for the current reference oils for test parameters are presented below.

TOP GROOVE CARBON
Unit of Measure: Demerits
Normal K Value

Reference Oil	Mean	Standard Deviation
831-1	46.02	5.90
831-2	46.02	5.90
831-3	46.02	5.90

TOP LAND CARBON
Unit of Measure: Demerits
Normal K Value

Reference Oil	Mean	Standard Deviation
831-1	21.87	7.89
831-2	21.87	7.89
831-3	21.87	7.89

OIL CONSUMPTION DELTA
Unit of Measure: SQRT (g/h)
Normal K Value

Reference Oil	Mean	Standard Deviation
831-1	5.5089	0.7141
831-2	5.5089	0.7141
831-3	5.5089	0.7141

SECOND RING TOP CARBON
Unit of Measure: LN (Demerits)
Expanded K Value

Reference Oil	Mean	Standard Deviation
831-1	2.8828	0.2900
831-2	2.8828	0.2900
831-3	2.8828	0.2900

B. Acceptance Criteria

1. New Test Stand

   a. First Test Stand in a Laboratory

      - A minimum of two (2) operationally valid calibration tests with no stand Shewhart severity alarms, must be conducted on any approved reference oil.

   b. All Subsequent New Test Stands in a Laboratory

      - One operationally valid test with no stand Shewhart severity alarms must be conducted on any approved reference oil.

2. Existing Test Stand

   - The test stand must have been previously accepted into the system by meeting LTMS calibration requirements.

   - One operationally valid test with no stand Shewhart severity alarms must be conducted on any approved reference oil.

3. Reference Oil Assignment

   Once test stands have been accepted into the system, the TMC will assign reference oils for continuing calibration according to the following reference oil mix:

   - 100% of the scheduled calibration tests should be conducted on reference oil 831 (or subsequent approved reblends).

4. Control Charts

   In Section 1, the construction of the four control charts that constitute the Lubricant Test Monitoring System is outlined. The constants used for the construction of the control charts for the C13, and the response necessary in the case of control chart limit alarms, are depicted below.

16. C13 Aeration Test (COAT) LTMS Requirements

The following are the specific COAT calibration test requirements.

A. Reference Oils and Critical Performance Criteria

The prediction error monitoring and severity adjustment parameter is Percent Aeration (Averaged from 40 through 50 hours using predicted baseline density from D4052 measurements). The reference oils required for calibration are reference oils accepted by the ASTM Caterpillar Surveillance Panel. The targets for the current reference oils for each parameter are presented below.

40-50 Hr Average Aeration
Unit of Measure: Percent

Reference Oil	Mean	Standard Deviation
832	10.67	0.203
833	11.94	0.285

B. Acceptance Criteria

1. New build on an engine-stand combination

- A minimum of three (3) operationally valid reference and/or matrix tests with no level 3 e_i alarms must be run on each engine-stand before calibration is considered.
- The three (3) tests must be conducted on reference oils 833, 832 and 833 in that order.
- Note that industry matrix runs may be included, as well as reference runs, at the discretion of the surveillance panel.
- Following the necessary tests, check the status of the control charts and follow the prescribed actions

2. Existing Test Stand

- The test stand must have been accepted into the system by meeting LTMS calibration requirements.
- All operationally valid calibration test results on reference oils 833 (PC11K) and 832 (PC11G) and subsequent approved reblends must be charted to determine if the test stand is currently “in control” as defined by the control charts from the Lubricant Test Monitoring System.
- Note that industry matrix runs may be included, as well as reference runs, at the discretion of the surveillance panel.

3. Reference Oil Assignment

Once test stands have been accepted into the system, the TMC will assign reference oils for continuing calibration according to the reference oil mix:

- Scheduled calibration tests should be conducted on reference oils 833 and 832 or subsequent approved reblends on a 2:1 ratio basis.

4. Chart Status

In Section 1, the construction of the control charts that constitute the Lubricant Test Monitoring System is outlined. For the COAT, Z_0=Mean Y_i of first three operationally valid calibration tests. The constants used for the construction of the control charts for the COAT, and the response necessary in the case of control chart limit alarms, are depicted below.

LUBRICANT TEST MONITORING SYSTEM CONSTANTS

		EWMA Chart		Engine –Stand Shewhart Prediction Error	
		Severity		Severity	
Chart Level	Limit Type	Lambda	Alarm	Limit Type	Limit
Engine - Stand	Level 1	0.3	0.000	Level 1	±1.351
	Level 2		±1.800	Level 2	±1.734
Industry	Level 1	0.2	0.775	Level 3	±2.066
	Level 2		±0.859	--	--

The following are the steps that must be taken in the case of exceeding control chart limits. The steps are listed in order of priority, although charts should be studied simultaneously to determine the cause(s) of a problem. In the case of multiple alarms, contact the TMC for guidance. The laboratory always has the option of removing any stand or engine from the system.

- Exceed engine – stand Shewhart chart of Prediction Error (e_i)

  Level 3:

  – Immediately conduct one additional reference test in the engine-stand that triggered the alarm. Do not update the control charts until the follow up reference test is completed and the Excessive Influence (refer to Section 1.A.5) has been performed.

Level 2:

– The Level 2 limit applies in situations that have been pre-determined by the surveillance panel to have a potential impact on test results. These situations may include the introduction of new critical parts, fuel batches, reference oil reblends, or other test components. When these conditions have been met and a Level 2 alarm is triggered, immediately conduct one additional reference test in the engine-stand that triggered the alarm.

Level 1:

– The Level 1 limit also applies to an engine in an existing test stand that has not run an acceptable reference in the past two years. The engine can calibrate with one test if the Level 1 limits are not exceeded. Otherwise, immediately conduct another reference test in the engine-stand.

- Exceed Engine – Stand EWMA of Standardized Test Result (Z_i)

Level 2:

– Immediately conduct one additional reference test in the engine-stand that triggered the alarm. The engine-stand that triggered the alarm is not qualified for non-reference tests until the Level 2 alarm is cleared.

– In instances where surveillance panel has deemed that industry-wide circumstances are impacting the Level 2 alarm, the TMC may be asked to review engine-stand calibration status in accordance with the surveillance panel's findings.

Level 1:

– The Level 1 limit applies to all reference tests that are control charted, even when other alarms have been triggered. Level 1 uses Z_i to determine the engine-stand severity adjustment (SA). Calculate the engine-stand SA as follows and confirm the calculation with the TMC:

Percent Aeration Average from 40 through 50 hours: $SA = -Z_i \times (0.285)$

- Exceed Industry EWMA of Standardized Test Result (Z_i)

Level 2:

– TMC informs the surveillance panel that the limit has been exceeded. The surveillance panel then investigates and pursues resolution of the alarm.

Level 1:

– The TMC investigates whether severity adjustments are adequately addressing the trend, investigates the possible causes, and communicates as appropriate with industry.

17. ISB LTMS Requirements

The following are the specific ISB calibration test requirements.

A. Reference Oils and Parameters

The critical parameters are Average Cam Shaft Wear and Average Tappet Weight Loss. The reference oils required for test stand and test laboratory calibration are reference oils accepted by the ASTM Cummins Test Surveillance Panel. The mean and standard deviation for the current reference oils for each critical parameter are presented below.

AVERAGE CAM SHAFT WEAR
Unit of Measure: Micrometers

Reference Oil	Mean	Standard Deviation
831-1	42.5	5.0
831-2	42.5	5.0
831-3	42.5	5.0

AVERAGE TAPPET WEIGHT LOSS
Unit of Measure: Milligrams

Reference Oil	Mean	Standard Deviation
831-1	97.2	14.8
831-2	97.2	14.8
831-3	97.2	14.8

B. Acceptance Criteria

1. New Test Stand

a. First Test Stand in a Laboratory

- A minimum of two (2) operationally valid calibration tests with no stand Shewhart severity alarms must be conducted on any approved reference oil.

b. All Subsequent New Test Stands in a Laboratory

- One operationally valid test with no stand Shewhart severity alarms must be conducted on any approved reference oil.

2. Existing Test Stand

- The test stand must have been previously accepted into the system by meeting LTMS calibration requirements.

19. T-8 / T-8E LTMS Requirements

The following are the specific T-8 and T-8E calibration test requirements.

A. Reference Oils and Parameters

The critical parameters are Viscosity Increase at 3.8% Soot (T-8 and T-8E) and Relative Viscosity at 4.8% Soot, 50% DIN Shear Loss (T-8E only). Relative Viscosity at 4.8% Soot, 100% DIN Shear Loss is a non-critical parameter (T-8E only). The reference oils required for test stand and test laboratory calibration are reference oils accepted by the ASTM Mack Test Surveillance Panel. The mean and standard deviation for the current reference oils for each critical and non-critical parameter are presented below.

VISCOSITY INCREASE @ 3.8% SOOT
Unit of Measure: cSt
CRITICAL PARAMETER

Reference Oil	Mean	Standard Deviation
1005-3	5.01	0.56
1005-4	5.01	0.56
1005-5	5.01	0.56

RELATIVE VISCOSITY @ 4.8% SOOT
50% DIN Shear Loss
Unit of Measure: unitless
CRITICAL PARAMETER

Reference Oil	Mean	Standard Deviation
1005-3	1.76	0.08
1005-4	1.76	0.08
1005-5	1.76	0.08

RELATIVE VISCOSITY @ 4.8% SOOT
100% DIN Shear Loss
Unit of Measure: unitless
NON-CRITICAL PARAMETER

Reference Oil	Mean	Standard Deviation
1005-3	2.00	0.09
1005-4	2.00	0.09
1005-5	2.00	0.09

B. Acceptance Criteria

1. New Test Stand

a. Less than four (4) Operationally Valid Calibration Results in Laboratory

23. T-13 LTMS Requirements

The following are the specific T-13 calibration test requirements.

A. Reference Oils and Critical Performance Criteria

The critical performance criteria are IR Oxidation Peak Height at 360 hours and percent increase in 40° kinematic viscosity from 300 to 360 hours. The reference oils required for test stand and test laboratory referencing are reference oils accepted by the ASTM T-13 Test Development Task Force. The means and standard deviations for the current reference oils for each critical performance criterion are presented below.

IR Oxidation Peak Height
Unit of Measure: absorbance / cm

Reference Oil	Mean	Standard Deviation
823	142.7	12.4

Percent Increase in Viscosity at 40°C from 300 to 360 hour
Unit of Measure: %

Reference Oil	Mean	Standard Deviation
823	86.9	23.2

B. Acceptance Criteria

1. New Test Lab

   a. The first two stands in a laboratory

   - A minimum of two (2) operationally valid calibration tests and/or matrix tests, with no Level 3 e_i alarms must be conducted in a new laboratory on any approved reference oils.
   - Note that industry matrix runs may be included, as well as reference runs, at the discretion of the surveillance panel.
   - Following the necessary tests, check the status of the control charts and follow the prescribed actions

   b. Third and subsequent stands in a laboratory

   - New test stands in an existing lab, and test stands in an existing test lab that have not run an acceptable reference in the past two years, may calibrate with one test provided e_i Level 1 limits are not exceeded. Otherwise a second test is required for calibration.

- For an existing test stand in an existing lab run one test.

- Following the necessary tests, check the status of the control charts and follow the prescribed actions

3. Reference Oil Assignment

Once test stands have been accepted into the system, the TMC will assign reference oils for continuing calibration according to the reference oil mix:

- 100% of the scheduled calibration tests should be conducted on reference oil 823 or subsequent approved reblends.

4. Control Charts

In Section 1, the construction of the control charts that constitute the Lubricant Test Monitoring System is outlined. For the T-13, Z_0=Mean Y_i of first two operationally valid tests in the laboratory. The constants used for the construction of the control charts for the T-13, and the response necessary in the case of control chart limit alarms, are depicted below. Note that control charting all parameters is required.

LUBRICANT TEST MONITORING SYSTEM CONSTANTS

		EWMA Chart		Laboratory Shewhart Prediction Error	
		Severity		Severity	
Chart Level	Limit Type	Lambda	Alarm	Limit Type	Limit
Lab	Level 1	0.3	0.000	Level 1	±1.351
	Level 2		±1.800	Level 2	±1.734
Industry	Level 1	0.2	0.775	Level 3	±2.066
	Level 2		±0.859	--	--

The following are the steps that must be taken in the case of exceeding control chart limits. The steps are listed in order of priority, although charts should be studied simultaneously to determine the cause(s) of a problem. In the case of multiple alarms, contact the TMC for guidance. The laboratory always has the option of removing any stand from the system.

- Exceed Laboratory chart of Prediction Error (e_i)

  Level 3:

  – Immediately conduct one additional reference test in the stand that triggered the alarm. Do not update the control charts until the follow up reference test is completed and the Excessive Influence (refer to Section 1.A.5) has been performed.

  Level 2:

  – The Level 2 limit applies in situations that have been pre-determined by the surveillance panel to have a potential impact on test results. These situations may include the introduction of new critical parts, fuel batches, reference oil reblends, or other test components. When these conditions have been met and a Level 2 alarm is triggered, immediately conduct one additional reference test in the stand that triggered the alarm.

  Level 1:
  – The Level 1 limit also applies to stand in an existing test lab that has not run an acceptable reference in the past two years. The stand can calibrate with one test if the Level 1 limits are not exceeded. Otherwise, immediately conduct another reference test in the stand.

- Exceed Engine – Stand EWMA of Standardized Test Result (Z_i)

  Level 2:

  – Immediately conduct one additional reference test in the engine-stand that triggered the alarm. The engine-stand that triggered the alarm is not qualified for non-reference tests until the Level 2 alarm is cleared.
  – In instances where surveillance panel has deemed that industry-wide circumstances are impacting the Level 2 alarm, the TMC may be asked to review engine-stand calibration status in accordance with the surveillance panel's findings.

  Level 1:

  – The Level 1 limit applies to all reference tests that are control charted, even when other alarms have been triggered. Level 1 uses Z_i to determine the engine-stand severity adjustment (SA). Calculate the engine-stand SA as follows and confirm the calculation with the TMC:

    IR Oxidation Peak Height at 360 hours: $SA = (-Z_i) \times (12.4)$
    Percent Increase in Viscosity at 40°C from 300 to 360 hour: $SA = (-Z_i) \times (23.2)$

- Exceed Industry EWMA of Standardized Test Result (Z_i)

Level 2:

– TMC informs the surveillance panel that the limit has been exceeded. The surveillance panel then investigates and pursues resolution of the alarm.

Level 1:

– The TMC investigates whether severity adjustments are adequately addressing the trend, investigates the possible causes, and communicates as appropriate with industry.

APPENDIX A

HISTORY OF LTMS REFERENCE OIL MEANS AND STANDARD DEVIATIONS

Sequence IIIF Reference Oil Targets														
Oil	n	Effective Dates		VIS80[3]		HRS		APV		WPD		SACLW	VIS60[4]	
		From[1]	To[2]	$\bar{X}$	s	$\bar{X}$	s	$\bar{X}$	s	$\bar{X}$	s	Maximum	$\bar{X}$	s
1006	6	6-10-00	11-14-01	0.0156989	0.0076717	- -	- -	9.14	0.263	3.29	0.284	20.0	5.41732	0.230855
	34	11-15-01	11-30-01	0.0156989	0.0076717	- -	- -	9.14	0.263	3.29	0.284	20.0	5.41732	0.230855
	35	12-1-01	8-1-03	0.0167362	0.0086503	- -	- -	9.23	0.213	3.32	0.327	20.0	5.41732	0.230855
1006-2	5	1-9-02	10-31-02	0.0496678	0.0090039	- -	- -	9.35	0.283	4.18	0.417	20.0	5.30933	0.168340
	14	11-1-02	6-30-03	0.0490642	0.0065297	- -	- -	9.46	0.203	4.04	0.407	20.0	5.41527	0.160503
	22	7-1-03	1-21-04	0.0461786	0.0079007	- -	- -	9.38	0.227	4.00	0.459	20.0	5.43687	0.171445
	30	1-22-04	5-13-13	0.0440739	0.0102981	- -	- -	9.35	0.223	3.94	0.448	20.0	5.46088	0.166630
1008	6	6-10-00	3-31-01	0.0872279	0.0087680	- -	- -	9.73	0.115	4.66	0.861	20.0	- -	- -
	24	4-1-01	9-4-01	0.0895442	0.0098604	- -	- -	9.75	0.102	4.57	0.803	20.0	- -	- -
	37	9-5-01	11-14-01	0.0899551	0.0096670	- -	- -	9.74	0.100	4.52	0.773	20.0	- -	- -
	38	11-15-01	5-13-13	0.0899551	0.0096670	- -	- -	9.74	0.100	4.52	0.773	20.0	4.21605	0.122356
1008-1[6]	--	5-16-02	4-20-03	0.0899551	0.0096670	- -	- -	9.74	0.100	4.52	0.773	20.0	4.21605	0.122356
	10	4-21-03	6-20-04	0.0911968	0.0063810	- -	- -	9.75	0.099	4.75	0.823	20.0	4.34110	0.139270
	20	6-21-04	5-13-13	0.0930792	0.0059248	- -	- -	9.77	0.103	4.57	0.699	20.0	4.33528	0.118673
433	5	6-10-00	11-14-01	0.1601833	0.0204379	- -	- -	9.41	0.257	4.96	0.697	20.0	- -	- -
	19	11-15-01	5-13-13	0.1601833	0.0204379	- -	- -	9.41	0.257	4.96	0.697	20.0	3.31554	0.111867
433-1	5	8-15-01	11-14-01	0.1700213	0.0433403	121.09	5.752	9.31	0.242	4.28	0.826	20.0	- -	- -
	6	11-15-01	2-28-02	0.1700213	0.0433403	121.09	5.752	9.31	0.242	4.28	0.826	20.0	3.41045	0.111867[5]
	11	3-1-02	2-23-03	0.1684402	0.0402156	121.09	5.752	9.27	0.281	4.27	0.557	20.0	3.55682	0.298299
	22	2-24-03	2-23-04	0.1643104	0.0321605	121.09	5.752	9.30	0.306	4.57	0.760	20.0	3.59344	0.227054
	31	2-24-04	6-12-10	0.1635099	0.0302263	121.09	5.752	9.30	0.300	4.59	0.697	20.0	3.55500	0.229905
	30	6-13-10	4-30-13	0.1635099	0.0302263	121.09	7.701	9.30	0.300	4.59	0.697	20.0	3.55500	0.229905
	30	5-1-13	***	0.1635099	0.0302263	121.09	7.701	9.30	0.300	4.59	0.697	N/A	3.55500	0.229905

1 Effective for all tests completed on or after this date.

2 *** = currently in effect.

3 Transformation is 1/Sqrt(VIS80).

4 Transformation is ln(VIS60).

5 Standard deviation based on oil 433.

6 Initial targets based on oil 1008.

C13 Reference Oil Targets											
Oil	n	Effective Dates		Top Groove Carbon		Top Land Carbon		Oil Consumption Δ^2		2^{nd} Ring Top Carbon[3]	
		From	To[1]	$\bar{X}$	s	$\bar{X}$	s	$\bar{X}$	s	$\bar{X}$	s
PC10A	3	5-28-05	2-20-06	45.55	6.44	23.18	5.57	6.2676	0.8226	2.3301	0.3430
PC10C	2	5-28-05	2-20-06	54.57	2.92	26.98	0.21	5.7229	1.8966	3.2447	0.3966
PC10D	3	5-28-05	2-20-06	39.18	5.85	23.58	2.33	3.8405	1.8509	2.4426	0.3400
PC10E	7	5-28-05	2-20-06	45.52	8.02	23.52	7.02	4.8593	1.4265	2.8197	0.4024
PC10F	3	5-28-05	2-20-06	54.08	11.09	36.32	2.82	6.5929	0.9750	3.8424	0.2573
PC10G	3	5-28-05	2-20-06	35.85	2.83	29.05	0.84	3.8066	0.8456	2.7134	0.1936
831 (PC10B)	8	5-28-05	3-12-08	45.18	7.42	24.99	7.59	5.7336	0.7280	2.8945	0.2055
	14	3-13-08	***	46.02	5.90	21.87	7.89	5.5089	0.7141	2.8828	0.2900
831-1[4]	--	05-10-08	***	46.02	5.90	21.87	7.89	5.5089	0.7141	2.8828	0.2900
831-2[4]	--	08-06-13	***	46.02	5.90	21.87	7.89	5.5089	0.7141	2.8828	0.2900
831-3[4]	--	06-16-15	***	46.02	5.90	21.87	7.89	5.5089	0.7141	2.8828	0.2900

1 *** = Currently in effect
2 Transformation for Oil Consumption Delta is sqrt(OC Δ)
3 Transformation for 2^{nd} Ring Top Carbon is ln(R2TC)
4 Targets based on oil 831

C13 Aeration Reference Oil Targets					
Oil	n	Effective Dates		40 - 50 Hour Average Aeration %	
		From	To[1]	$\bar{X}$	s
PC11G	5	11-01-2014	***	10.67	0.203
PC11H	3	11-01-2014	***	12.14	0.285
PC11I	3	11-01-2014	***	10.92	0.139
PC11J	6	11-01-2014	***	10.60	0.203
PC11K	7	11-01-2014	***	11.94	0.285
PC11L	6	11-01-2014	***	10.73	0.139
832(PC11G)	-	5-01-2015	***	10.67	0.203
833(PC11K)	--	4-01-2015	***	11.94	0.285

ISB Reference Oil Targets							
Oil	n	Effective Dates		Average Camshaft Wear		Average Tappet Weight Loss	
		From	To[1]	$\overline{X}$	s	$\overline{X}$	s
821 (PC10E)	6	6-4-05	12-31-05	34.6	4.6	56.2	9.6
830-2	6	6-4-05	12-31-05	39.8	9.0	85.9	16.0
831 (PC10B)	6	6-4-05	1-24-07	41.9	5.6	88.7	15.9
	10	1-25-07	8-6-07	42.8	5.4	94.9	15.3
	14	8-7-07	***	42.5	5.0	97.2	14.8
831-1[2]	--	8-7-07	***	42.5	5.0	97.2	14.8
831-2[2]	--	8-6-13	***	42.5	5.0	97.2	14.8
831-3[2]	--	8-11-15	***	42.5	5.0	97.2	14.8

1 *** = currently in effect
2 Targets based on oil 831

T-8 Reference Oil Targets					
		Effective Dates		Viscosity Increase @ 3.8% Soot	
Oil	n	From[1]	To[2]	$\overline{X}$	s
1004-1	30	4-1-94	***	5.13	1.19
1004-2	10	7-1-95	10-31-95	4.49	1.19[3]
	20	11-1-95	1-31-96	4.46	1.19[3]
	30	2-1-96	9-30-96	4.46	1.19[3]
	59	10-1-96	***	4.92	0.93
1004-3	--	11-15-97	4-30-98	4.92[4]	0.93[4]
	10	5-1-98	9-13-98	4.71	0.97
	22	9-14-98	1-31-99	4.57	0.95
	30	2-1-99	***	4.57	0.90
1005-2	5	5-24-07	1-24-08	5.85[5]	0.72[5]
	3	1-25-08	2-6-08	4.83	0.72[5]
	5	2-7-08	***	5.11	0.66
1005-3[6]	--	08-12-10	9-16-11	5.11	0.66
	--	9-17-11	***	5.01[7]	0.56[7]
1005-4[7]	--	09-21-12	***	5.01[7]	0.56[7]
1005-4[7]	--	02-04-15	***	5.01[7]	0.56[7]
1005-5[7]	--	02-04-15	***	5.01[7]	0.56[7]

1 Effective for all tests completed on or after this date.
2 *** = currently in effect.
3 Standard deviation based on 1004-1.
4 Targets based on 1004-2.
5 Targets based on previous tests on 1005.
6 Targets based on 1005-2.
7 Targets based on all blends of 1005.

T-8E Reference Oil Targets							
		Effective Dates		Relative Viscosity @ 4.8% Soot 50% DIN Shear Loss		Relative Viscosity @ 4.8% Soot 100% DIN Shear Loss	
Oil	n	From[1]	To[2]	$\overline{X}$	s	$\overline{X}$	s
1004-2	24	1-27-97	***	2.02	0.26	--	--
1004-3	--	11-15-97	4-30-98	2.02[3]	0.26[3]	--	--
	10	5-1-98	9-13-98	2.10	0.29	--	--
	21	9-14-98	1-31-99	2.09	0.27	--	--
	30	2-1-99	***	2.07	0.26	--	--
	59	2-1-98	***	--	--	2.21	0.27
1005-2	5	5-24-07	1-24-08	2.09[4]	0.15[4]	2.42[4]	0.16[4]
	3	1-25-08	2-6-08	1.74	0.15[4]	1.98	0.16[4]
	5	2-7-08	***	1.78	0.11	2.03	0.12
1005-3[5]	--	08-12-10	9-16-11	1.78	0.11	2.03	0.12
	--	9-17-11	***	1.76[6]	0.08[6]	2.00[6]	0.09[6]
1005-4[6]	--	09-21-12	***	1.76[6]	0.08[6]	2.00[6]	0.09[6]
1005-5[6]	--	02-04-15	***	1.76[6]	0.08[6]	2.00[6]	0.09[6]

1 Effective for all tests completed on or after this date.
2 *** = currently in effect.
3 Targets based on 1004-2.
4 Targets based on previous tests on 1005.
5 Targets based on 1005-2
6 Targets based on all blends of 1005.

T-13 Reference Oil Targets							
		Effective Dates		IR Oxidation Peak Height absorbance / cm		% Increase in Viscosity at 40°C from 300 to 360 hour	
Oil	n	From	To[1]	$\bar{X}$	s	$\bar{X}$	s
PC11A	6	10-01-2014	***	142.7	12.4	86.9	23.2
PC11B	3	10-01-2014	***	59.7	12.4	25.2	23.2
PC11C	4	10-01-2014	***	121.1	12.4	68.8	23.2
PC11D	7	10-01-2014	***	133.5	12.4	77.6	23.2
PC11E	7	10-01-2014	***	59.2	12.4	23.2	23.2
PC11F	4	10-01-2014	***	123.6	12.4	87.1	23.2
823(PC11A)	-	05-01-2015	***	142.7	12.4	86.9	23.2

1 *** = currently in effect

L-33-1 Reference Oil Targets						
			Effective Dates		Rust	
Oil	Gear Version	n	From[1]	To	$\bar{X}$	s
121	V94.1	12[2]	6-5-96	4-19-00	9.370[2]	0.280[2]
	V95.1	12[2]	6-5-96	4-19-00	9.370[2]	0.280[2]
121-1	V94.1	--	1-19-98	4-29-99	9.370[3]	0.280[3]
	V94.1	45[2]	4-30-99	11-17-00	9.390[2]	0.218[2]
	V95.1	--	1-19-98	4-29-99	9.370[3]	0.280[3]
	V95.1	45[2]	4-30-99	11-17-00	9.390[2]	0.218[2]
	V99.1	8	4-20-00	11-17-00	9.830	0.260[4]
121-2	V94.1	--	12-14-99	11-17-00	9.390[5]	0.218[5]
	V95.1	--	12-14-99	11-17-00	9.390[5]	0.218[5]
	V99.1	--	4-20-00	11-17-00	9.830[6]	0.260[4]
123	V94.1	54[2]	5-5-95	4-19-00	9.000[2]	0.330[2]
	V95.1	54[2]	5-5-95	4-19-00	9.000[2]	0.330[2]
	V99.1	12	6-11-02	8-24-04	8.430	0.390
	V01.1	--	11-25-02	8-24-04	8.430[10]	0.390[10]
	V99.1 & V01.1	30	8-25-04	***	8.560	0.230
123-1	V94.1	13[7]	4-20-00	11-17-00	8.240[7]	0.330[8]
	V95.1	--	12-14-99	4-19-00	9.000[9]	0.330[9]
	V95.1	13[7]	4-20-00	11-17-00	8.240[7]	0.330[8]
	V99.1	13[7]	4-20-00	11-17-00	8.240[7]	0.330[8]
123-2	V99.1	--	11-25-02	8-24-04	8.430[10]	0.390[10]
	V99.1 & V01.1	--	8-25-04	6-1-06	8.560[9]	0.230[9]
	V99.1 & V01.1	15	6-2-06	***	8.740	0.260
151-3	V99.1	13	6-11-02	8-24-04	9.690	0.350
	V01.1	--	11-25-02	8-24-04	9.690[11]	0.350[11]
	V99.1 & V01.1	30	8-25-04	***	9.640	0.250
155	V99.1 & V01.1	--	6-2-06	---	9.580	0.250[12]
155-1	V99.1 & V01.1	--	4-4-12	---	9.580	0.250[12]

1 Effective for all tests completed on or after this date.
2 Based on V94.1 & V95.1 data.
3 Based on oil 121 data.
4 Based on lab pooled s of V94.1 & V95.1 data (all blends of oil 121).
5 Based on oil 121-1 data.
6 Based on V99.1 data on oil 121-1.
7 Based on V99.1 and V95.1 data.
8 Based on lab pooled s of V94.1 & V95.1 data (all blends of oil 123).
9 Based on oil 123 data.
10 Based on V99.1 data on oil 123.
11 Based on V99.1 data on oil 151-3.
12 Based on V99.1 & V01.1 data on oil 151-3.

Test Area	Effective		Condition	Description
	From	To		
T-12	August 26, 2014	***	All tests using VUXO Hardware	Multiply Average Top Ring Weight Loss by 0.719
				Multiply Average Cylinder Liner Wear by 0.818
				$\Delta Lead_{Final}$ = exp[(ln(ΔLead) x 0.813)]
				$\Delta Lead\ (250\text{-}300)_{Final}$ = exp[(ln(ΔLead 250-300) x 0.710)]
				OC = exp[(ln($OC_{100\text{-}300}$) x 0.913)]
	August 4, 2015	***	All test using VUXOA or VUXOB Hardware	Multiply Average Top Ring Weight Loss by 0.912
				Multiply Average Cylinder Liner Wear by 0.953
				$\Delta Lead\ (250\text{-}300)_{Final}$ = exp[(ln(ΔLead 250-300) x 0.895)]
				$\Delta Lead_{Final}$ = exp[(ln(ΔLead) x 0.954)]
				OC = exp[(ln($OC_{100\text{-}300}$) x 0.942)]
T-13	None		All Tests	None
RFWT	None		All Tests	None
EOAT	None		All Tests	None
T-12A	None		All Tests	None

APPENDIX C

HISTORY OF SEVERITY ADJUSTMENT (SA)
STANDARD DEVIATIONS

Test	Parameter	s	Effective Dates	
			From	To
Sequence IIIF	VIS80	0.0129546	20000610	20130513
		0.0000000	20130514	***
	HRS	7.701	20130514	***
	APV	0.220	20000610	***
	WPD	0.658	20000610	***
	VIS60	0.17334	20011115	20130513
	VIS60	0.5*HRS SA	20130514	***
Sequence IIIG	PVIS	0.2919	20030501	***
	WPD	0.60	20030501	***
	ACLW	0.1936	20030501	20040120
		0.1903	20040121	***
Sequence IIIGA	MRV Viscosity	0.30763	20031103	20040526
Sequence IIIGB	Phos. Retention	2.33	20081112	***
Sequence IVA	ACW	9.47	19980819	20010524
		12.50	20010525	20050630
		12.52	20050701	20120208
		15.72	20120209	20120710
		14.87	20120711	***