T-11 Alternate Fuel Acceptance Criteria

- Single test stand with a history of at least three (3) successful calibration tests over a span of not less than one calendar year

- Engine rebuild immediately prior to test sequence
    - No rebuilds during test sequence
    - Intent is to conduct all tests without replacement of major internal or external hardware.

- Conduct 1 calibration test using oil 822-2
    - Test must meet all LTMS calibration acceptance requirements
    - Calculate new stand Zi value

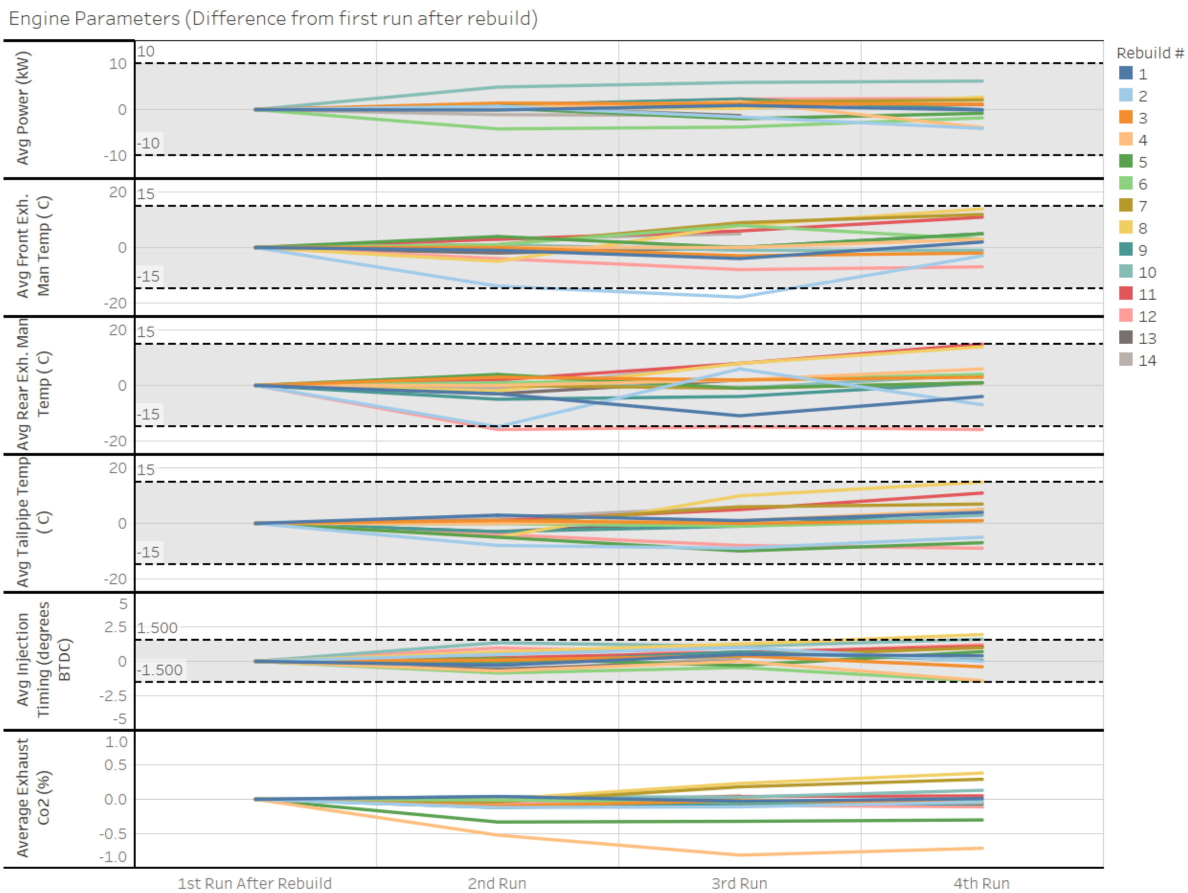
- Conduct 2 tests on the alternate fuel using oil 822-2
    - Calculate Yi and Ei for these two tests. For all Ei values, use the stand Zi which was calculated immediate following the calibration test on the current fuel
    - Each test must meet the following criteria
        - For Soot @12cSt and Soot @15cSt, Ei < 1.734
        - For Soot @ 4 cSt, Ei < 2.066
        - MRV not included
        - Average front and rear exhaust manifold temps should be within +/- 15 deg.C of the calibration test
        - Average power within +/- 10 kW of the calibration test
        - Average injection timing within +/- 1.5 deg of calibration test
        - Tests must be operationally valid with no negative QIs

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?



Engine Parameters (Difference from first run after rebuild)
Avg Power (kW)
Avg Front Exh. Man Temp (C)
Avg Rear Exh. Man Temp (C)
Avg Tailpipe Temp (C)
Avg Injection Timing (degrees BTDC)
Average Exhaust Co2 (%)
1st Run After Rebuild
2nd Run
3rd Run
4th Run
Rebuild #
1
2
3
4
5
6
7
8
9
10
11
12
13
14

Example of T-11 Acceptance Testing

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

- Single test stand

- Engine rebuild immediately prior to test sequence
    - No rebuilds during test sequence
    - Intent is to conduct all tests without replacement of major internal or external hardware.

- Conduct 1 calibration test using oil 822-2
    - Test must meet all LTMS calibration acceptance requirements
    - Calculate new Stand Zi value (Stand was an added word)

Example

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

Parameter	Current Stand Zi
Soot @ 4 cSt Viscosity Increase	-1.0
Soot @ 12 cSt Viscosity Increase	-0.5
Soot @ 15 cSt Viscosity Increase	-1.3

The stand runs a new calibration test on 822-2 using the current fuel. Based on the results, the following are the Yi and new Stand Zi values for each parameter:

Parameter	Yi for Calibration Test	New Stand Zi
Soot @ 4 cSt Viscosity Increase	-0.5	(0.3*-0.5)+(0.7*-1.0) = **-0.85**
Soot @ 12 cSt Viscosity Increase	-0.1	(0.3*-0.1)+(0.7*-0.5) = **-0.38**
Soot @ 15 cSt Viscosity Increase	-1.6	(0.3*-1.6)+(0.7*-1.3) = **-1.39**

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

- Conduct 2 tests on the alternate fuel using oil 822-2
    - Calculate Yi and Ei for these two tests. For both Ei values, use the Stand Zi which was calculated immediate following the calibration test on the current fuel.
    - Each test must meet the following criteria
        - For Soot @12cSt and Soot @15cSt, Ei < 1.734
        - For Soot @ 4 cSt, Ei < 2.066
        - MRV not included
        - Average front and rear exhaust manifold temps should be within +/- 15 deg.C of the calibration test
        - Average power within +/- 10 kW of the calibration test
        - Average injection timing within +/- 3 deg of calibration test
        - Tests must be operationally valid with no negative QIs

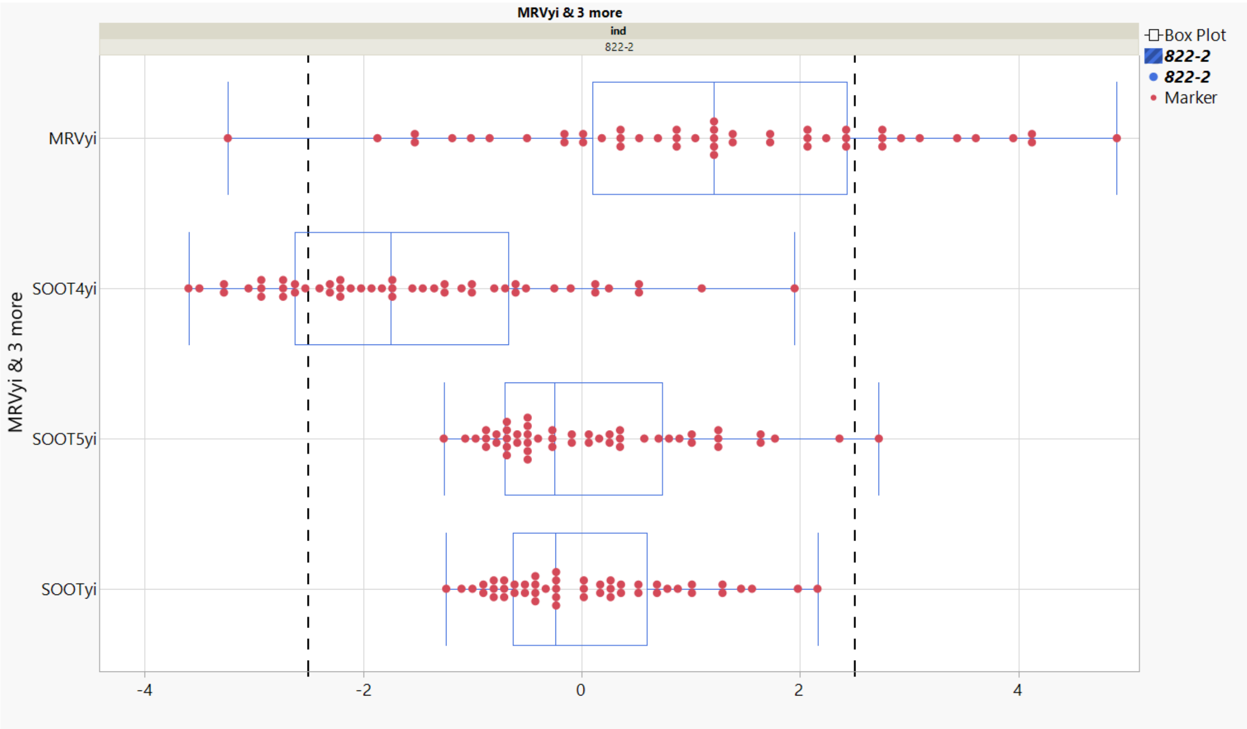
Example

The same stand now runs another test on oil 822-2, but using the alternative fuel. The Yi and Ei results for this first alternative fuel test are shown below.

Parameter	Yi for Alt. Fuel Test #1	Ei = Yi – Z(i-1)
Soot @ 4 cSt Viscosity Increase	-2.4	-2.4 – (-0.85) = **-1.55**
Soot @ 12 cSt Viscosity Increase	-2.0	-2.0 – (-0.38) = **-1.62**
Soot @ 15 cSt Viscosity Increase	-3.0	-3.0 – (-1.39) = **-1.61**

Assuming all operational data was acceptable, this first round of tests passes the statistical criteria, since Ei values are less than 1.734 for Soot @12cSt and Soot@15cSt and Ei is less than 2.066 for Soot @4cSt.

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. 20/49 fail this criteria for at least one parameter. Note that this data is limited to 822-2 only (reason shown later).



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

Parameter	Yi for Alt. Fuel Test #1	Ei = Yi – Z(i-1)
Soot @ 4 cSt Viscosity Increase	0.5	0.5 – (-0.85) = **1.35**
Soot @ 12 cSt Viscosity Increase	1.2	1.2 – (-0.38) = **1.58**
Soot @ 15 cSt Viscosity Increase	0.2	0.2 – (-1.39) = **1.59**

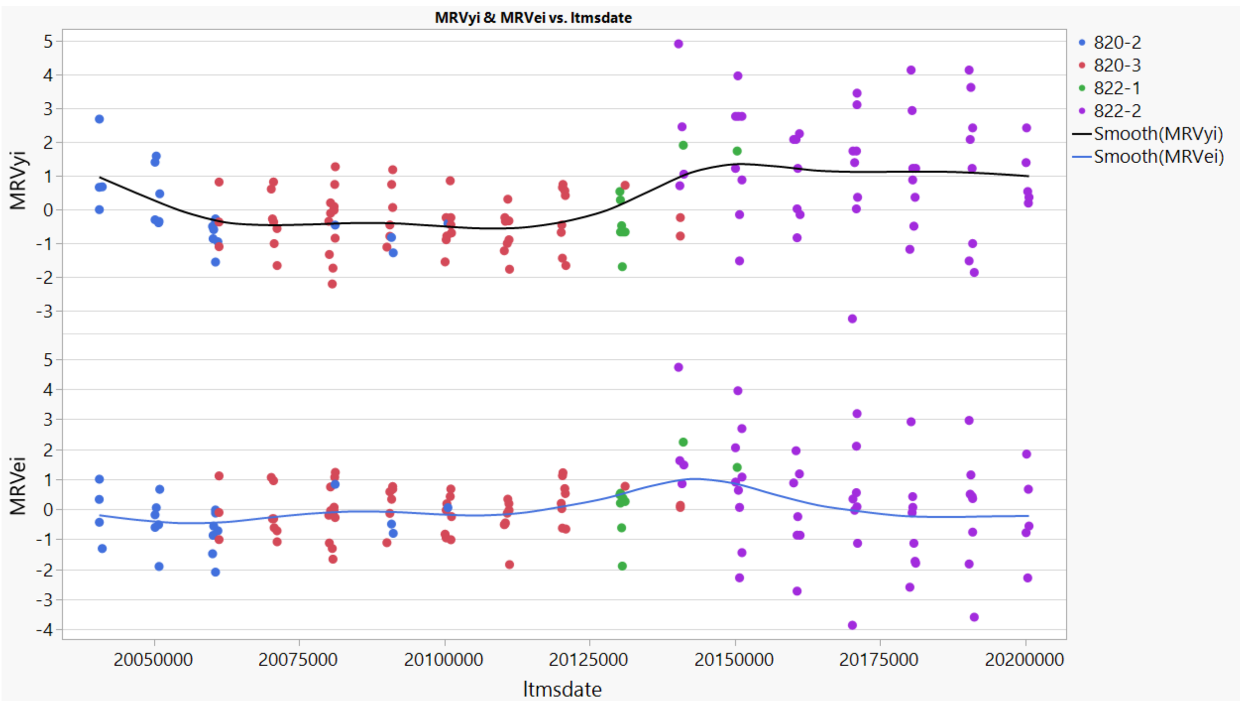
Assuming all operational data was acceptable, this second round of tests passes the statistical criteria, since Ei values are less than 1.734 for Soot @12cSt and Soot@15cSt and Ei is less than 2.066 for Soot @4cSt.

<u>Based on the two reference tests, the fuel meets the criteria set forth in the testing portion of the approval process.</u>

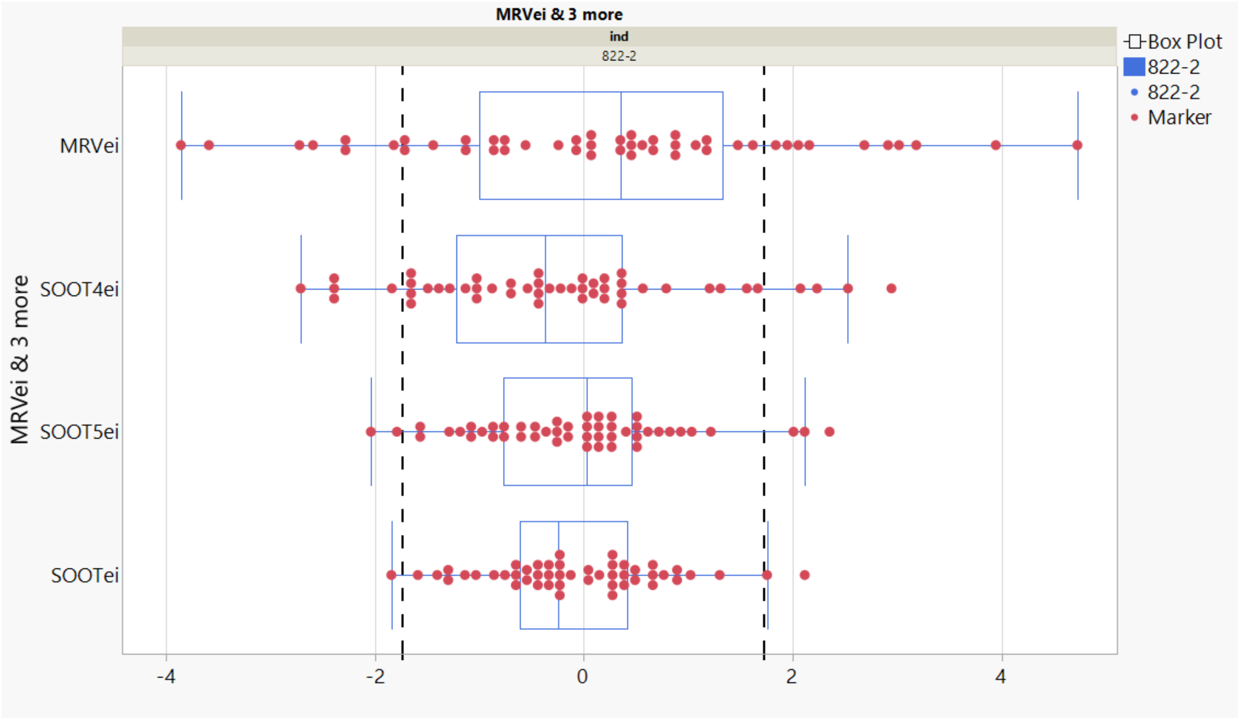
<u>Discussion:</u> This example is intended to start discussion on whether any precision monitoring is necessary. The two tests result on alternate fuel gave results which were about 3 sigma or more apart. It should be noted that newer test types which use level 2 ei limits for hardware approval traditionally 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.

Probability of Pass

To determine probability of pass, only data from oil 822-2 was used. This was mainly to accommodate an apparent changes in MRV performance with this oils introduction.



A plot of historical Ei values for 49 reference tests on oil 822-2 is shown below with the level 2 Ei limit:



<u>Probability of Passing the Ei Criteria of Ei < 1.734</u>

Parameter	Probability of 2 Tests w/ Ei < 1.734
Soot @ 4 cSt Viscosity Increase	67%
Soot @ 12 cSt Viscosity Increase	88%
Soot @ 15 cSt Viscosity Increase	81%
MRV Viscosity	40%
All Parameters	24%
All 3 Soot Parameters (No MRV)	54%

<u>Probability of Pass using Ei level 2 limit of 1.734 for Soot @ 12 cSt and Soot @15cSt and Ei level 3 limit of 2.066 for Soot @4cSt and MRV.</u>

Parameter	Probability of 2 Tests Meeting Ei Limit
Soot @ 4 cSt Viscosity Increase	70%
Soot @ 12 cSt Viscosity Increase	88%
Soot @ 15 cSt Viscosity Increase	92%
MRV Viscosity	54%
All 3 Soot Parameters (No MRV)	**57%**

Probability of Passing a Potential Yi Criteria of Yi < 2.5

Parameter	Probability of 2 Tests w/ Yi < 2.5
Soot @ 4 cSt Viscosity Increase	51%
Soot @ 12 cSt Viscosity Increase	100%
Soot @ 15 cSt Viscosity Increase	96%
MRV Viscosity	57%
All Parameters	35%
All 3 Soot Parameters (No MRV)	48%

Appendix – Relevant LTMS Information

T-11 LTMS Targets

SOOT @ 4.0 cSt VISCOSITY INCREASE
Unit of Measure: %
NONCRITICAL PARAMETER

Reference Oil	Mean	Standard Deviation
820-3	3.95	0.30
822-1	4.09	0.20
822-2	4.09	0.20

SOOT @ 12.0 cSt VISCOSITY INCREASE
Unit of Measure: %
CRITICAL PARAMETER

Reference Oil	Mean	Standard Deviation
820-3	5.92	0.22
822-1	5.81	0.50
822-2	5.81	0.50

SOOT @ 15.0 cSt VISCOSITY INCREASE
Unit of Measure: %
NONCRITICAL PARAMETER

Reference Oil	Mean	Standard Deviation
820-3	6.51	0.20
822-1	6.48	0.61
822-2	6.48	0.61

MRV VISCOSITY
Unit of Measure: cP
NONCRITICAL PARAMETER

Reference Oil	Mean	Standard Deviation
820-3	14981	916
822-1	13948	584
822-2	13948	584

T-11 LTMS Constants

LUBRICANT TEST MONITORING SYSTEM CONSTANTS

		EWMA Chart				Shewhart Chart	
		LAMBDA		K		K	
Chart Level	Limit Type	Precision	Severity	Precision	Severity	Precision	Severity
Stand	Reduced	--	--	--	--	--	1.43
	Action	0.3	0.3	1.74	2.05	1.74	1.75
Lab	Warning	0.2	--	1.74	--	--	--
	Action	0.2	0.2	2.58	1.96	1.74	1.75
Industry	Warning	0.2	0.2	1.74	2.05	--	--
	Action	0.2	0.2	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 = (LAMBDA) Y_i + (1 - LAMBDA) Z_{i-1}

where: $0 \leq$ LAMBDA ≤ 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 (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).

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