# Caterpillar 1N Alternate Fuel Acceptance Criteria

- Single test stand and associated rebuild hardware

- Intent is to conduct all tests without replacement of major internal or external hardware outside of typical rebuild process between runs

- Conduct 1 calibration test using oil 809-1 or 811-2
    - Test must meet all LTMS calibration acceptance requirements
    - Calculate new Zi value

- Total of 3 tests
- Conduct 2 tests on the alternate fuel using the same oil as above and one test using the other reference oil
    - Calculate Yi and Ei for these three tests. For all Ei values, use the Zi which was calculated immediate following the calibration test on the current fuel
    - Each test must meet the following criteria
        - For each parameter (4 total), Ei < 1.734
        - Average exhaust temperatures within +/-7 degrees C of the calibration test
        - Average power within +/- 1 kW of the calibration test
        - Average coolant delta temperature within +/- 0.75 deg C of calibration test
            - It should be noted that this is a ranged parameter with +/-1 deg C tolerance typically
        - Tests must be operationally valid

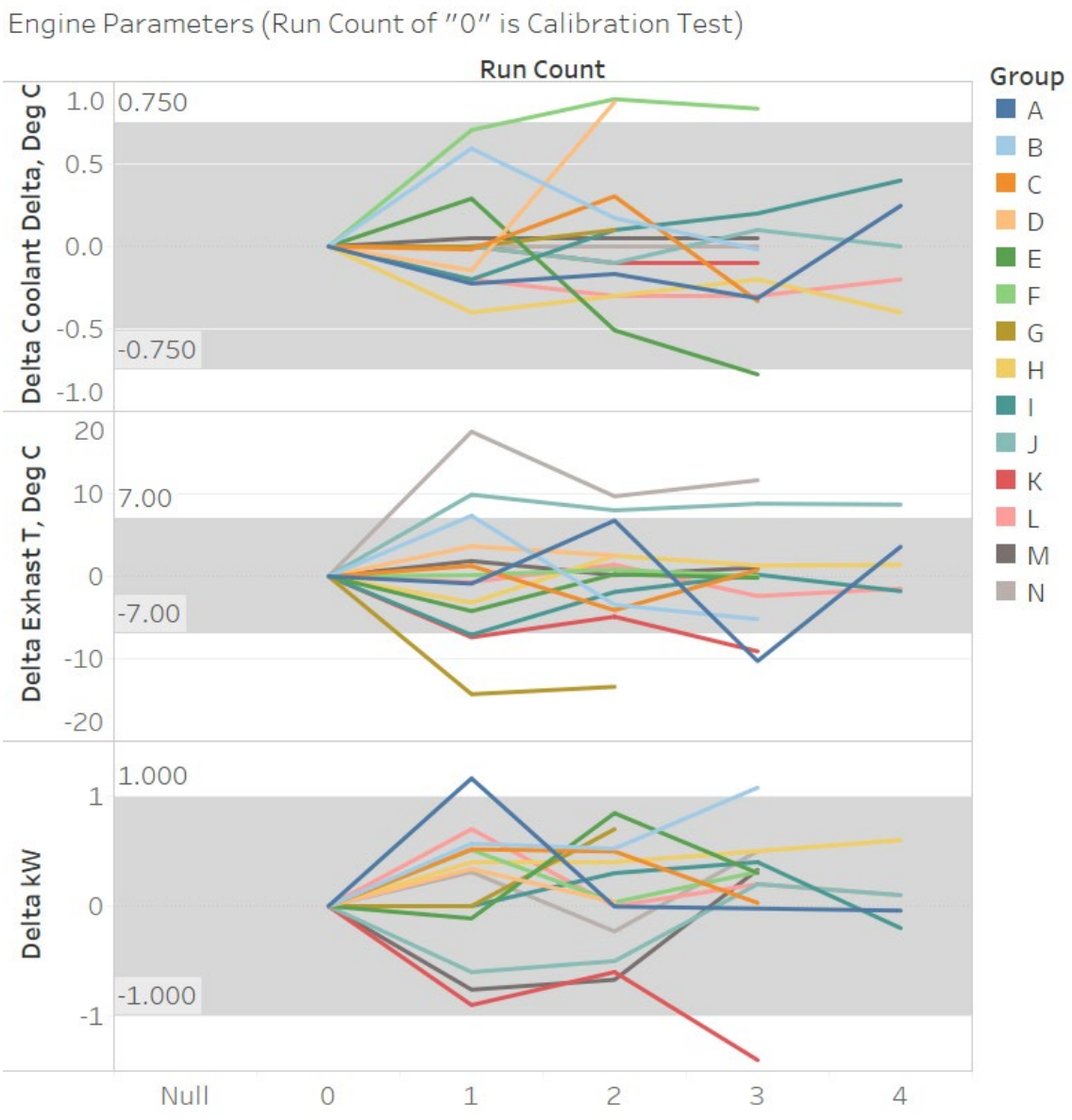
## Note:

In the gasoline sequence test approval criteria, it has been helpful to view these requirements as the "free pass" requirements, rather than "pass/fail" requirements. If these requirements are met, the Mack SP is comfortable that no additional review is necessary to approve the fuel. On the other hand, if these criteria are not met, there may be a very good explanation to the reason, unrelated to the fuel. In these cases, the SP may still determine a path forward to approve the fuel, but the requirements will have to be determined on a case by case basis depending on the data.

## Additional questions for consideration:

1) Assuming a new fuel is approved, what will the implementation process look like? Will the whole industry choose a single supplier amongst all approved suppliers, or will each lab be able to make its own decision on which approved fuel supplier it wishes to use?
2) If switching to a new fuel, previous Zi values and severity adjustments will be based on calibration data from a different fuel.
    a. Is any additional referencing required?
        i. If not, can switchover happen in the middle of a calibration period?
    b. How will we handle severity adjustments?
3) For a test stand that runs the procedure described in this document, is the stand still calibrated and able to continue candidate testing?

Data shown is sourced from multiple labs. Each “Group” is an acceptable reference test followed by the next 3-4 runs of that reference interval.



# Example of 1N Acceptance Testing

*****Fuel Approval Requirements given as bulleted items

- Single test stand and associated rebuild hardware

- Intent is to conduct all tests without replacement of major internal or external hardware outside of typical rebuild process between runs

- Conduct 1 calibration test using oil 809-1 or 811-2
    - Test must meet all LTMS calibration acceptance requirements
    - Calculate new stand Zi value

## Example

Current Stand Zi for each parameter listed below for the stand chosen.

| Parameter | Current Stand Zi |
|---|---|
| Weighted Demerits | -1.0 |
| Top Groove Fill | -0.5 |
| Top Land Heavy Carbon | -0.2 |
| Average Oil Consumption | 0.2 |

The stand runs a new calibration test on 811-2 using the current fuel. Based on the results, the following are the Yi and new Stand Zi values for each parameter.

| Parameter | Result | Yi | New Stand Zi |
|---|---|---|---|
| Weighted Demerits | 262.8 | -0.50 | (0.3*-0.5)+(0.7*-1.0) = **-0.85** |
| Top Groove Fill | 18 | -0.05 | (0.3*-0.05)+(0.7*-0.5) = **-0.37** |
| Top Land Heavy Carbon | 0 | -0.61 | (0.3*-0.61)+(0.7*-0.2) = **-0.32** |
| Average Oil Consumption | 0.26 | 0.80 | (0.3*0.8)+(0.7*0.2) = **0.38** |

This test is operationally valid and meets all LTMS statistical criteria for calibration.

- Total of 3 tests
- Conduct 2 tests on the alternate fuel using the same oil as above and one test using the other reference oil
    - Calculate Yi and Ei for these three tests. For all Ei values, use the Zi which was calculated immediate following the calibration test on the current fuel
    - Each test must meet the following criteria
        - For each parameter (4 total), Ei < 1.734
        - Average exhaust temperatures within +/-7 degrees C of the calibration test
        - Average power within +/- 1 kW of the calibration test
        - Average coolant delta temperature within +/- 0.75 deg C of calibration test
            - It should be noted that this is a ranged parameter with +/-1 deg C tolerance typically

- Tests must be operationally valid

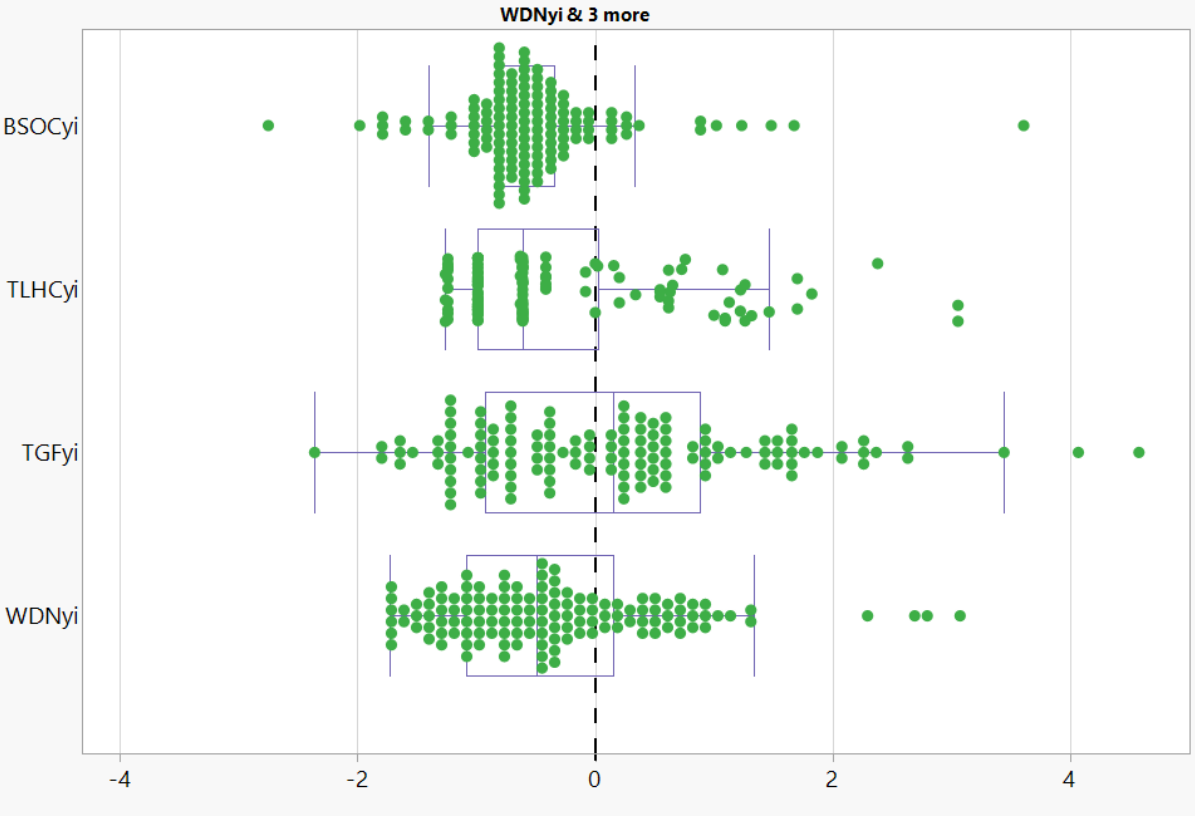
## Example

The same stand now runs another test on oil 811-2, but using the alternative fuel. The Yi and Ei results for this first alternative fuel test are shown below.

| Parameter | Result | Yi for Alt. Fuel Test #1 | Ei = Yi – Z(i-1) |
|---|---|---|---|
| Weighted Demerits | 186.1 | -2.55 | -2.55 – (-0.85) = **-1.70** |
| Top Groove Fill | 8.4 | -2.00 | -2.0 – (-0.37) = **-1.63** |
| Top Land Heavy Carbon | 0 | -0.32 | -0.61 – (-0.32) = **-0.29** |
| Average Oil Consumption | 0.23 | 0.14 | 0.14 – 0.38 = **-0.24** |

Assuming all operational data was acceptable, this first round of tests passes the statistical criteria, since all Ei values are less than 1.734.

*Discussion:* This example is intended to start discussion on whether a severity limit on Yi is needed. The prediction error (Ei) only ensures the stand is reasonably close to recent historical performance, but does not directly check that the performance is close to target. Something like Yi +/- 2.5 might help this. A plot of historical Yi's is shown below for all 809-1 and 811-2 operationally valid reference tests (AC and OC).




Next, the 2nd alternate fuel test is run, with results below:

| Parameter | Result | Yi for Alt. Fuel Test #2 | Ei = Yi – Z(i-1) |
|---|---|---|---|
| Weighted Demerits | 311.4 | 0.80 | 0.8 – (-0.85) = **1.65** |
| Top Groove Fill | 29 | 1.22 | 1.22 – (-0.37) = **1.59** |
| Top Land Heavy Carbon | 1 | 0.55 | 0.55 – (-0.32) = **0.87** |
| Average Oil Consumption | 0.26 | 2.00 | 2.0 – 0.38 = **-1.62** |

Assuming all operational data was acceptable, this second round of tests passes the statistical criteria, since all Ei values are less than 1.734

*Discussion:* This example is intended to start discussion on whether any precision monitoring is necessary. The two tests result on alternate fuel gave results which were about 3 sigma or more apart. It should be noted that newer test types which use level 2 ei limits for hardware approval traditionally have not had precision monitoring (I think). The maximum difference two results on alternate fuel could be from each other is about 3.45 sigma because of the level two ei limit of +/- 1.734.

Finally, the stand would run a third test on the alternate fuel, but this time the other reference oil would be used. In this example, that would be 809-1. This test would be evaluated just as shown in the previous two tables. Assuming all ei values < 1.734 for this test as well, and all operational criteria are likewise met, the fuel will have passed the statistical criteria.

# Appendix – Relevant LTMS Information

1N LTMS Targets

WEIGHTED DEMERITS
Unit of Measure: Demerits
CRITICAL PARAMETER

| Reference Oil | Mean | Standard Deviation |
|---|---|---|
| 809-1 | 205.0 | 34.6 |
| 811-1 | 273.2 | 35.5 |
| 811-2 | 281.5 | 37.4 |

TOP GROOVE FILL
Unit of Measure: LN(TGF+1)
CRITICAL PARAMETER

| Reference Oil | Mean | Standard Deviation |
|---|---|---|
| 809-1 | 3.410591 | 0.563970 |
| 811-1 | 3.077855 | 0.362927 |
| 811-2 | 2.961267 | 0.361554 |

TOP LAND HEAVY CARBON
Unit of Measure: LN(TLHC+1)
NONCRITICAL PARAMETER

| Reference Oil | Mean | Standard Deviation |
|---|---|---|
| 809-1 | 1.1970 | 1.2130 |
| 811-1 | 0.454 | 0.6590 |
| 811-2 | 0.366 | 0.6000 |

AVERAGE OIL CONSUMPTION
Unit of Measure: g/kW-h
NONCRITICAL PARAMETER

| Reference Oil | Mean | Standard Deviation |
|---|---|---|
| 809-1 | 0.308 | 0.175 |
| 811-1 | 0.218 | 0.053 |
| 811-2 | 0.223 | 0.052 |

1N LTMS Constants

| | | EWMA Chart | | | | Shewhart Chart | |
|---|---|---|---|---|---|---|---|
| | | LAMBDA | | K | | K | |
| Chart Level | Limit Type | Precision | Severity | Precision | Severity | Precision | Severity |
| Stand | Reduced K | -- | -- | -- | -- | 1.48 | 1.43 |
| | Action | 0.3 | 0.3 | 1.80 | 2.10 | 1.80 | 1.75 |
| Lab | Warning | 0.2 | -- | 1.80 | -- | -- | -- |
| | Action | 0.2 | 0.2 | 2.58 | 1.96 | 1.80 | 1.75 |
| Industry | Warning | 0.15 | 0.15 | 1.74 | 2.05 | -- | -- |
| | Action | 0.15 | 0.15 | 2.58 | 2.81 | -- | -- |

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).

$0 \pm K$

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.

$$Z_i = (\text{LAMBDA})\, Y_i + (1 - \text{LAMBDA})\, Z_{i-1}$$

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

$Z_0 = 0$ (An alternate, fast start $Z_0$ could be indicated for a specific test. Section 4.0 under the specific test area will denote this option)

LAMBDA ($\lambda$) 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).

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

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).

$$0 \pm K$$