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***COMMITTEE D02 ON PETROLEUM PRODUCTS, LIQUID FUELS, AND LUBRICANTS***

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Issued: 02.28.2017
Reply to: Dan Worcester
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These are the unapproved minutes of the 02.23.2017 Sequence VI Meeting.



The meeting was called to order at 8:30 AM Central Time by Chair Greg Miranda.

Agenda

The Agenda is the included as Attachment 1.

1.0 Roll Call

The Attendance list is Attachment 2.

2. **Approval of Meeting minutes from 02.16.2017 Seq. VI SP conference call.**

Approve the Surveillance Panel minutes.

2.1 Greg made the motion and Rich seconded.

2.2 The vote received unanimous approval.

3. **Old Business and Update Item Review**

3.1 VIE/F Hardware taskforce update

One dependent lab has a calibrated VID stand. The VID test is unavailable at the two independent labs. This will make oils provisional. The industry will need to run the VIE to VID equivalency matrix. Jim Linden noted the 0W-16 is also provisional and Charlie commented that the API should send a memo related to the VID test no longer being available.

3.2 Industry Update Greg Miranda

The GM Kit order letter has gone to labs. Labs would need to provide space to run a matrix to prove out the engine response. The Stat group will provide a matrix and the recommendation on when to move forward with testing. Current plans are for all labs to switch to kit engines the summer of 2017.

**Action 1:** Stat Group will provide VIE short block testing matrix.

3.3 Seq. VIF PM Analysis & LTMS Discussions All

3.3.1 Review updated Seq. VIF Precision Matrix analysis

The presentation is included as Attachment 3. The Stat Group did a review for 5 tests per engine from the Precision Matrix, and 4 tests run by a dependent lab. Reference Oil 543 does not show an engine hour correction response. Changing to 5 tests does modify the engine hour equations, and those are now:

FEI1 = 0.000252*(ENHREND –776) + FEI1_Original

FEI2 = 0.000135*(ENHREND –776) + FEI2_Original

3.3.2 Review Seq. VIF LTMS Requirements

Kevin recommended the VIE format will be followed for test hours and engine life. There was discussion on 6 runs per engine. Labs need to continue to gather data and run a 5$^{th}$ donated test on each engine as is being done on the VIE. Runs may focus on 543 and 1011 to gather more data. The 1$^{st}$, 2$^{nd}$ and 5$^{th}$ runs on engines will provide additional data.

**Motion 1:** Next three Seq. VIF engines at each lab will conduct a 5th run reference test with analysis to be completed after the 5th reference test is reported. TMC will not assign Seq. VIF reference oils for a new engine on the same stand until the 5th test is reported to the TMC on the prior engine, unless a documented reason is provided for not conducting that 5th run test. Stats group will provide guidance to TMC on selection of reference oil assignment.

Robert Stockwell, Second: Jim Linden Result: 13-0-0 Motion Passes

3.3.2 Review Seq. VIF LTMS Requirements

The presentation is included as Attachment 4. There was discussion on more focus on 1011, but the consensus was to use 3 oils in random assignments. There was also discussion on how to introduce a new lab. This will be more critical on the VIF as only 2 labs participated in the Precision Matrix. Motion #4 covers this issue, and a lab would donate testing. There should be back to back valid acceptable reference oil passes. Effective date would be two weeks from this meeting.

**Action 2:** Stats group will recommend to TMC testing for next 3 VIF engines in each lab

**Motion 2:** That the SP accepts the four test LTMS requirements presented on 2/23/17 for the Seq. VIF procedure (VIF-LTMS-02-21-17-4-OR-5-Run-LTMS.pdf). Seq. VIF calibration period will adopt the same method as the Seq. VIE procedure.

Charlie Leverett, Second Rich Grundza Result: 13-0-0 Motion Passes

**Motion 3:** Set the Sequence VIF reference oil assignment protocol at equal proportion with random assignment for all three reference oils (1011, 542-2, 543).

Rich Grundza, Second Robert Stockwell Result: 13-0-0 Motion Passes

**Motion 4**: For a new lab (defined as a lab that did not participate in the precision matrix) to be calibrated, the lab must run four operationally valid tests on multiple reference oils, to be assigned by the TMC, in a single engine and stand combination, with at least one replicated reference oil, and with a minimum of two consecutive results that meet the acceptance criteria of the defined LTMS.

Rich Grundza, Robert Stockwell Result: 10-0-3 Motion Passes

3.3.3 Finalize Seq. VIF LTMS Requirements

Adoption of weighting factors & SAs
Acceptance limits
LS means, standard deviations for calculated Yi, and pooled standard deviations for SAs

**Motion 5**: Official Sequence VIF calibration will start on 3/9/2017 for stand-engine combinations that have completed calibration testing following criteria established in the Sequence VIF LTMS document and using the Sequence VIF current test procedure and associated surveillance panel meeting minutes.

Greg Miranda, Second: Adrian Alfonso  Result: 13-0-0 Motion Passes

There will need to be work on the VIF procedure. Dan Worcester will be the Task Force Leader to update using the VIE version currently out for ballot. TMC will also need to add the VIF to the main LTMS document. There was also discussion that the VIE calibration requirements in the procedure need to be modified. This will be with an Information Letter. There was also discussion on whether a lab could run an additional 50 hours of break in and start a new reference as if it were a new engine. A stand will usually be calibrated as either a VIE or VIF due to the referencing and hours requirements on an engine.

3.3.4 Additional Seq. VIF Items
Establish date of stand/engine calibration
RO selection

**Action 3:** Update VIF LTMS requirements document - TMC
**Action 4:** Incorporate changes into VIF procedure; Task force – Led by Dan Worcester
Hap will be the facilitator for the VIF procedure.
**Action 5:** Rich & Greg will issue information letter to correct VIE calibration requirement

**Motion 6:** A lab may run a minimum of an additional 50 hours of break-in to reset engine-stand calibration, effectively voiding prior tests on that engine-stand combination in calibration determination.

Adrian Alfonso, Second: Rich Grundza  Result: 13-0-0 Motion Passes

**Motion 7:** Sequence VIF LTMS industry control charts will consist of EWMA of the Yi results, using Lambda of 0.2 and level 1 alarm at +/- 0.859 with an action for the TMC to inform the surveillance panel that the limit has been exceeded, and the surveillance panel then investigates and pursues resolution of the alarm. Zo for the industry charts will be the average of the first three valid tests.

Dan Worcester, Second: Jim Linden  Result: 13-0-0 Motion Passes

Discussion was on how to include MTAC [multiple test acceptance criteria]. This was done on the VIE but is actually a Class Panel action.

**Motion 8:** The Sequence VI surveillance panel recommends to the PCEOCP that MTAC would be appropriate to handle replicate candidate tests in the Sequence VIF.

Jo Martinez; Second: Doyle Boese Results: 13-0-0 Motion Passes

**Motion 9:** The Sequence VI surveillance panel, having established severity and precision control charting via an LTMS system, having established test stand/engine calibration and reference periods, having secured sources for test parts, fuel and reference oils, having identified parameters that may be used for pass-fail criteria, having an up-to-date test procedure (in progress) and having established continuous surveillance as noted in the Scope and Objectives of the Sequence VI surveillance panel, hereby wishes to inform the Passenger Car Engine Oil Classification Panel, the Auto Oil Advisory Panel and the American Chemistry Council PAPTG, that the Sequence VIF test is ready for inclusion in ILSAC oil category GF-6B.

Greg Miranda; Second: Rich Grundza Result: 13-0-0 Motion Passes.

**Action 6:** Add VIF to Seq VI Surveillance Panel scope and objectives – Greg

3.3.5 Appendix K Template Review

The group went through Appendix K and updated responses.

**4. New Business**

4.1 Sequence VIE Test Severity Review

See Attachment 5. Some recent VIE tests have had the engine abandoned. This data is not included in TMC file, but is included in the presentation. There has been a response shift since the Precision Matrix, especially for FEI 2. No root cause has been found at this point. Oil 1010-1 is more severe than the other two reference oils. There has not been a reference run above the target zero line [mild]. All labs have shifted but some more severely than others. The offset is about 0.2. Discrimination has been lost, especially for FEI 2. There may be some client input on test response for candidate oils.

**Action 7:** Test sponsors to provide data/feeling regarding VIE severity

4.2 Approval of BL-5

We will need to run the matrix to compare BL-2 to BL-5. Rich has sent BL-2 to Intertek and SwRI for this testing. There is a stash of BL-4 and BL-5 at TMC.

**Action 7:** Rich survey labs for status of current VIE calibrated stands for BL5

4.3 Approval of 542 Re-blend

There are 80 gallons of 542-2 remaining. TMC would need to issue 542-3 for references at labs.

**5.0 Next Meeting.**

5.1 The next meeting will be a conference call in 3 weeks. Greg will send an agenda.

The meetings adjourned at 3:32 PM.

**Sequence VI Surveillance Panel Face-To-Face Meeting Agenda**
**February 23, 2017 @ 08:00-17:00 CST**

**Meeting Location**

Intertek Automotive Research
5404 Bandera Road
San Antonio, TX 78238

**Audio Connection**

Call-in Number: +1-415-655-0001
Conference Code: 198 127 665

**Webex Meeting URL:**
https://meetings.webex.com/collabs/#/meetings/detail?uuid=MAMABN539PV9O5U3JPKQPSQXZF-20XT&rnd=891359.45502

1. **Roll Call (08:30 – 08:40)**

   *1.1. SP Membership changes and additions*

2. **Approval of Meeting minutes from February 16, 2017 Seq. VI SP meeting**

3. **Old Business**

| | | | |
|---|---|---|---|
| 3.1 | 08:45 – 09:00 | VIE/F Hardware taskforce update | Adrian Alfonso |
| 3.2 | 09:00 – 09:15 | Industry Update<br>• Efforts to extend life of VID procedure<br>• VID calibrated Status at dependent lab<br>• Test Unavailable at independent labs | Greg Miranda |
| 3.3 | | Seq. VIF PM Analysis & LTMS Discussions | All |
| 3.3.1 | 09:15 – 10:00 | Review updated Seq. VIF Precision Matrix analysis | |
| 3.3.2 | 10:00 – 10:30 | Review Seq. VIF LTMS Requirements | |
| | 10:30 – 10:45 | *******************BREAK********************* | |
| 3.3.3 | 10:45 – 12:00 | Finalize Seq. VIF LTMS Requirements<br>• Adoption of weighting factors & SAs<br>• acceptance limits<br>• LS means, standard deviations for calculated Yi, and pooled standard deviations for SAs | |

| | | | |
|---|---|---|---|
| | | • Stand/engine calibration requirements<br>• etc. | |
| | 12:00 – 13:00 | ********************LUNCH********************* | |
| 3.3.4 | 13:00 – 14:00 | <u>Finalize Seq. VIF LTMS Requirements:</u><br><br>***Continued*** | |
| 3.3.5 | 14:00 – 15:00 | <u>Additional Seq. VIF Items</u><br>• Establish date of stand/engine calibration<br>• RO selection<br>• etc. | |
| | 15:00 – 15:15 | ********************BREAK********************* | |
| 3.3.6 | 15:15 – 16:30 | Appendix K Template Review | TBD |
| 3.3.7 | 16:30 – 16:45 | Seq. VIF Procedural Document Discussion and plan for update and finalization | |

**4. New Business Items (Time Permitting)**

*4.1. Sequence VIE Test Severity Review*

**5. Next Meeting**

5.1. TBD

**6. Meeting Adjourned**

**Motion 1:** Next three Seq. VIF engines at each lab will conduct a 5th run reference test with analysis to be completed after the 5th reference test is reported. TMC will not assign Seq. VIF reference oils for a new engine on the same stand until the 5th test is reported to the TMC on the prior engine, unless a documented reason is provided for not conducting that 5th run test. Stats group will provide guidance to TMC on selection of reference oil assignment.

Robert Stockwell, Second: Jim Linden

Result: 13-0-0 Motion Passes

**Motion 2:** That the SP accepts the four test LTMS requirements presented on 2/23/17 for the Seq. VIF procedure (VIF-LTMS-02-21-17-4-OR-5-Run-LTMS.pdf). Seq. VIF calibration period will adopt the same method as the Seq. VIE procedure.

Charlie Leverett, Second Rich Grundza

Result: 13-0-0 Motion Passes

**Motion 3:** Set the Sequence VIF reference oil assignment protocol at equal proportion with random assignment for all three reference oils (1011, 542-2, 543).

Rich Grundza, Second Robert Stockwell

Result: 13-0-0 Motion Passes

**Motion 4**: For a new lab (defined as a lab that did not participate in the precision matrix) to be calibrated, the lab must run four operationally valid tests on multiple reference oils, to be assigned by the TMC, in a single engine and stand combination, with at least one replicated reference oil, and with a minimum of two consecutive results that meet the acceptance criteria of the defined LTMS.

Rich Grundza, Robert Stockwell

Result: 10-0-3 Motion Passes

**Motion 5**: Official Sequence VIF calibration will start on 3/9/2017 for stand-engine combinations that have completed calibration testing following criteria established in the Sequence VIF LTMS document and using the Sequence VIF current test procedure and associated surveillance panel meeting minutes.

Greg Miranda, Second: Adrian Alfonso

Result: 13-0-0 Motion Passes

**Motion 6:** A lab may run a minimum of an additional 50 hours of break-in to reset engine-stand calibration, effectively voiding prior tests on that engine-stand combination in calibration determination.

Adrian Alfonso, Second: Rich Grundza

Result: 13-0-0 Motion Passes

**Motion 7:** Sequence VIF LTMS industry control charts will consist of EWMA of the Yi results, using Lambda of 0.2 and level 1 alarm at +/- 0.859 with an action for the TMC to inform the surveillance panel that the limit has been exceeded, and the surveillance panel then investigates and pursues resolution of the alarm. Zo for the industry charts will be the average of the first three valid tests.

Dan Worcester, Second: Jim Linden

Result: 13-0-0 Motion Passes

**Motion 8:** The Sequence VI surveillance panel recommends to the PCEOCP that MTAC would be appropriate to handle replicate candidate tests in the Sequence VIF.

Jo Martinez; Second: Doyle Boese

Results: 13-0-0 Motion Passes

**Motion 9:** The Sequence VI surveillance panel, having established severity and precision control charting via an LTMS system, having established test stand/engine calibration and reference periods, having secured sources for test parts, fuel and reference oils, having identified parameters that may be used for pass-fail criteria, having an up-to-date test procedure (in progress) and having established continuous surveillance as noted in the Scope and Objectives of the Sequence VI surveillance panel, hereby wishes to inform the Passenger Car Engine Oil Classification Panel, the Auto Oil Advisory Panel and the American Chemistry Council PAPTG, that the Sequence VIF test is ready for inclusion in ILSAC oil category GF-6B.

Greg Miranda; Second: Rich Grundza

Result: 13-0-0 Motion Passes.

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**ASTM SEQUENCE VI**

| Name | Email/Phone | Company | Attend |
|---|---|---|---|

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|---|---|---|---|
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| MOTION: | #1 5 Run Review | #2 VIF LTMS | #3 Oils | #4 New Lab |
|---|---|---|---|---|
| Adrian Alfonso **Voting Member** | APPROVE | APPROVE | APPROVE | APPROVE |
| Jason Bowden **Voting Member** | APPROVE | APPROVE | APPROVE | WAIVE |
| Amol Savant **Voting Member** | APPROVE | APPROVE | APPROVE | WAIVE |
| Tim Cushing **Voting Member** | APPROVE | APPROVE | APPROVE | APPROVE |
| Rich Grundza **Voting Member** | APPROVE | APPROVE | APPROVE | WAIVE |
| Jeff Hsu **Voting Member** | APPROVE | APPROVE | APPROVE | APPROVE |
| Teri Kowalski [JL] **Voting Member** | APPROVE | APPROVE | APPROVE | APPROVE |
| Dan Lanctot **Voting Member** | | | | |
| Greg Miranda **Voting Member** | APPROVE | APPROVE | APPROVE | APPROVE |
| Katerina Pecinovsky **Voting Member** | APPROVE | APPROVE | APPROVE | APPROVE |
| Brianne Pentz **Voting Member** | | | | |
| Andy Ritchie [CL] **Voting Member** | APPROVE | APPROVE | APPROVE | APPROVE |
| Ron Romano **Voting Member** | | | | |
| Clifford Salvesen **Voting Member** | APPROVE | APPROVE | APPROVE | APPROVE |
| Kaustav Sinha [RS]**Voting Member** | APPROVE | APPROVE | APPROVE | APPROVE |
| Haiying Tang **Voting Member** | | | | |
| Dan Worcester **Voting Member** | APPROVE | APPROVE | APPROVE | APPROVE |
| VOTES | 13-0-0 | 13-0-0 | 13-0-0 | 10-0-3 |

**ASTM SEQUENCE VI**

| Name | Email/Phone | Company | Attend |
|---|---|---|---|

| MOTION: | #5 VIF Start | #6 Break In 50 | #7 EWMA | #8 MTAC |
|---|---|---|---|---|
| Adrian Alfonso<br>**Voting Member** | APPROVE | APPROVE | APPROVE | APPROVE |
| Jason Bowden<br>**Voting Member** | APPROVE | APPROVE | APPROVE | APPROVE |
| Amol Savant<br>**Voting Member** | APPROVE | APPROVE | APPROVE | APPROVE |
| Tim Cushing<br>**Voting Member** | APPROVE | APPROVE | APPROVE | APPROVE |
| Rich Grundza<br>**Voting Member** | APPROVE | APPROVE | APPROVE | APPROVE |
| Jeff Hsu<br>**Voting Member** | APPROVE | APPROVE | APPROVE | APPROVE |
| Teri Kowalski<br>**Voting Member** | APPROVE | APPROVE | APPROVE | APPROVE |
| Dan Lanctot<br>**Voting Member** | | | | |
| Greg Miranda<br>**Voting Member** | APPROVE | APPROVE | APPROVE | APPROVE |
| Katerina Pecinovsky<br>**Voting Member** | APPROVE | APPROVE | APPROVE | APPROVE |
| Brianne Pentz<br>**Voting Member** | | | | |
| Andy Ritchie<br>**Voting Member** | APPROVE | APPROVE | APPROVE | APPROVE |
| Ron Romano<br>**Voting Member** | | | | |
| Clifford Salvesen<br>**Voting Member** | APPROVE | APPROVE | APPROVE | APPROVE |
| Kaustav Sinha<br>**Voting Member** | APPROVE | APPROVE | APPROVE | APPROVE |
| Haiying Tang<br>**Voting Member** | | | | |
| Dan Worcester<br>**Voting Member** | APPROVE | APPROVE | APPROVE | APPROVE |
| VOTES | 13-0-0 | 13-0-0 | 13-0-0 | 13-0-0 |

**ASTM SEQUENCE VI**

| Name | Email/Phone | Company | Attend |
|---|---|---|---|

| **MOTION:** | **#9 PCEOCP** | | | |
|---|---|---|---|---|
| Adrian Alfonso **Voting Member** | APPROVE | | | |
| Jason Bowden **Voting Member** | APPROVE | | | |
| Amol Savant **Voting Member** | APPROVE | | | |
| Tim Cushing **Voting Member** | APPROVE | | | |
| Rich Grundza **Voting Member** | APPROVE | | | |
| Jeff Hsu **Voting Member** | APPROVE | | | |
| Teri Kowalski **Voting Member** | APPROVE | | | |
| Dan Lanctot **Voting Member** | | | | |
| Greg Miranda **Voting Member** | APPROVE | | | |
| Katerina Pecinovsky **Voting Member** | APPROVE | | | |
| Brianne Pentz **Voting Member** | | | | |
| Andy Ritchie **Voting Member** | APPROVE | | | |
| Ron Romano **Voting Member** | | | | |
| Clifford Salvesen **Voting Member** | APPROVE | | | |
| Kaustav Sinha **Voting Member** | APPROVE | | | |
| Haiying Tang **Voting Member** | | | | |
| Dan Worcester **Voting Member** | APPROVE | | | |
| VOTES | 13-0-0 | | | |

# VIF Precision Matrix Analysis (with 5th runs, n=21)

Statistics Group

Date: February 23, 2017

# Statistics Group

- Arthur Andrews, ExxonMobil
- Doyle Boese, Infineum
- Jo Martinez, Chevron Oronite
- Kevin O'Malley, Lubrizol
- Martin Chadwick, Intertek
- Richard Grundza, TMC
- Lisa Dingwell, Afton
- Todd Dvorak, Afton
- Travis Kostan, SwRI

# Data for Analysis

- 21 tests considered
- Analysis includes 3 tests in addition to the tests included in *VIF Precision Matrix Statistical Analysis n=18 2-16-17.pptx*
  - Testkeys: 113231, 117508, 117512

| Run Order | EOT Engine Hours | SwRI #1 | | SwRI #2 | | IAR #1 | | IAR #2 | |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 350 | Stage 1 Sense Check | 543 112952-VIF | Stage 2 Sense Check | 1011 112953-VIF | Stage 1 Sense Check | 542-2 112957-VIF | Stage 2 Sense Check | 1011 112955-VIF Baseline Shift |
| 2 | 550 | | 542-2 112951-VIF | | 542-2 116037-VIF | | 543 112958-VIF | | 543 113824-VIF |
| 3 | 750 | | 542-2 113818-VIF | | 1011 112954-VIF | | 543 113823-VIF | | 1011 112956-VIF |
| 4 | 950 | | 543 113819-VIF | | 543 113820-VIF | | 542-2 113822-VIF EBP Calibration Shift<br>542-2 113231-VIF | | 542-2 116030-VIF |
| 5 | 1150 | 1011 117508-VIF | | 543 113821-VIF Worn Throttle Controller<br>543 117512-VIF | | 1011 116832-VIF | | 542-2 116031-VIF Baseline Shift | |
| 6 | 1350 | 543 117626-VIF | | 1011 117509-VIF | | 543 113825-VIF | | 1011 117495-VIF | |
| 7 | 1550 | 542-2 116038-VIF | | 542-2 117511-VIF | | 1011 117496-VIF | | 543 117494-VIF | |
| 8 | 1750 | 1011 117510-VIF | | | | 542-2 117493-VIF | | | |

Excluded From Analysis

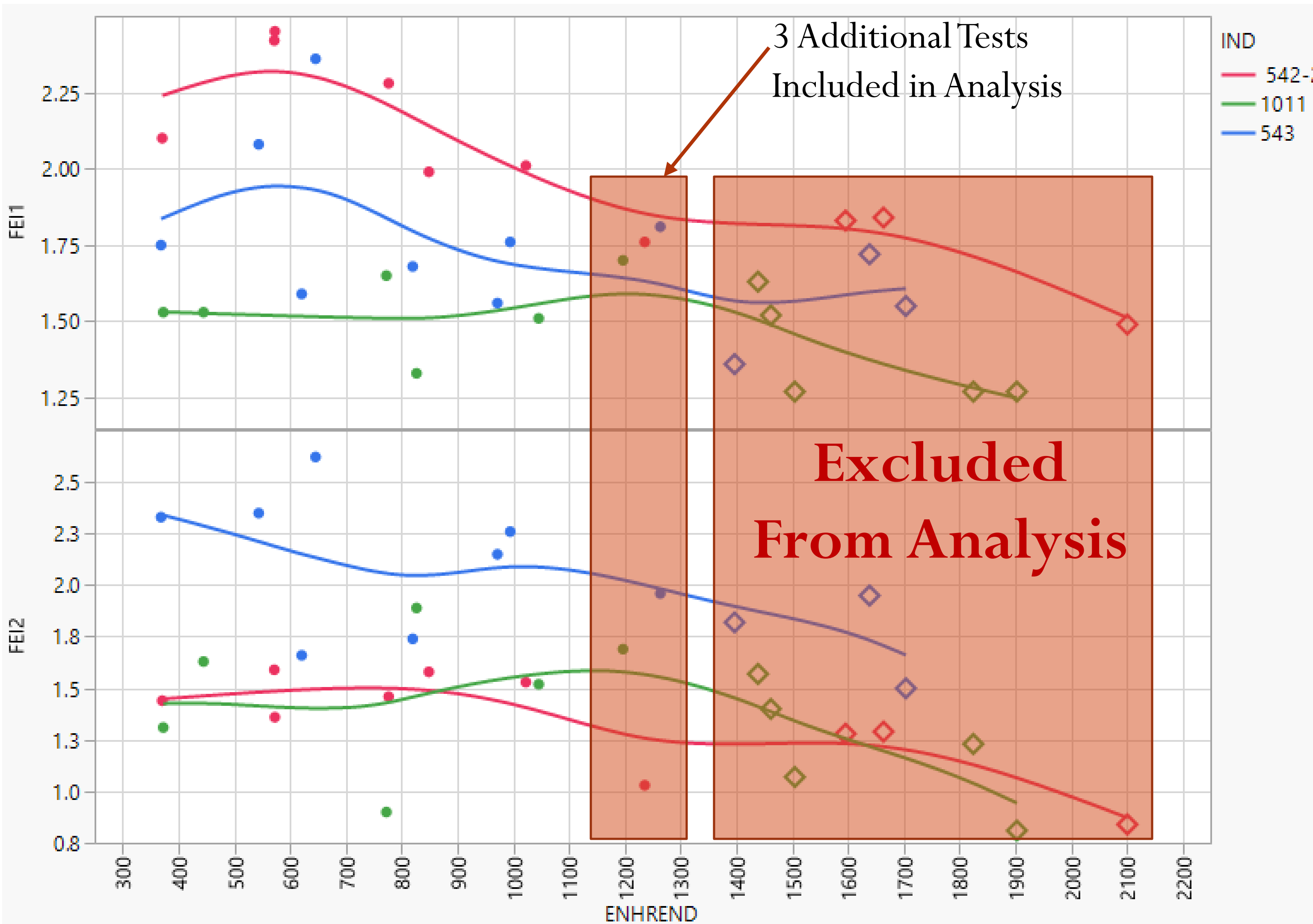
| LZ | |
|---|---|
| Additional Testing | 1011 118268-VIF |
| | 543 118267-VIF |
| | 542-2 119631-VIF |
| | 1011 119628-VIF |

Test Reported | Under Review | Invalid

- Table is from Frank Faber's 6-21-16 matrix update plus 4 additional tests

# Data for Analysis

- FEI1_OR and FEI2_OR:

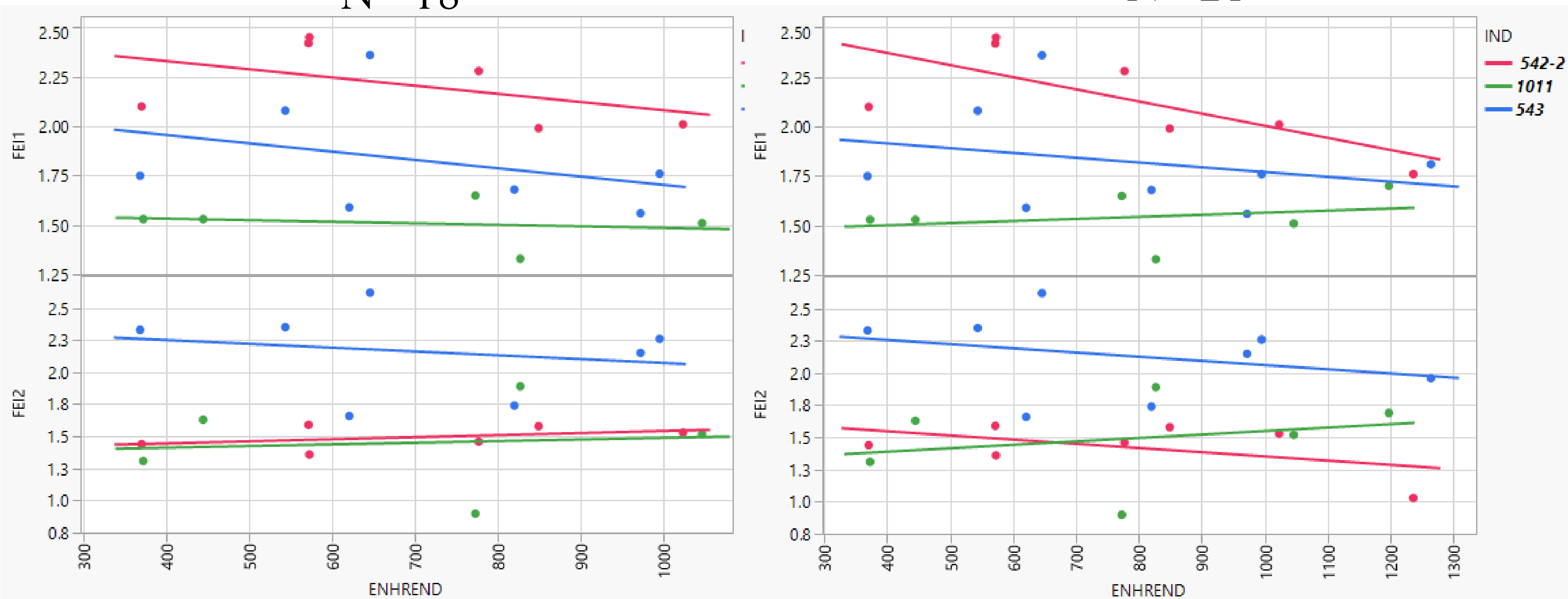


# Data for Analysis

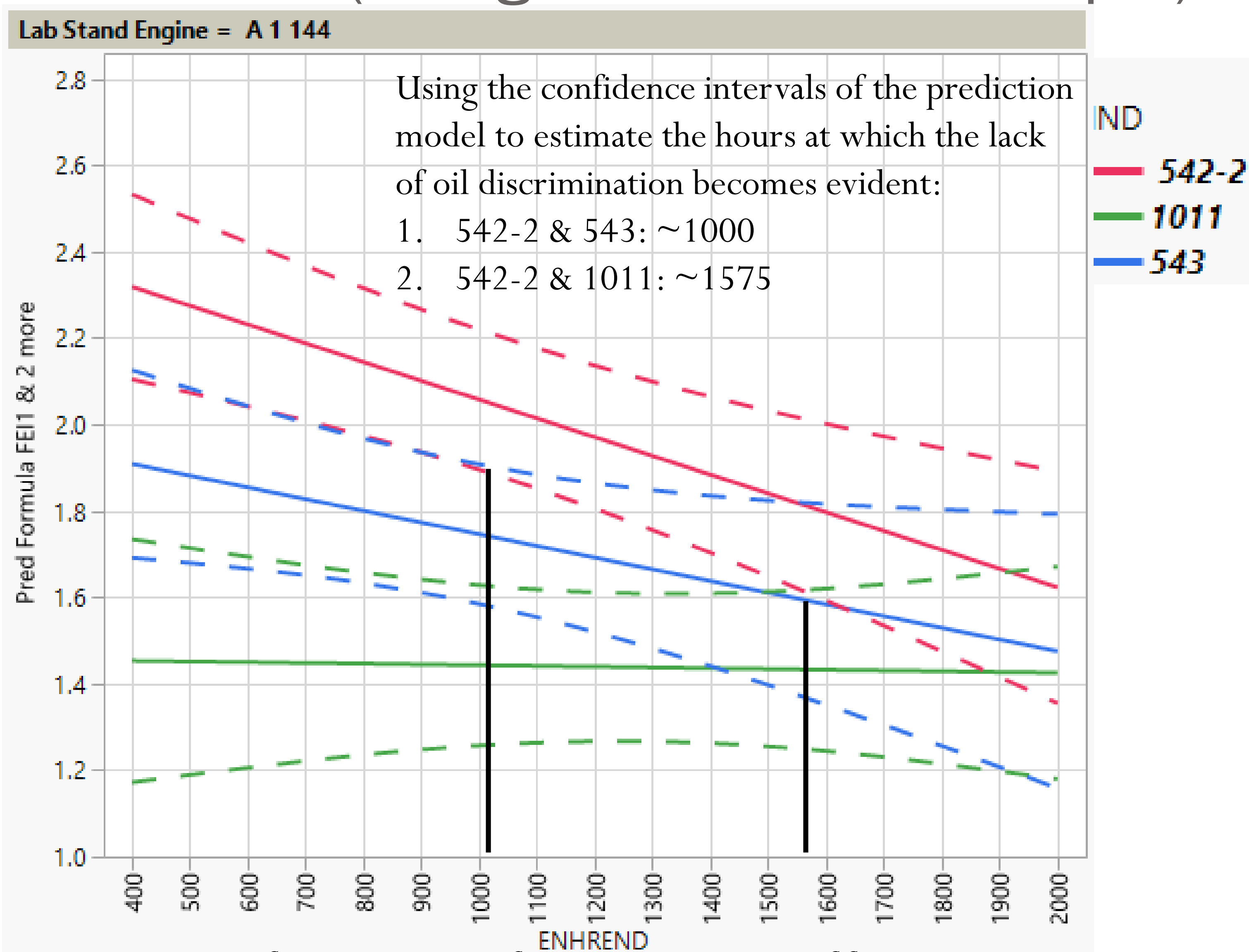
- FEI1_OR and FEI2_OR:

N=18

N=21

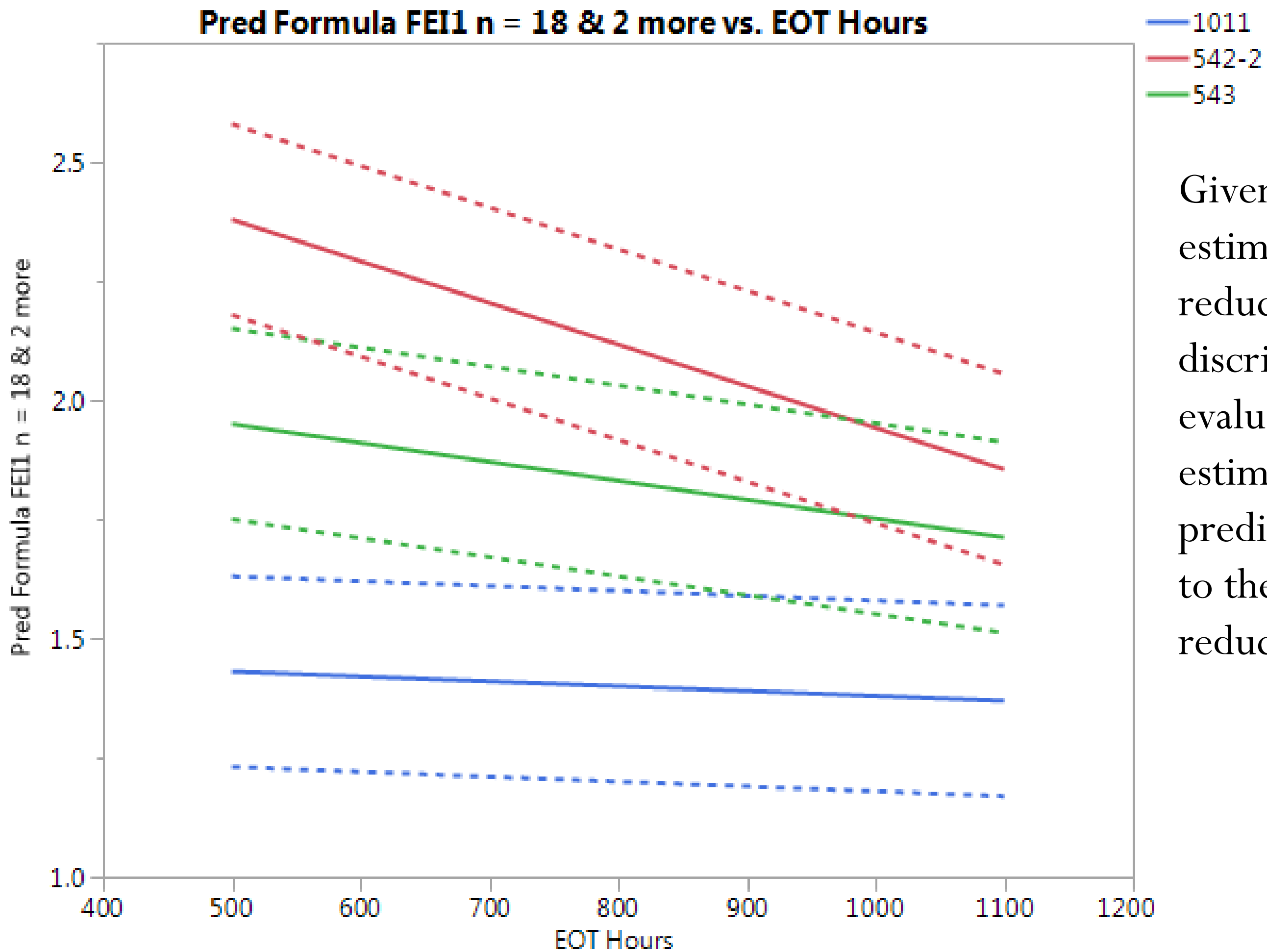


# Assess Engine Life Based on Oil Discrimination n = 32 FEI1 (Using A 144 as an example)




*Refer to VIF Engine Life Analysis 11-29-16.pdf for more detail.*

# Assess Engine Life Based on Oil Discrimination n = 18 FEI1 (Using A 144 as an example)

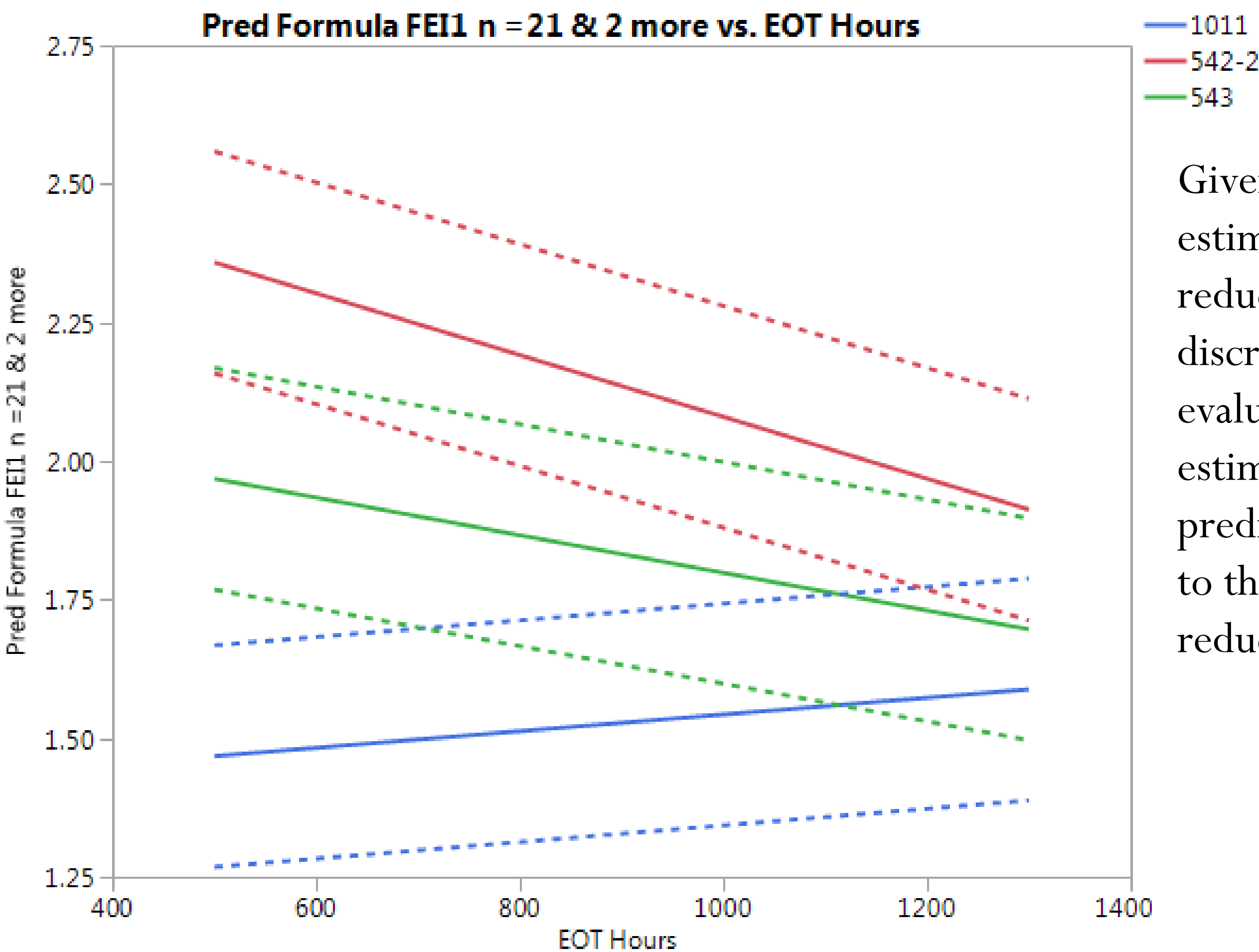



Given the change in the estimated slopes by oil in the reduced dataset, oil discrimination can be evaluated by applying the estimated error from the prediction model with n=32 to the estimated slopes in the reduced dataset.

Utilized a confidence interval half width of 0.2 to enable contrast with full dataset plot.

Refer to *VIF Engine Life Analysis 11-29-16.pdf* for more detail.

# Assess Engine Life Based on Oil Discrimination n = 21 FEI1 (Using A 144 as an example)




Given the change in the estimated slopes by oil in the reduced dataset, oil discrimination can be evaluated by applying the estimated error from the prediction model with n=32 to the estimated slopes in the reduced dataset.

Utilized a confidence interval half width of 0.2 to enable contrast with full dataset plot.

Refer to *VIF Engine Life Analysis 11-29-16.pdf* for more detail.

# Executive Summary

- Comparison of N=18 and N=21 Analyses:

| | N=18 | N=21 |
|---|---|---|
| Engine Hours Transformation | None | None |
| Oil Discrimination | FEI1: 542-2 > 543 > 1011<br>FEI2: 543 > (542-2 & 1011) | FEI1: 542-2 > 543 > 1011<br>FEI2: 543 > (542-2 & 1011) |
| Lab differences | No significant Difference (marginal for FEI2) | No significant Difference (marginal for FEI2) |
| Engine Differences | FEI2: G58 < G96 | FEI2: G58 < G96; A122 < A144 |
| Engine Hours Adjustment | FEI1 = FEI1_OR + 0.000403*(ENHREND – 700)<br>FEI2 = FEI2_OR + 0.000293*(ENHREND – 700) | FEI1 = FEI1_OR + 0.000252*(ENHREND – 776)<br>FEI2 = FEI2_OR + 0.000135*(ENHREND – 776) |
| Estimated within engine test precision | FEI1 = 0.21; FEI2 = 0.19 | FEI1 s: 0.21; FEI2 s: 0.18 |
| Estimated test precision across labs and engines | FEI1 = 0.22; FEI2 = 0.30 | FEI1 s: 0.22; FEI2 s: 0.29 |

# Executive Summary

- Comparison of N=18 and N=21 Analyses:
  - Oil targets, oil standard deviations, and test precision estimates:
  - N=18

| | Target | | Standard Deviation | | $S_{repeatability}$ | | $S_{reproducibility}$ | |
|---|---|---|---|---|---|---|---|---|
| Oil | FEI1 | FEI2 | FEI1 | FEI2 | FEI1 | FEI2 | FEI1 | FEI2 |
| 542-2 (n=6) | 2.23 | 1.52 | 0.18 | 0.13 | 0.21 | 0.19 | 0.22 | 0.30 |
| 1011 (n=5) | 1.45 | 1.41 | 0.14 | 0.39 | 0.21 | 0.19 | 0.22 | 0.30 |
| 543 (n=7) | 1.88 | 2.25 | 0.27 | 0.34 | 0.21 | 0.19 | 0.22 | 0.30 |

  - N=21

| | Target | | Standard Deviation | | $S_{repeatability}$ | | $S_{reproducibility}$ | |
|---|---|---|---|---|---|---|---|---|
| Oil | FEI1 | FEI2 | FEI1 | FEI2 | FEI1 | FEI2 | FEI1 | FEI2 |
| 542-2 (n=7) | 2.18 | 1.49 | 0.20 | 0.18 | 0.21 | 0.18 | 0.22 | 0.29 |
| 1011 (n=6) | 1.50 | 1.47 | 0.17 | 0.36 | 0.21 | 0.18 | 0.22 | 0.29 |
| 543 (n=8) | 1.85 | 2.23 | 0.26 | 0.32 | 0.21 | 0.18 | 0.22 | 0.29 |

# Appendix 1

VIF Analysis Details (N=21)

# Review Data for Analysis

- Data summary:
  - 3 Labs {A, G, B}
  - 3 Reference Oils {1011, 542-2, 543}
  - 5 Engines {58 & 96 at Lab G; 122 & 144 at Lab A; 306 at Lab B}

- 36 tests were considered; 21 were included in this analysis
  - These 21 valid tests have ENHREND < 1300

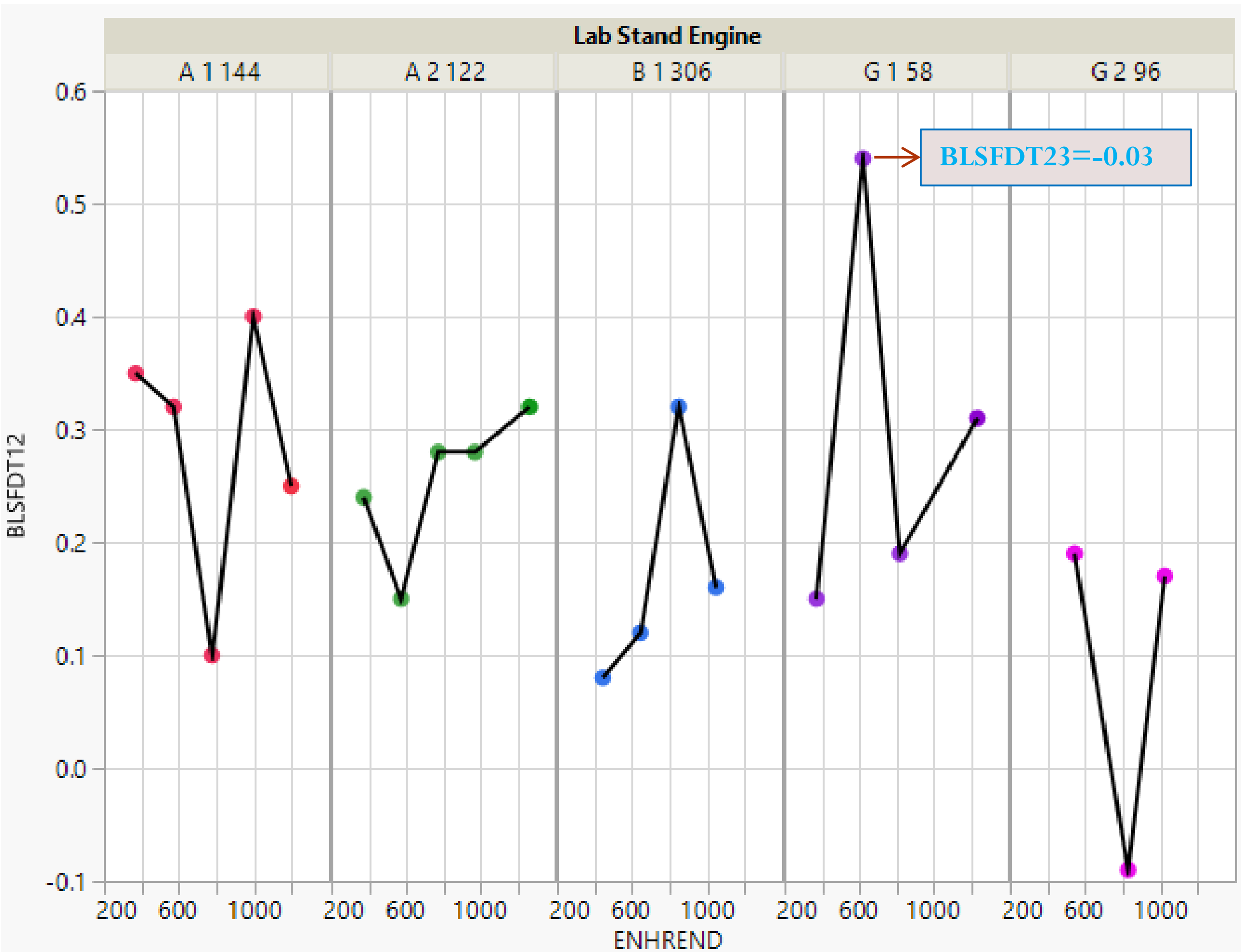
# Data for Analysis

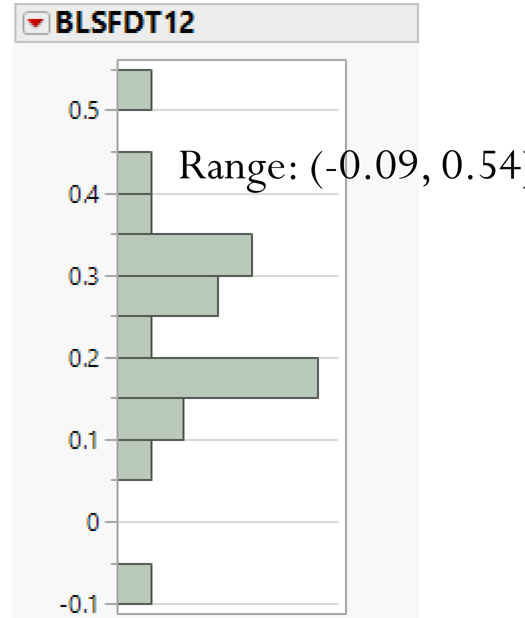
- Average engine hour age[1]:
  - Average EngHrs = 776

| LTMSLAB | ENGNO | Average ENHREND | Max ENHREND |
|---|---|---|---|
| A | 122 | 791 | 1264 |
| A | 144 | 782 | 1197 |
| G | 58 | 762 | 1236 |
| G | 96 | 798 | 1023 |
| B | 306 | 747 | 1046 |

*[1]For reference: VID Ln(EngHrs) = 7.37 ($e^{7.37}$ = 1598 hours)*
*VIE ENHREND = 675 Hours*

# BL SHIFT % DELTA, BLB1 VS BLB2



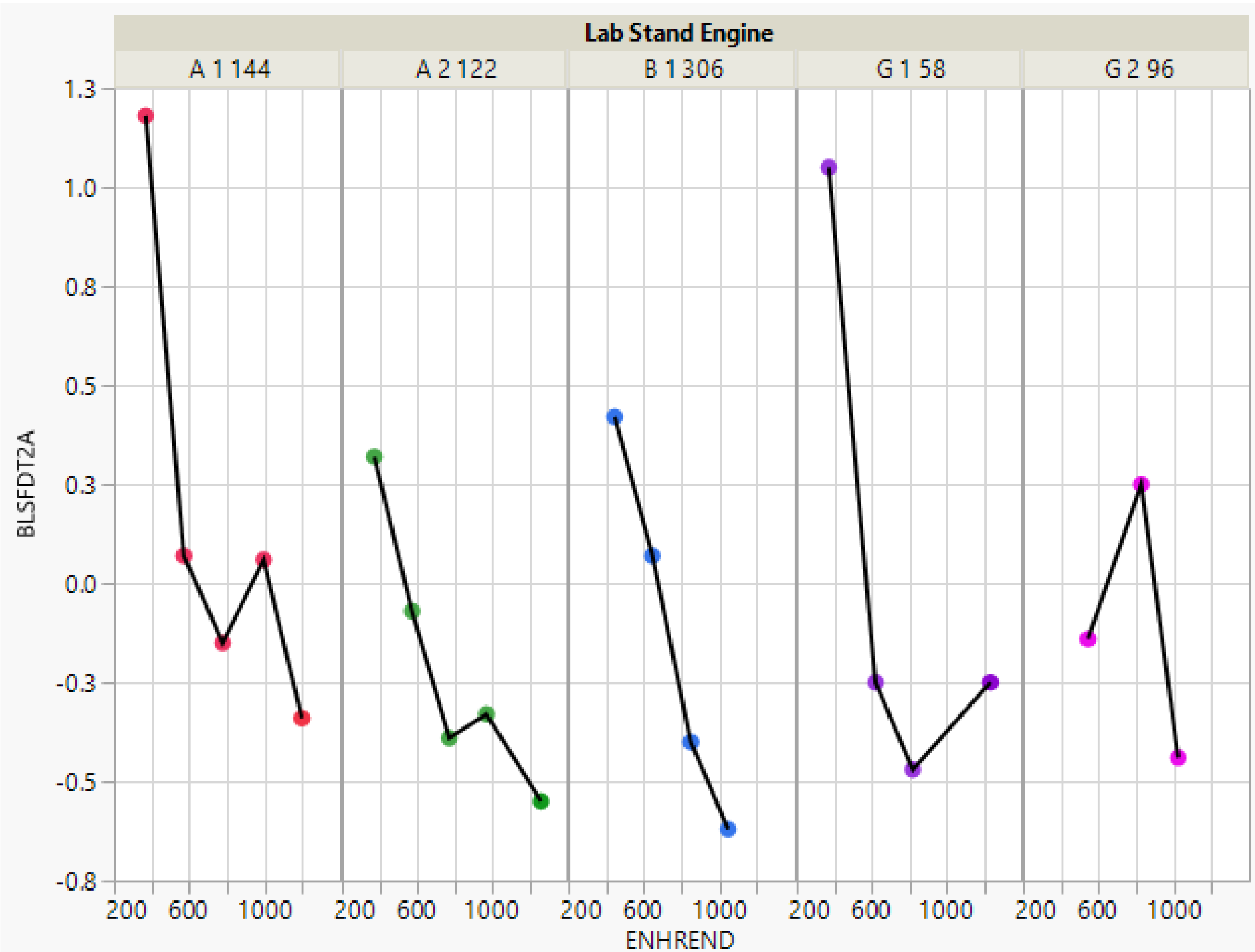

**Quantiles**

| | | |
|---|---|---|
| 100.0% | maximum | 0.54 |
| 99.5% | | 0.54 |
| 97.5% | | 0.54 |
| 90.0% | | 0.39 |
| 75.0% | quartile | 0.32 |
| 50.0% | median | 0.24 |
| 25.0% | quartile | 0.15 |
| 10.0% | | 0.084 |
| 2.5% | | -0.09 |
| 0.5% | | -0.09 |
| 0.0% | minimum | -0.09 |

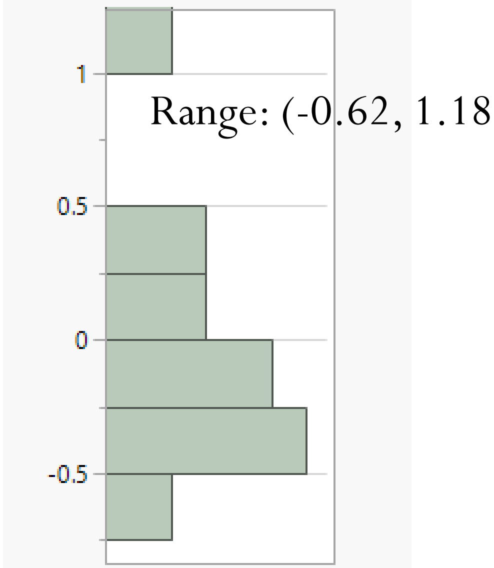
**Summary Statistics**

| | |
|---|---|
| Mean | 0.23 |
| Std Dev | 0.1330413 |
| Std Err Mean | 0.029032 |
| Upper 95% Mean | 0.2905597 |
| Lower 95% Mean | 0.1694403 |
| N | 21 |

# BL SHIFT % DELTA, BLB2 VS BLA




BLSFDT2A




## Quantiles

| | | |
|---|---|---|
| 100.0% | maximum | 1.18 |
| 99.5% | | 1.18 |
| 97.5% | | 1.18 |
| 90.0% | | 0.924 |
| 75.0% | quartile | 0.16 |
| 50.0% | median | -0.15 |
| 25.0% | quartile | -0.395 |
| 10.0% | | -0.534 |
| 2.5% | | -0.62 |
| 0.5% | | -0.62 |
| 0.0% | minimum | -0.62 |

## Summary Statistics

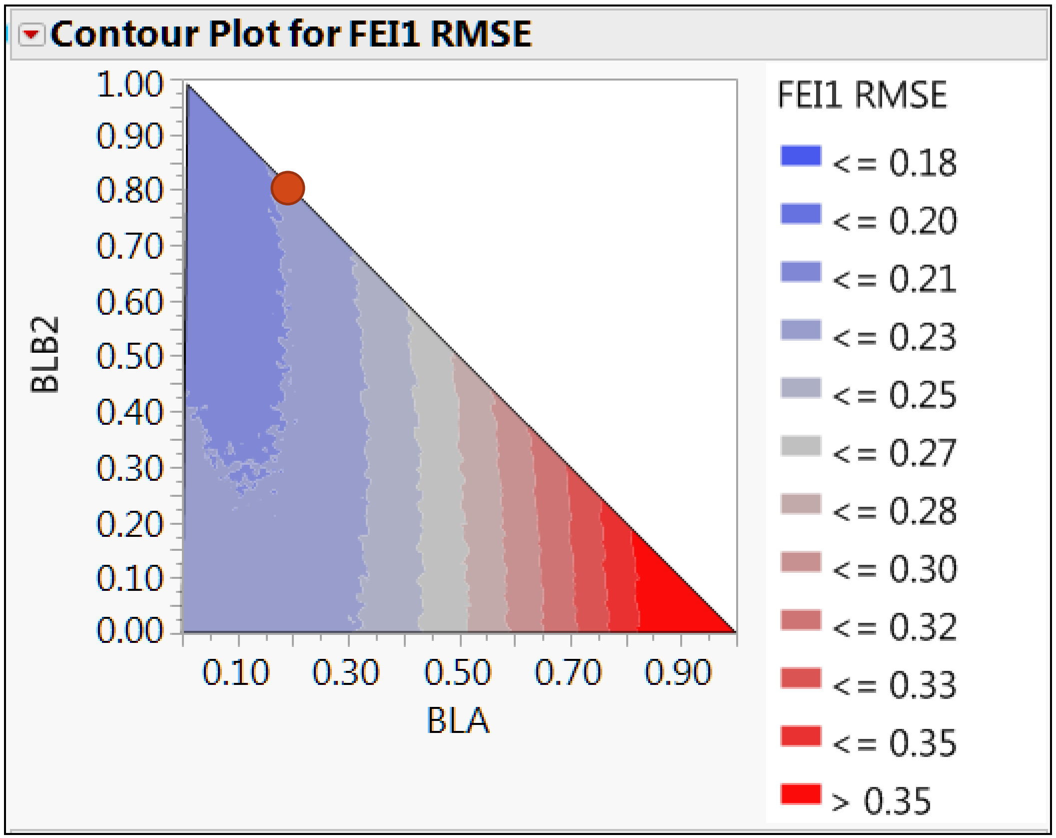
| | |
|---|---|
| Mean | -0.046667 |
| Std Dev | 0.4803055 |
| Std Err Mean | 0.1048112 |
| Upper 95% Mean | 0.1719658 |
| Lower 95% Mean | -0.265299 |
| N | 21 |

# Evaluating Baseline Weight Scenarios

- Excel Program developed to evaluate 10,000 different weight combinations of BLB1, BLB2, and BLA
- Excel based prediction model for precision (RMSE) included Lab, Eng(Lab), Oil, and EngHr factors
- All BL weight combinations summed to a value of 1.0
- For those runs that included a BLB3, BL weights were applied to BLB2 & BLB3 in lieu of BLB1 & BLB2
- Results are shown on the following slides

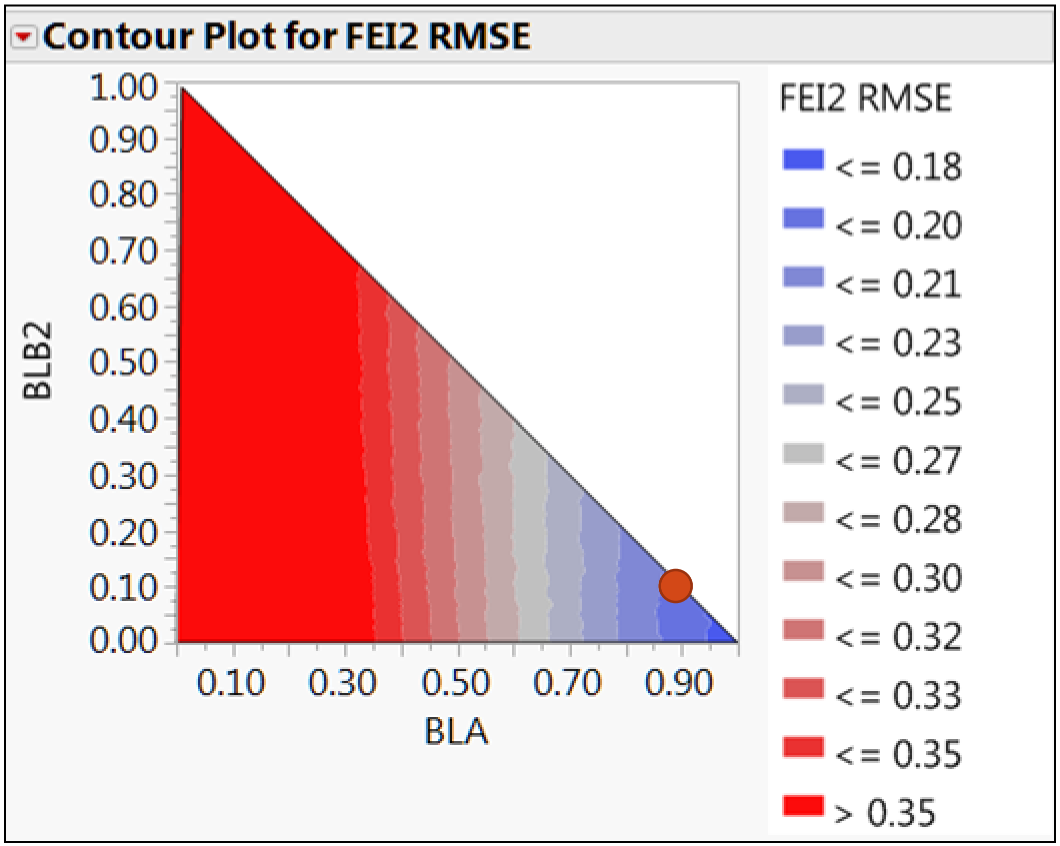
# Evaluating Baseline Weight Scenarios

- Plot of RMSE vs. baseline (BL) weight combinations for FEI1 shown below:
  - RMSE of weights can be interpreted from plot- if BL weights sum to 1.0
  - VID & VIE FEI1 Baseline weights are 80% & 20% (shown in red circle)



# Evaluating Baseline Weight Scenarios

- Plot of RMSE vs. baseline weight combinations for FEI2 shown below
  - RMSE of weights can be interpreted from plot- if BL weights sum to 1.0
  - VID & VIE FEI2 Baseline weights are 10% & 90% (shown in red circle)

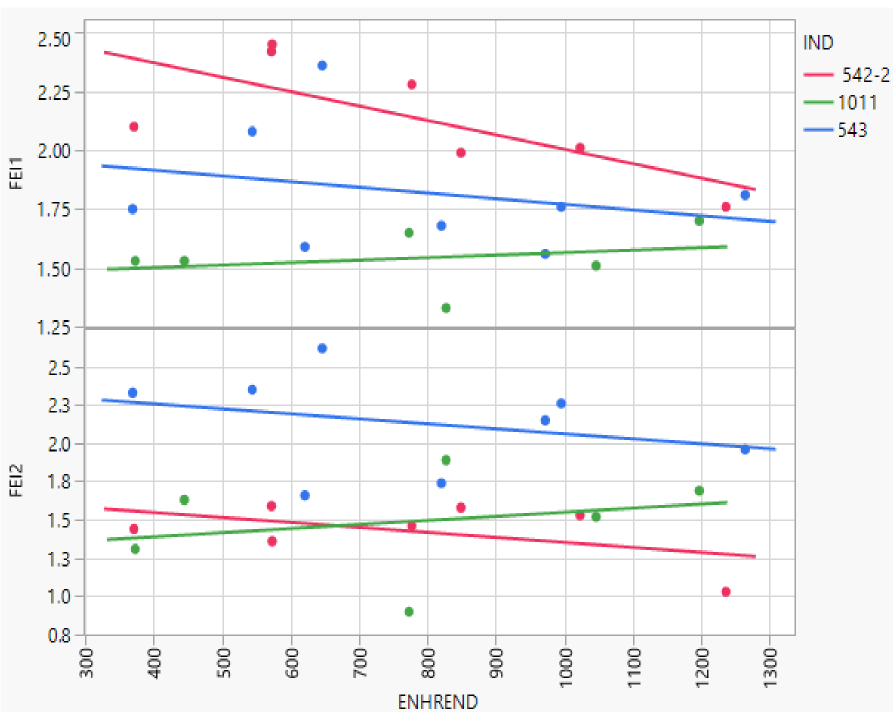


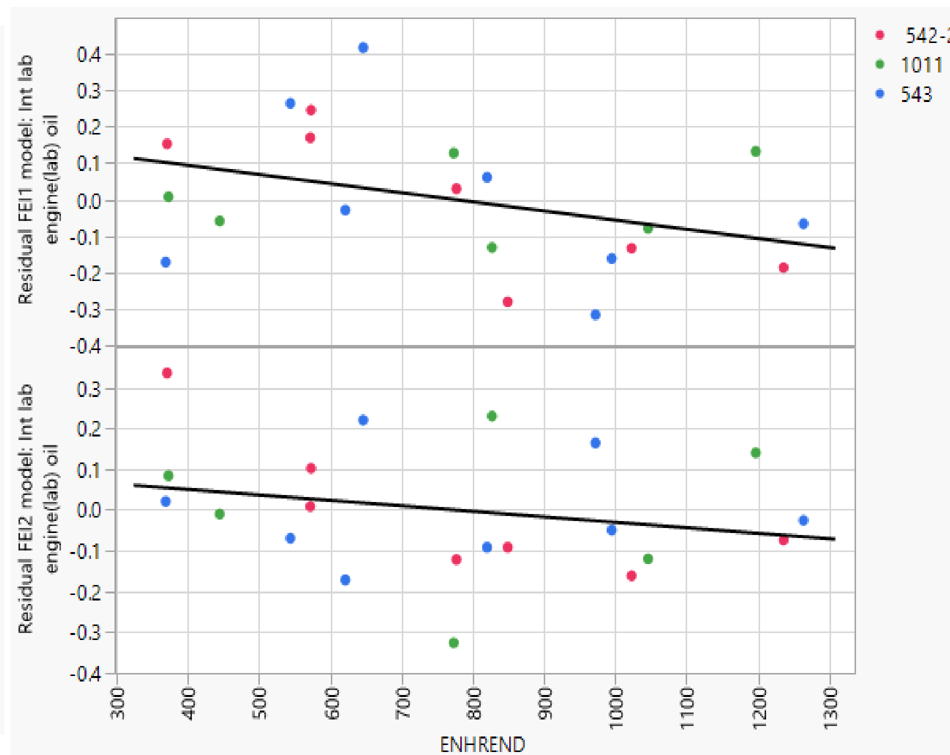
# Agenda

- **Evaluating Engine Hour Adjustment**
- Analyzing Data
  - FEI1
  - FEI2
  - Comparing VIF Precision and Oil Discrimination with other Tests

# Evaluating Engine Hour Adjustment

- Analyses of FEI1 and FEI2 model *residuals* were explored to identify the best method for Engine Hour Adjustment
  - The residuals were based on a model fit with LTMSLAB, IND, and ENGNO(LTMSLAB) factors
- A linear adjustment was selected to be consistent with the VIE approach



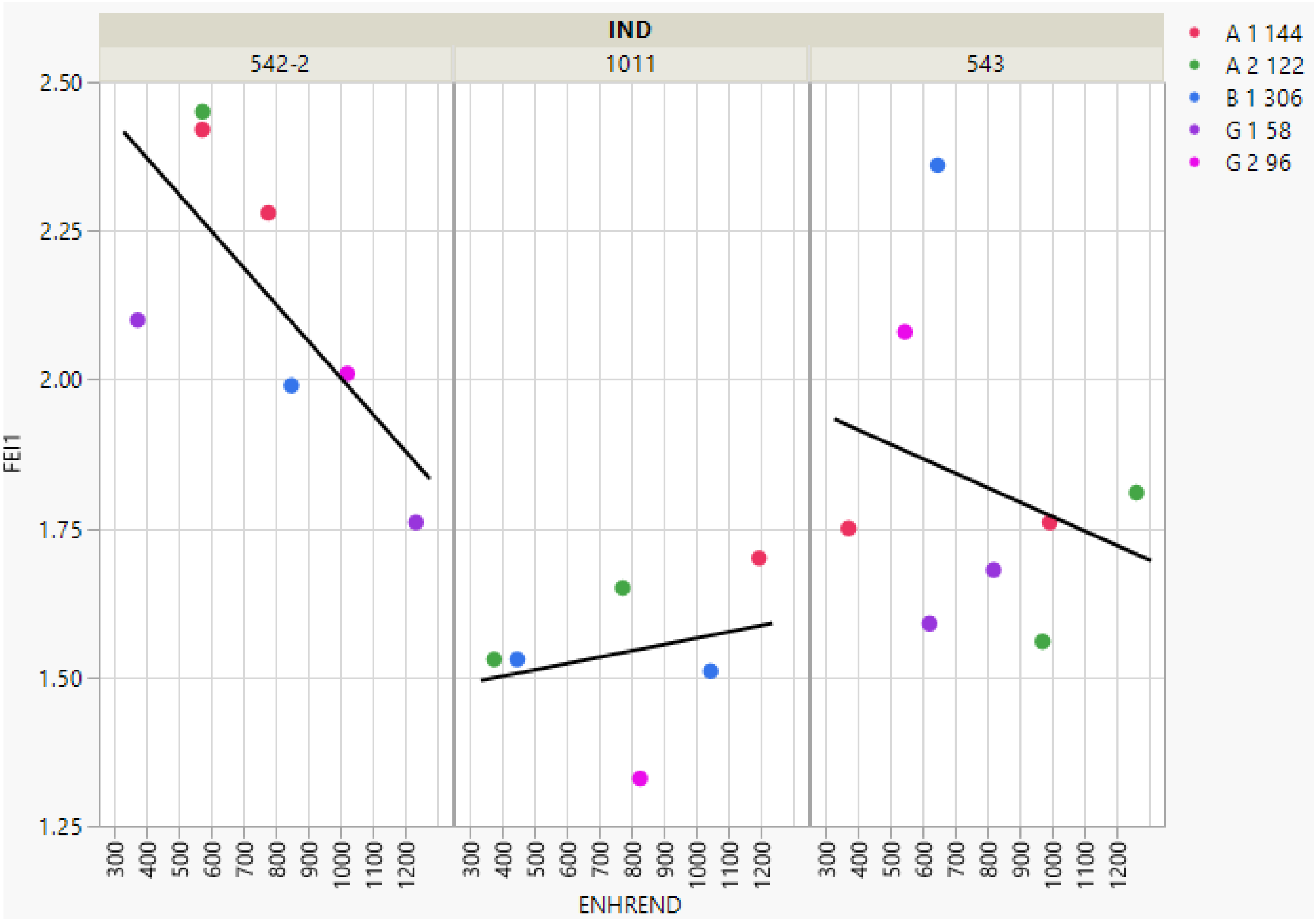



# Agenda

- Evaluating Alternatives for Engine Hour Adjustment
- **Analyzing Data**
  - **FEI1**
  - FEI2
  - Comparing VIF Precision and Oil Discrimination with other Tests

# Analyzing Data – FEI1

- Plot of FEI1_OR



# Analyzing Data – FEI1

- Overall ANOVA Summary of FEI1 data:
  - Oils significantly differ
  - Test Precision: 0.22 *(contrast w/ VID PM test precision of 0.12; VIE is 0.30)*

**Summary of Fit**

| | |
|---|---|
| RSquare | 0.715969 |
| RSquare Adj | 0.56303 |
| Root Mean Square Error | 0.216846 |
| Mean of Response | 1.85 |
| Observations (or Sum Wgts) | 21 |

**Analysis of Variance**

| Source | DF | Sum of Squares | Mean Square | F Ratio |
|---|---|---|---|---|
| Model | 7 | 1.5409090 | 0.220130 | 4.6814 |
| Error | 13 | 0.6112910 | 0.047022 | Prob > F |
| C. Total | 20 | 2.1522000 | | 0.0081* |

**Parameter Estimates**

| Term | Estimate | Prob>\|t\| |
|---|---|---|
| Intercept | 2.0384021 | <.0001* |
| LTMSLAB[ A] | 0.0499342 | 0.4540 |
| LTMSLAB[ B] | 0.0835183 | 0.3341 |
| LTMSLAB[ A]:ENGNO[122] | -0.021784 | 0.7599 |
| LTMSLAB[ G]:ENGNO[58] | -0.10287 | 0.2477 |
| IND[ 542-2] | 0.3358206 | 0.0003* |
| IND[1011] | -0.344997 | 0.0005* |
| ENHREND | -0.000252 | 0.1617 |

**Effect Tests**

| Source | DF | Prob > F |
|---|---|---|
| LTMSLAB | 2 | 0.2111 |
| ENGNO[LTMSLAB] | 2 | 0.4717 |
| IND | 2 | 0.0006* |
| ENHREND | 1 | 0.1617 |

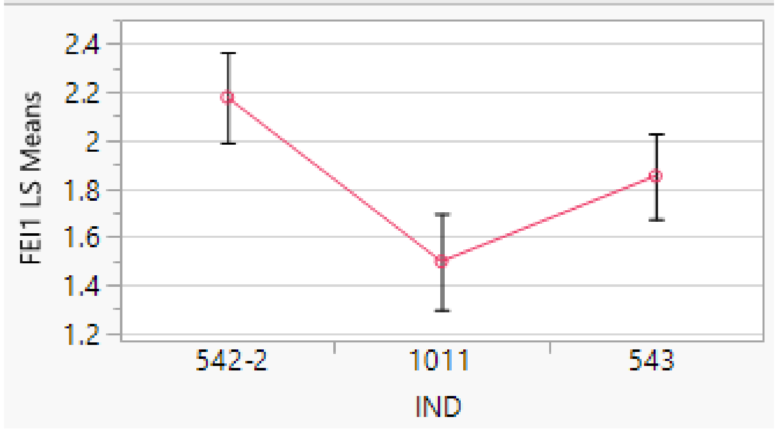
FEI1 Engine Hours Adjustment:
FEI1 = FEI1_OR + 0.000252*(ENHREND – 776)

# Analyzing Data – FEI1

- Oils significantly differ:
  - All pairwise oil comparisons are significantly different
  - 1011 < 543 < 542-2

| Level | Least Sq Mean |
|---|---|
| 542-2 | 2.1786515 |
| 1011 | 1.4978340 |
| 543 | 1.8520072 |

**LS Means Plot**

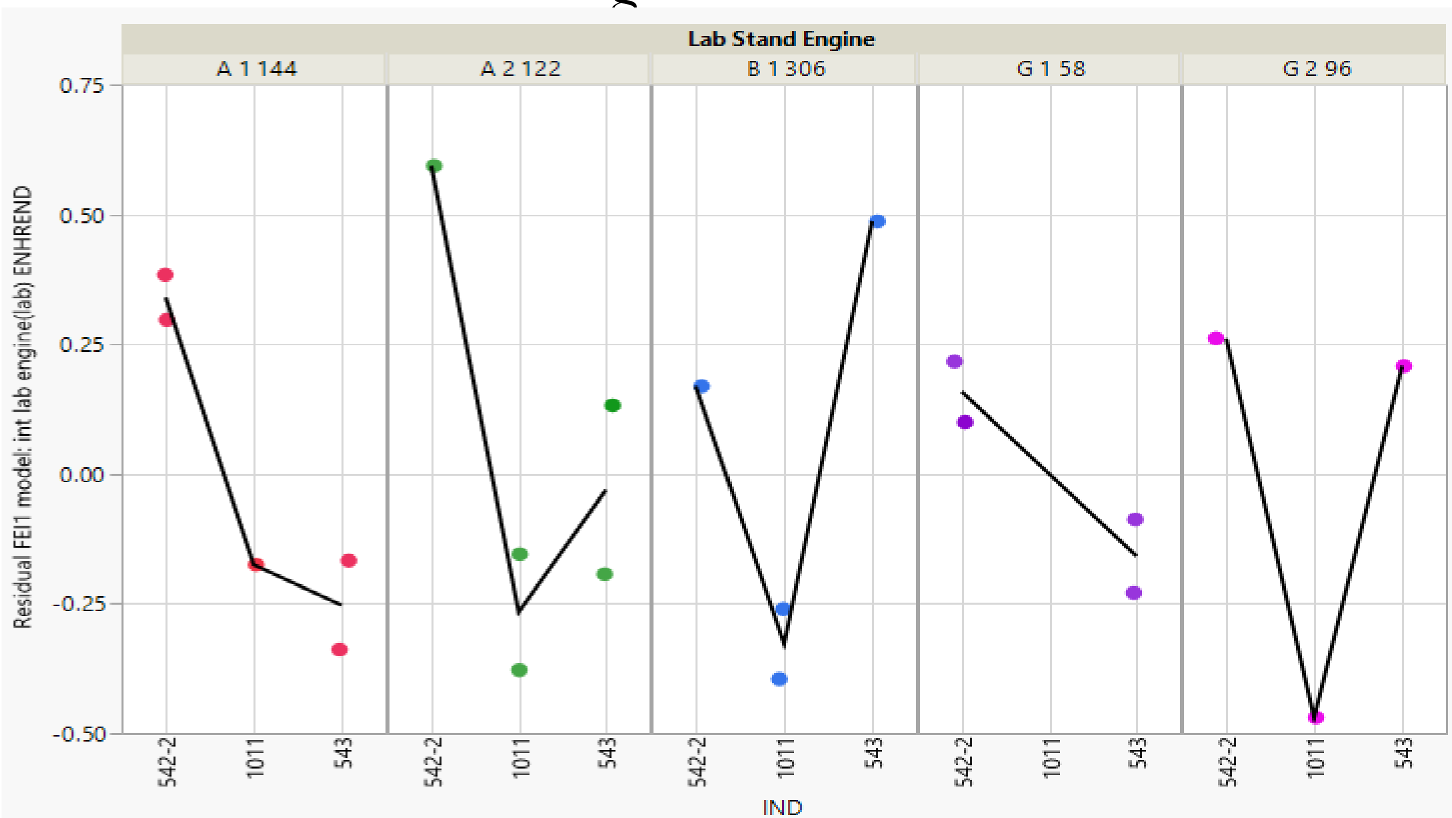



| Level | - Level | Difference | p-Value |
|---|---|---|---|
| 542-2 | 1011 | 0.6808175 | 0.0004* |
| 543 | 1011 | 0.3541733 | 0.0336* |
| 542-2 | 543 | 0.3266442 | 0.0315* |

| Ref Oil | VID FEI1 Target | VIE FEI1 Target |
|---|---|---|
| 542 | 1.49 | 2.56 |

# Analyzing Data – FEI1

- FEI1 Oil Discrimination by Engine
  - Contrast below plot with oil ranking of {1011 < 543 < 542-2}
  - Engines do not appear to separate oils the same way, but caution should be used when basing conclusions on limited data.




These residuals are based on a model fit with LTMSLAB, ENGNO(LTMSLAB), and ENHREND

# Analyzing Data – FEI1

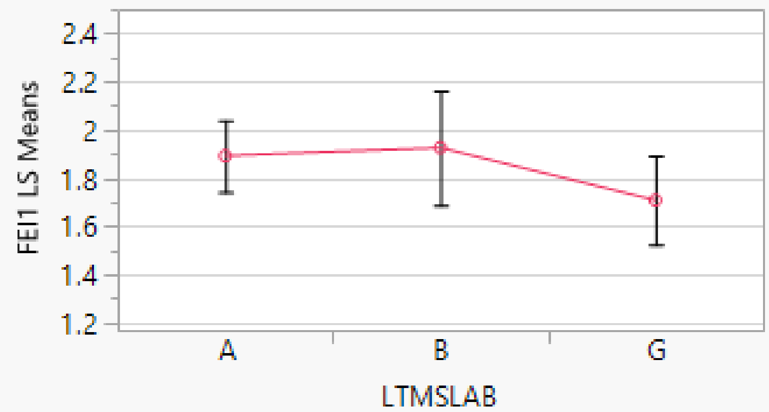
- The difference between labs is not statistically significant

**Effect Tests**

| Source | DF | Prob > F |
|---|---|---|
| LTMSLAB | 2 | 0.2111 |
| ENGNO[LTMSLAB] | 2 | 0.4717 |
| IND | 2 | 0.0006* |
| ENHREND | 1 | 0.1617 |

| Level | Least Sq Mean |
|---|---|
| A | 1.8927651 |
| B | 1.9263491 |
| G | 1.7093784 |

**LS Means Plot**




| Level | - Level | Difference | p-Value |
|---|---|---|---|
| B | G | 0.2169707 | 0.3091 |
| A | G | 0.1833867 | 0.2473 |
| B | A | 0.0335840 | 0.9643 |

# Analyzing Data – FEI1

- Engine differences within the same Lab:
  - Comparisons: {A-144 vs. A-122} & {G-58 vs. G-96}
  - Conclusion: the differences between the engines are not statistically significant

**Parameter Estimates**

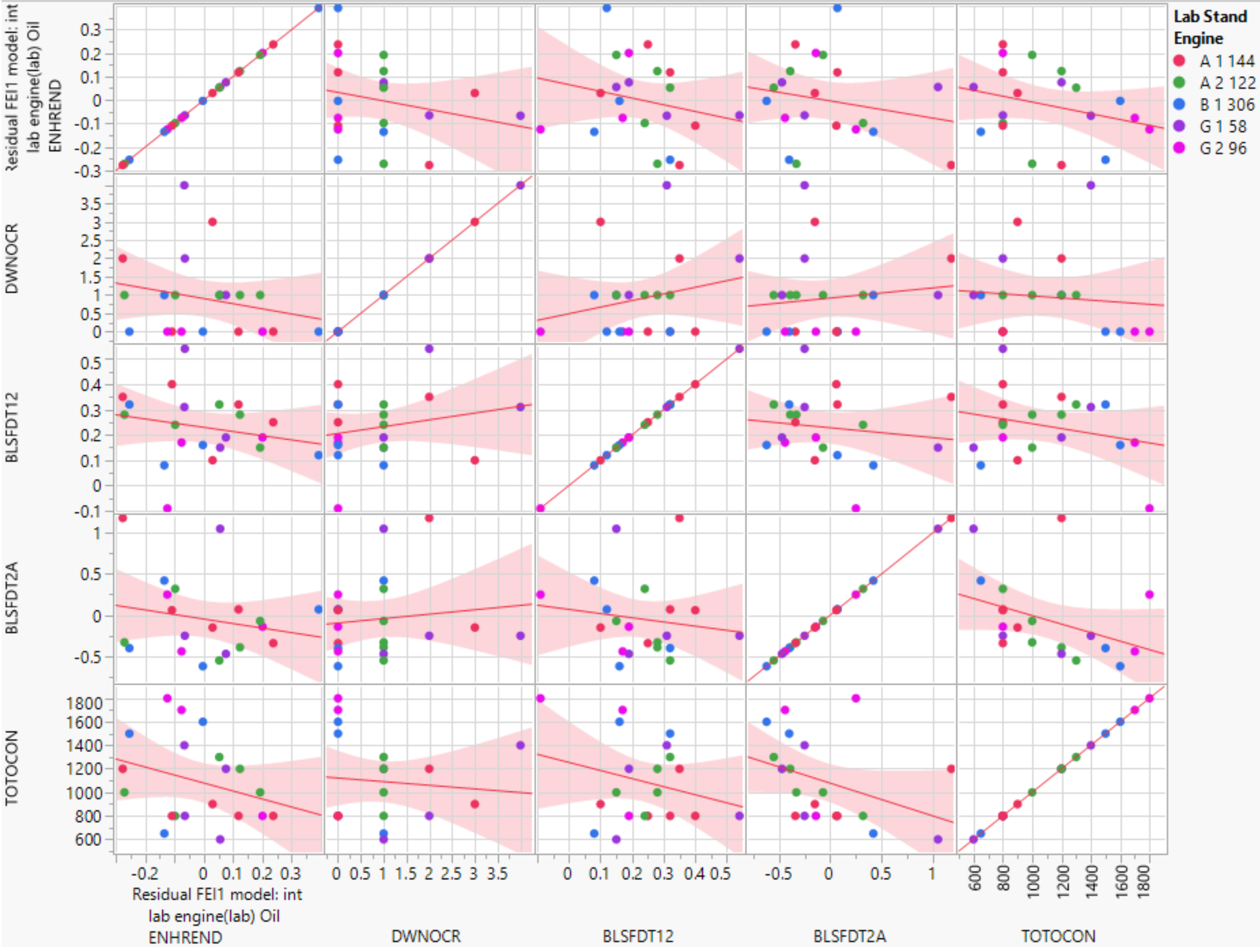
| Term | Estimate | Prob>\|t\| |
|---|---|---|
| Intercept | 2.0384021 | <.0001* |
| LTMSLAB[ A] | 0.0499342 | 0.4540 |
| LTMSLAB[ B] | 0.0835183 | 0.3341 |
| LTMSLAB[ A]:ENGNO[122] | -0.021784 | 0.7599 |
| LTMSLAB[ G]:ENGNO[58] | -0.10287 | 0.2477 |
| IND[ 542-2] | 0.3358206 | 0.0003* |
| IND[1011] | -0.344997 | 0.0005* |
| ENHREND | -0.000252 | 0.1617 |

**Effect Tests**

| Source | DF | Prob > F |
|---|---|---|
| LTMSLAB | 2 | 0.2111 |
| ENGNO[LTMSLAB] | 2 | 0.4717 |
| IND | 2 | 0.0006* |
| ENHREND | 1 | 0.1617 |

# Analyzing Data – FEI1

- Matrix Plot of FEI1 residuals vs. some other related test variables
  - No observable trends that correlate with FEI1 residuals



# FEI1 Precision

| Model: FEI1 Engine hours adjusted vs. Oil, Lab, Engine(Lab) | | Model: FEI1 Engine hours adjusted vs. Oil |
|---|---|---|
| **Model RMSE** | **Repeatability** | **Reproducibility** |
| • s = 0.21<br>• VIE Precision Matrix s=0.29<br>• VID Precision Matrix s=0.14<br>• VID LTMS s=0.12 | • s = 0.21<br>• r = 0.58 | • s = 0.22<br>• R = 0.61 |

# FEI1 Precision

Based upon the Seq. VIF and VID pooled standard deviations ($s_r$) and ASTM's repeatability ($r$), there is no significant difference between an FEI1 result[1] of 1.42 – 2.00 for the VIF and 1.61 – 2.00 for the VID.

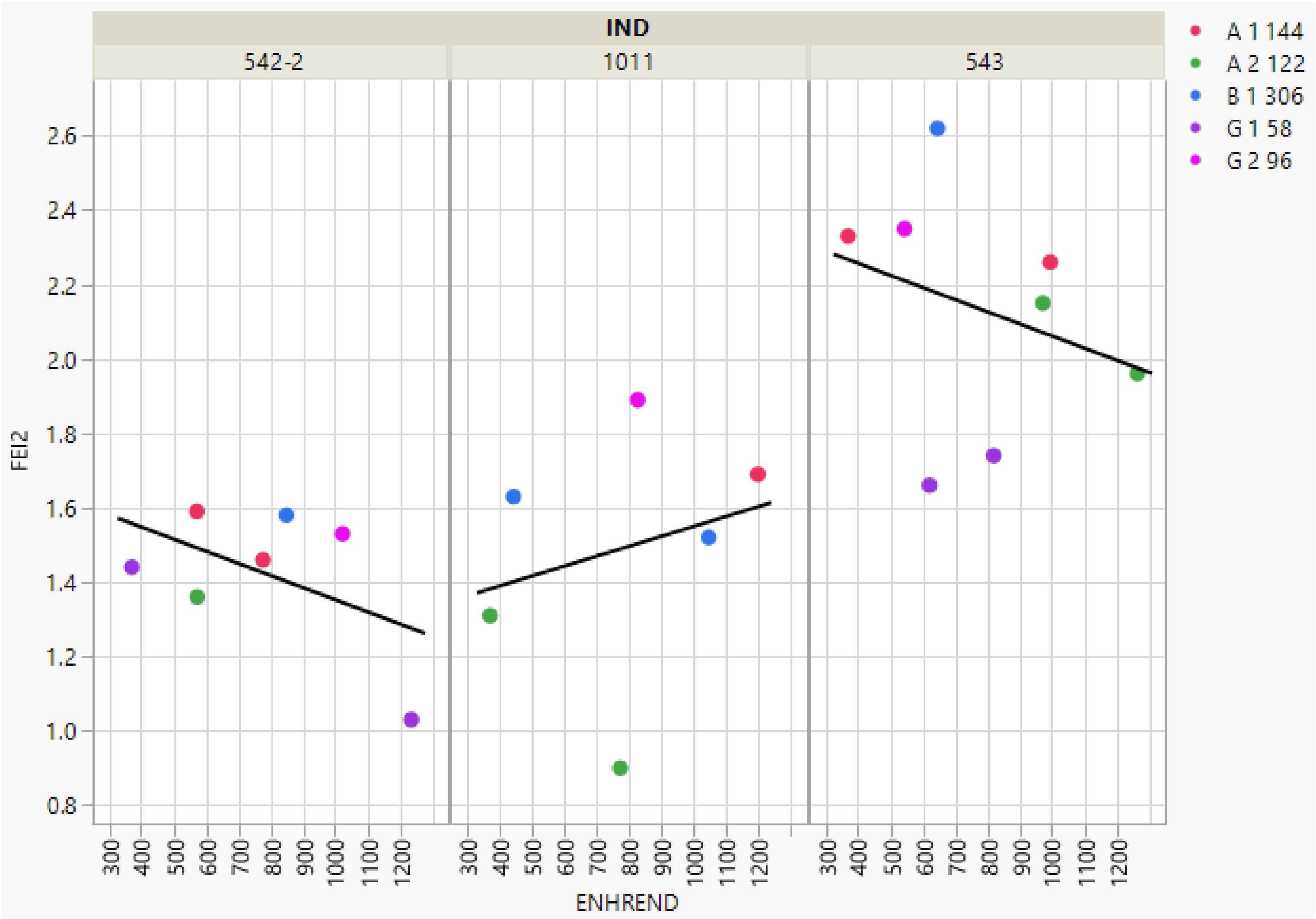
*Note 1: An FEI1 of 2.0 was arbitrarily selected in the calculations as the upper pass/fail limit.*

# Agenda

- Evaluating Engine Hour Adjustment
- **Analyzing Data**
  - FEI1
  - **FEI2**
  - Comparing VIF Precision and Oil Discrimination with other Tests

# Analyzing Data – FEI2

- Plot of FEI2_OR



# Analyzing Data – FEI2

- Overall ANOVA Summary of FEI2 data:
  - Oil and engines within lab effects are statistically significant
  - Labs marginally differ
  - Test Precision: 0.19 *(contrast w/ VID PM test precision of 0.14; VIE is 0.12)*

**Summary of Fit**

| | |
|---|---|
| RSquare | 0.877983 |
| RSquare Adj | 0.812282 |
| Root Mean Square Error | 0.190319 |
| Mean of Response | 1.714286 |
| Observations (or Sum Wgts) | 21 |

**Analysis of Variance**

| Source | DF | Sum of Squares | Mean Square | F Ratio |
|---|---|---|---|---|
| Model | 7 | 3.3882383 | 0.484034 | 13.3633 |
| Error | 13 | 0.4708760 | 0.036221 | Prob > F |
| C. Total | 20 | 3.8591143 | | <.0001* |

**Parameter Estimates**

| Term | Estimate | Prob>\|t\| |
|---|---|---|
| Intercept | 1.8322014 | <.0001* |
| LTMSLAB[ A] | -0.074617 | 0.2115 |
| LTMSLAB[ B] | 0.1719895 | 0.0350* |
| LTMSLAB[ A]:ENGNO[122] | -0.161278 | 0.0207* |
| LTMSLAB[ G]:ENGNO[58] | -0.296248 | 0.0016* |
| IND[ 542-2] | -0.232462 | 0.0022* |
| IND[1011] | -0.263603 | 0.0016* |
| ENHREND | -0.000135 | 0.3817 |

**Effect Tests**

| Source | DF | Prob > F |
|---|---|---|
| LTMSLAB | 2 | 0.0995 |
| ENGNO[LTMSLAB] | 2 | 0.0012* |
| IND | 2 | <.0001* |
| ENHREND | 1 | 0.3817 |

FEI2 Engine Hours Adjustment:

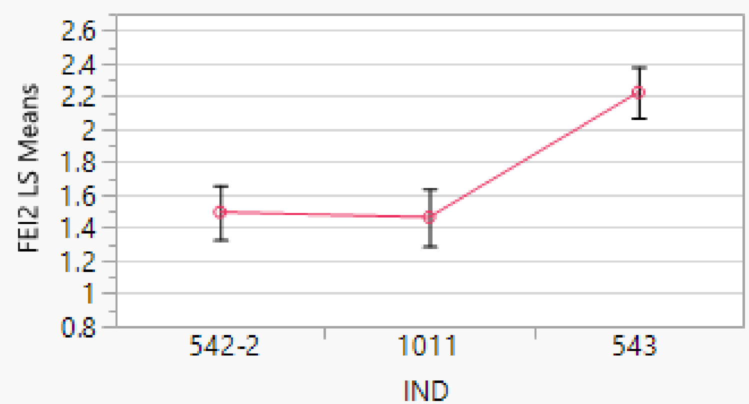
FEI2 = FEI2_OR + 0.000135*(ENHREND – 776)

# Analyzing Data – FEI2

- Oils significantly differ:
  - 543 > {1011 & 542-2}

| Level | Least Sq Mean |
|---|---|
| 542-2 | 1.4949854 |
| 1011 | 1.4638444 |
| 543 | 2.2235130 |

**LS Means Plot**

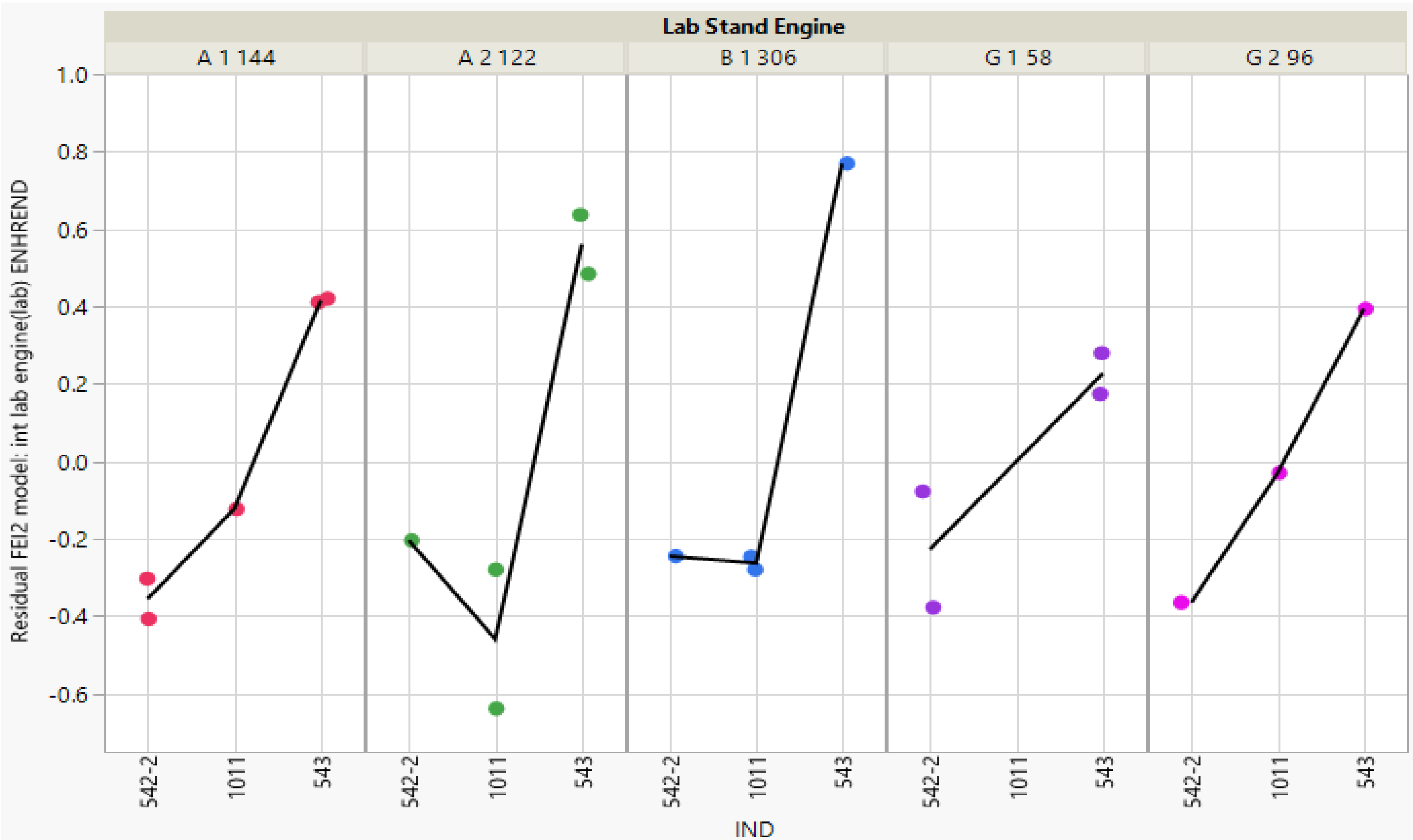



| Level | - Level | Difference | p-Value |
|---|---|---|---|
| 543 | 1011 | 0.7596686 | <.0001* |
| 543 | 542-2 | 0.7285275 | <.0001* |
| 542-2 | 1011 | 0.0311411 | 0.9595 |

| Ref Oil | VID FEI2 Target | VIE FEI2 Target |
|---|---|---|
| 542 | 0.8 | 1.73 |

# Analyzing Data – FEI2

- FEI2 Oil Discrimination by Engine
  - Contrast below plot with oil ranking: 543 > {1011 & 542-2}
  - Oil ranking is generally consistent across engines. There is less of a difference in oils in engine 58. Caution should be used when basing conclusions on limited data.




These residuals are based on a model fit with LTMSLAB, ENGNO(LTMSLAB), and ENHREND

# Analyzing Data – FEI2

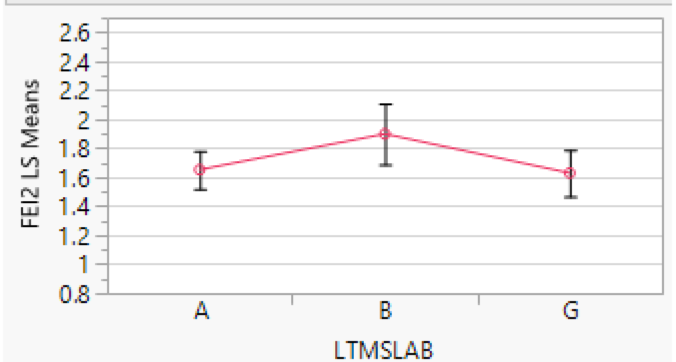
- Labs marginally differ
  - Lab B tends to be higher than both A and G

**Effect Tests**

| Source | DF | Prob > F |
|---|---|---|
| LTMSLAB | 2 | 0.0995 |
| ENGNO[LTMSLAB] | 2 | 0.0012* |
| IND | 2 | <.0001* |
| ENHREND | 1 | 0.3817 |

| Level | Least Sq Mean |
|---|---|
| A | 1.6528304 |
| B | 1.8994371 |
| G | 1.6300752 |

**LS Means Plot**




| Level | - Level | Difference | p-Value |
|---|---|---|---|
| B | G | 0.2693619 | 0.1150 |
| B | A | 0.2466067 | 0.1176 |
| A | G | 0.0227552 | 0.9692 |

## Analyzing Data – FEI2

- Engine differences within the same Lab:
  - Comparisons: {A-144 vs. A-122} & {G-58 vs. G-96}
  - Conclusion: Engines within labs A & G significantly differ from one another

**Parameter Estimates**

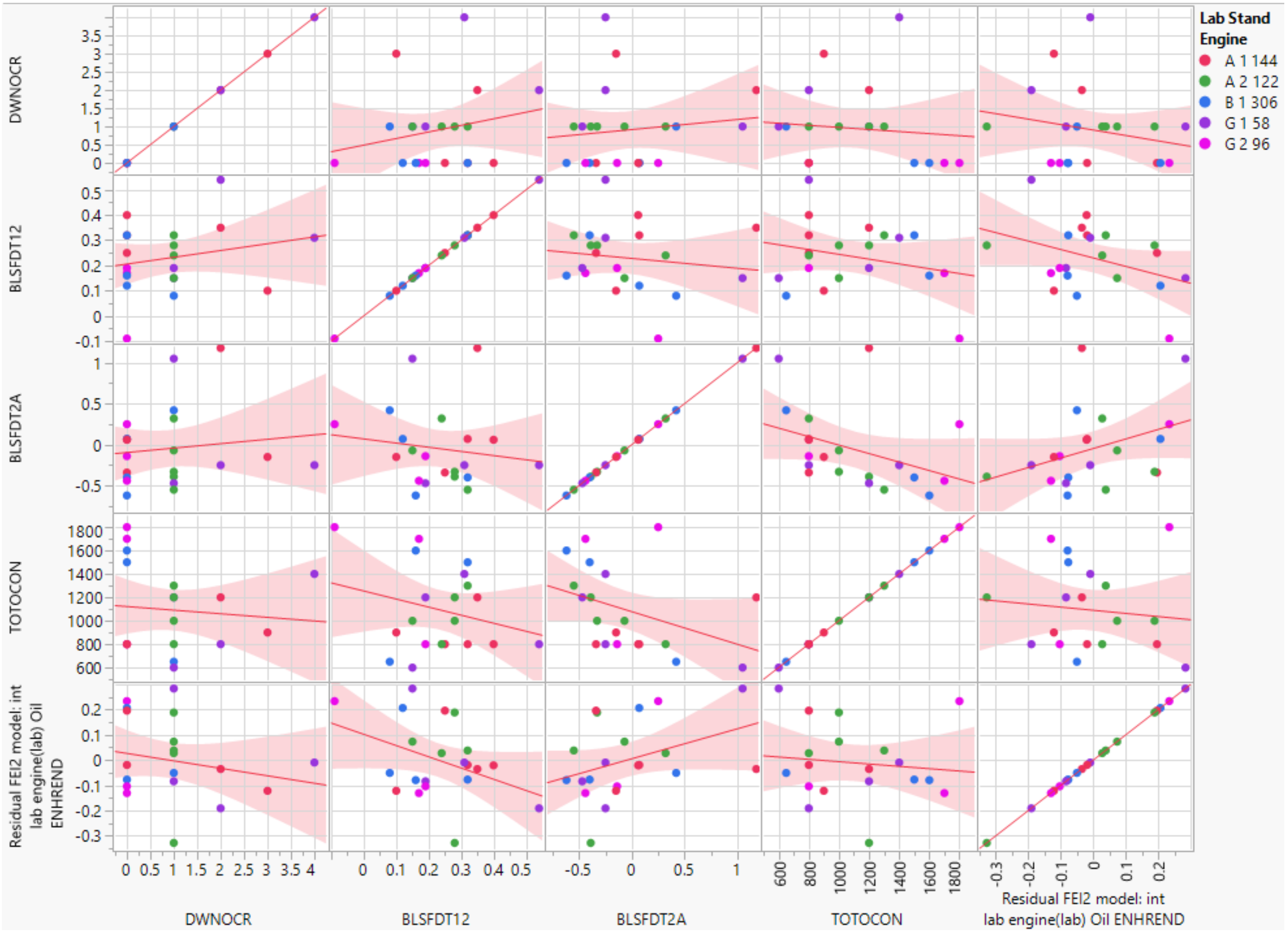
| Term | Estimate | Prob>\|t\| |
|---|---|---|
| Intercept | 1.8322014 | <.0001* |
| LTMSLAB[ A] | -0.074617 | 0.2115 |
| LTMSLAB[ B] | 0.1719895 | 0.0350* |
| LTMSLAB[ A]:ENGNO[122] | -0.161278 | 0.0207* |
| LTMSLAB[ G]:ENGNO[58] | -0.296248 | 0.0016* |
| IND[ 542-2] | -0.232462 | 0.0022* |
| IND[1011] | -0.263603 | 0.0016* |
| ENHREND | -0.000135 | 0.3817 |

**Effect Tests**

| Source | DF | Prob > F |
|---|---|---|
| LTMSLAB | 2 | 0.0995 |
| ENGNO[LTMSLAB] | 2 | 0.0012* |
| IND | 2 | <.0001* |
| ENHREND | 1 | 0.3817 |

# Analyzing Data – FEI2

- Matrix Plot of FEI2 residuals vs. some other related test variables
  - Data suggest higher FEI2 when BLB2 vs. BLA is higher



# FEI2 Precision

| Model: FEI2 Engine hours adjusted vs. Oil, Lab, Engine(Lab) | | Model: FEI2 Engine hours adjusted vs. Oil |
|---|---|---|
| **Model RMSE** | **Repeatability** | **Reproducibility** |
| • s = 0.18<br><br>• VIE Precision Matrix s=0.12<br>• VID Precision Matrix s=0.16<br>• VID LTMS s=0.14 | • s = 0.18<br>• r = 0.50 | • s = 0.29<br>• R = 0.80 |

# FEI2 Precision

Based upon the Seq. VIF and VID pooled standard deviations ($s_r$) and ASTM's repeatability ($r$), there is no significant difference between an FEI2 result[1] of 1.00 – 1.50 for the VIF and 1.06 – 1.50 for the VID.

*Note 1: An FEI2 of 1.5 was arbitrarily selected in the calculations as the upper pass/fail limit.*

# Agenda

- Evaluating Engine Hour Adjustment
- **Analyzing Data**
  - FEI1
  - **FEI2**
  - **Comparing VIF Precision and Oil Discrimination with other Tests**

# Comparing VIF Precision and Oil Discrimination with other Tests

**Sequence VID FEI1**

| Oil | | Target (LTMS) | | | |
|---|---|---|---|---|---|
| 540 | (GF5A) | 1.32 | | Method Standard Deviation | 0.13 |
| 541 | (GF5D) | 0.87 | | Full span of results (st devs) | 4.77 |
| 542 | (GF5X) | 1.49 | | Span of Oil 1010 - Oil 542 (st devs | 1.15 |
| 1010 | | 1.34 | | | |

**Sequence VID FEI2**

| Oil | | Target (LTMS) | | | |
|---|---|---|---|---|---|
| 540 | (GF5A) | 1.04 | | Method Standard Deviation | 0.14 |
| 541 | (GF5D) | 0.71 | | Full span of results (st devs) | 2.79 |
| 542 | (GF5X) | 0.8 | | Span of Oil 1010 - Oil 542 (st devs | 2.14 |
| 1010 | | 1.1 | | | |

**Sequence VIE FEI1**

| Oil | | Target (LTMS) | | | |
|---|---|---|---|---|---|
| 1010-1 | | 1.90 | | Regression RMSE | 0.29 |
| 542-2 | | 2.56 | | Full span of results (st devs) | 4.34 |
| 544 | | 1.30 | | Span of Oil 1010 - Oil 542 (st devs | 2.28 |

**Sequence VIE FEI2**

| Oil | | Target (LTMS) | | | |
|---|---|---|---|---|---|
| 1010-1 | | 1.82 | | Regression RMSE | 0.25 |
| 542-2 | | 1.73 | | Full span of results (st devs) | 1.64 |
| 544 | | 1.41 | | Span of Oil 1010 - Oil 542 (st devs | 0.36 |

**Sequence VIF FEI1**

| Oil | | Target (LTMS) | | | |
|---|---|---|---|---|---|
| 542-2 | | 2.17 | | Regression RMSE | 0.22 |
| 1011 | | 1.50 | | Full span of results (st devs) | 3.05 |
| 543 | | 1.85 | | | |

**Sequence VIF FEI2**

| Oil | | Target (LTMS) | | | |
|---|---|---|---|---|---|
| 542-2 | | 1.49 | | Regression RMSE | 0.29 |
| 1011 | | 1.47 | | Full span of results (st devs) | 2.62 |
| 543 | | 2.23 | | | |

<u>Comments</u>

- A method of measuring test precision and oil discrimination is to divide the (FEI difference of best and worst performing reference oils) by the (test precision)
- The result is the # *of standard deviations that separate reference oil performance*
- Comparing the standard deviation alone is not necessarily meaningful; what if the standard deviation is larger, but oils span a larger FEI range? This is what appears to be the case for VIE FEI1
- Granted, this approach is influenced by choice of reference oils
- Engine tests typically show reference oil discrimination of about 1-3 standard deviations (see next slide)

# Comparing VIF Precision and Oil Discrimination with other Tests

- Sequence IIIG ln(PVIS): oils separated by 2.0 standard deviations
- Sequence IIIG WPD: oils separated by 2.3 standard deviations
- Sequence IVA wear: oils separated by 1.2 standard deviations
- Sequence VID FEI2: oils separated by 2.9 standard deviations

## Seq IIIG

PERCENT VISCOSITY INCREASE
Unit of Measure: LN(PVIS)

| Reference Oil | Mean | Standard Deviation |
|---|---|---|
| 434 | 4.7269 | 0.3859 |
| 435 | 5.1838 | 0.3096 |
| 435-2 | 5.1838 | 0.3096 |
| 438 | 4.5706 | 0.1768 |

## Seq IIIG

WEIGHTED PISTON DEPOSITS
Unit of Measure: Merits

| Reference Oil | Mean | Standard Deviation |
|---|---|---|
| 434 | 4.80 | 0.96 |
| 435 | 3.59 | 0.58 |
| 435-2 | 3.59 | 0.58 |
| 438 | 3.20 | 0.33 |

## Seq IVA

AVERAGE CAMSHAFT WEAR
Unit of Measure: micrometers

| Reference Oil | Mean | Standard Deviation |
|---|---|---|
| 1006-2 | 102.18 | 13.54 |
| 1007 | 84.76 | 15.40 |

## Seq VID

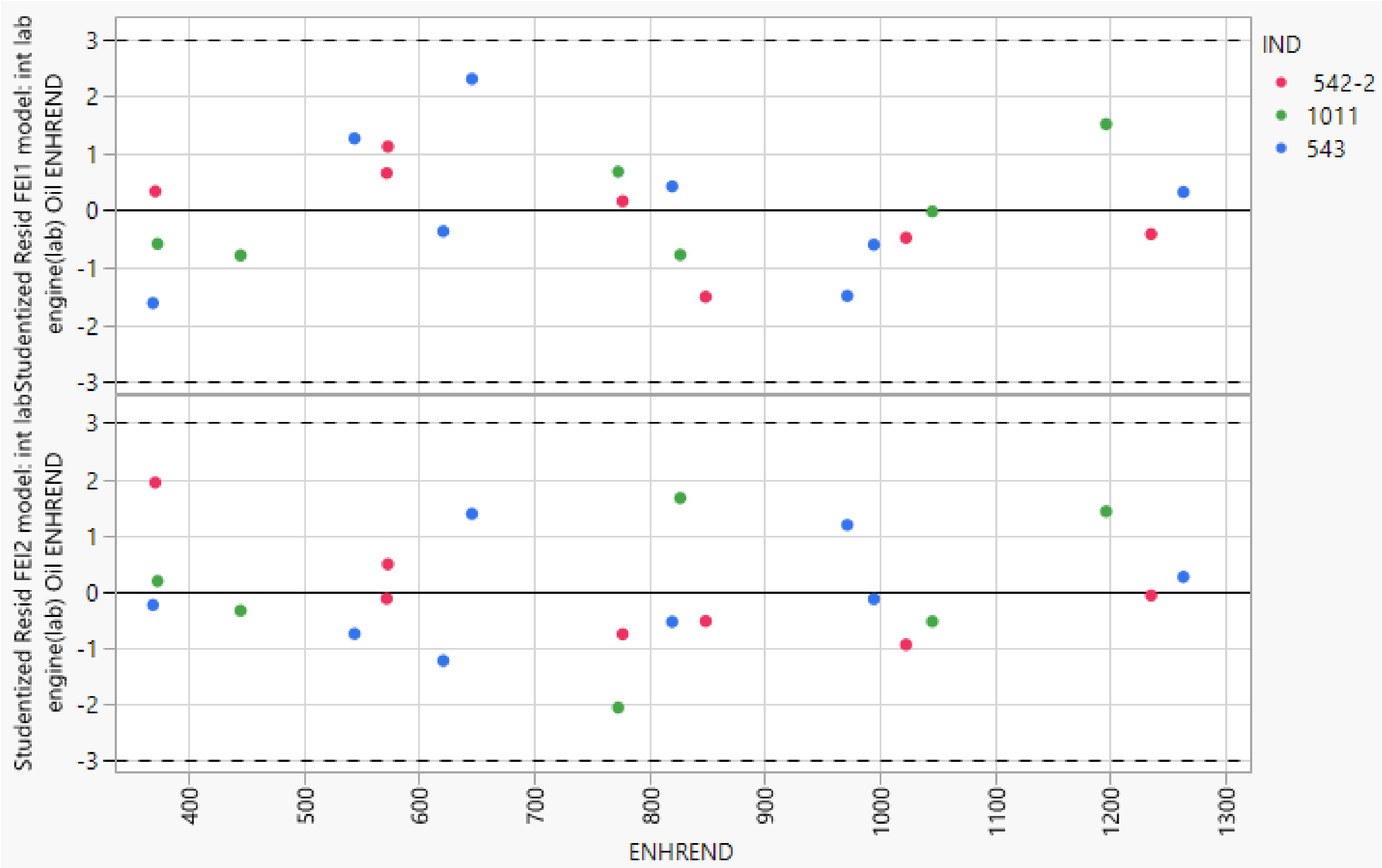
FUEL ECONOMY IMPROVEMENT at 100 Hours
Unit of Measure: Percent

| Reference Oil | Mean | Standard Deviation |
|---|---|---|
| 540 (GF5A) | 1.04 | 0.14 |
| 541 (GF5D) | 0.71 | 0.14 |
| 542 (GF5X) | 0.80 | 0.14 |
| 1010 | 1.10 | 0.18 |

# Appendix 1.1

Residual Diagnostics Model

# Residual Check
# Model: Oil, Lab, Engine(Lab), ENHREND

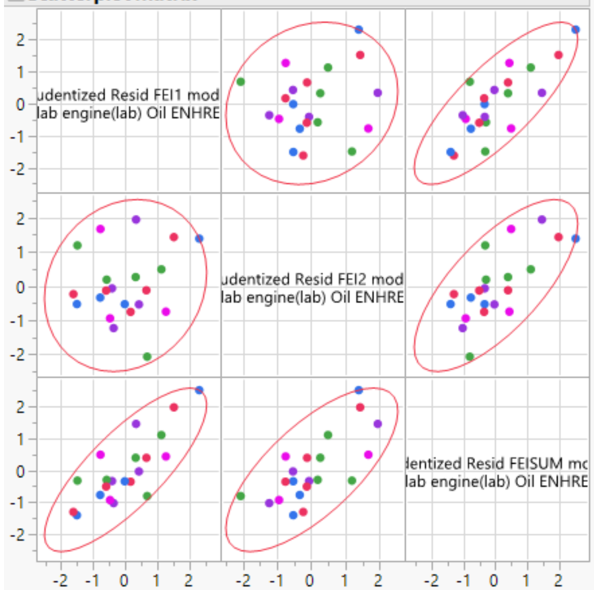


# Correlation among parameters Model: Oil, Lab, Engine(Lab), ENHREND

**Correlations**

| | Studentized Resid FEI1 model: int lab engine(lab) Oil ENHREND | Studentized Resid FEI2 model: int lab engine(lab) Oil ENHREND | Studentized Resid FEISUM model: int lab engine(lab) Oil ENHREND |
|---|---|---|---|
| Studentized Resid FEI1 model: int lab engine(lab) Oil ENHREND | 1.0000 | 0.1477 | 0.7947 |
| Studentized Resid FEI2 model: int lab engine(lab) Oil ENHREND | 0.1477 | 1.0000 | 0.7178 |
| Studentized Resid FEISUM model: int lab engine(lab) Oil ENHREND | 0.7947 | 0.7178 | 1.0000 |

**Scatterplot Matrix**



# VIF LTMS

Industry Statistician Team

Date: 02-21-2017

# Statistics Group

- Arthur Andrews, ExxonMobil
- Doyle Boese, Infineum
- Jo Martinez, Chevron Oronite
- Kevin O'Malley, Lubrizol
- Martin Chadwick, Intertek
- Richard Grundza, TMC
- Lisa Dingwell, Afton
- Todd Dvorak, Afton
- Travis Kostan, SwRI

# VIF LTMS

- With a limited VIF engine life and the relationship of engine age on the FEIs for the first & second runs, the Statistics Team recommends an LTMS that is based on a minimum two test calibration.
- The following slides outline the proposed VIF LTMS for a 4 or 5 run engine life.

# 4 Run Engine Life - LTMS

# Engine Hour Adjustment for VIF LTMS

- The VIF LTMS is based on the below engine hour adjustment:
  - FEI1 EngHr Adjustment:

$$FEI1 = 0.000403*(ENHREND - 700) + FEI1\_Original$$

  - FEI2 EngHr Adjustment:

$$FEI2 = 0.000293*(ENHREND - 700)+FEI2\_Original$$

# How are Yi's Calculated?

- $Y_i$ calculation method equation:

$$Y_i = \frac{FEI\_HrsAdj - RO\_Target\_FEI}{RO\_StdDev}$$

- As indicated in the above equation, the $Y_i$ calculation is based on engine hour adjusted FEI results and LSMean[1] targets (shown in below table) for each reference oil.

| | Target | |
|---|---|---|
| Oil | FEI1 | FEI2 |
| 542-2 (n=6) | 2.23 | 1.52 |
| 1011 (n=5) | 1.45 | 1.41 |
| 543 (n=7) | 1.88 | 2.25 |



*Note 1: FEI1 and FEI2 LSMeans were based on the n = 18 EngHr adj result data with Oil, Lab, and Eng(Lab) in the model*

# How are Yi's Calculated?

- For the denominator part of the $Y_i$ equation, the standard deviations of the engine hour adjusted FEI results by reference oil (shown in below table) will be used for the calculation

| | Standard Deviation | |
|---|---|---|
| Oil | FEI1 | FEI2 |
| 542-2 (n=6) | 0.18 | 0.13 |
| 1011 (n=5) | 0.14 | 0.39 |
| 543 (n=7) | 0.27 | 0.34 |

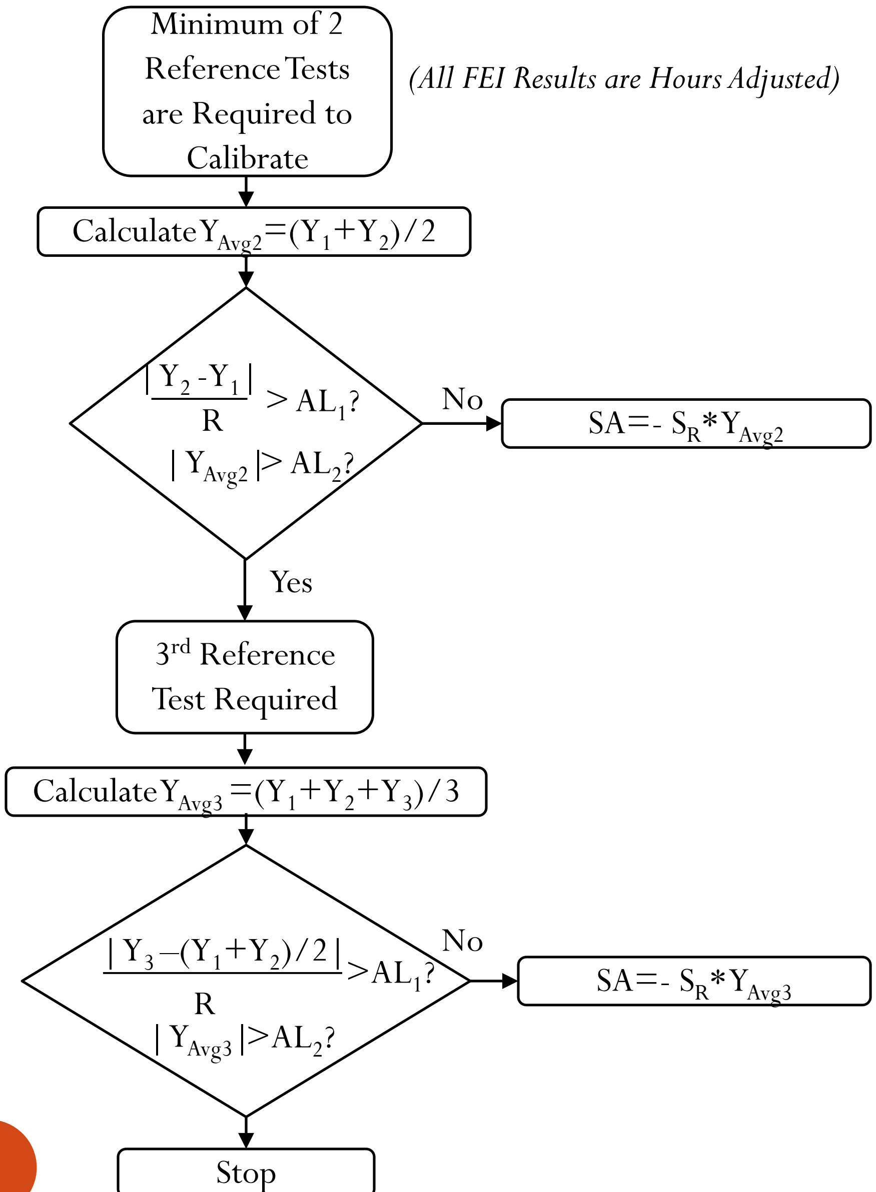
- Note that severity adjustment calculation will be based on $S_R$ (reproducibility standard deviation) rather than the individual standard deviation for the oil.
  - FEI1 $S_R = 0.22$
  - FEI2 $S_R = 0.30$



*Note: Oil standard deviations were based on EngHr adjusted data*

# VIF LTMS Flow Chart

*(All FEI Results are Hours Adjusted)*




<u>Where:</u>

$AL_1 = 2.8$

$AL_2 = 2.0$

$S_R$ = Reproducibility S (FEI1=0.22, FEI2=0.30)

R = Stdev Ratio (FEI1=0.95, FEI2 = 0.63)

*For reference, the VIE selections are listed below:*

$AL_2 = 2.8$

$AL_3 = 2$

*R for FEI1* = 1

*R for FEI2* = 0.48

# 5 Run Engine Life - LTMS

# Engine Hour Adjustment for VIF LTMS

- The VIF LTMS is based on the below engine hour adjustment:
  - FEI1 EngHr Adjustment:

$$FEI1 = 0.000252*(ENHREND - 776) + FEI1\_Original$$

  - FEI2 EngHr Adjustment:

$$FEI2 = 0.000135*(ENHREND - 776) + FEI2\_Original$$

# How are Yi's Calculated?

- $Y_i$ calculation method equation:

$$Y_i = \frac{FEI\_HrsAdj - RO\_Target\_FEI}{RO\_StdDev}$$

- As indicated in the above equation, the $Y_i$ calculation is based on engine hour adjusted FEI results and LSMean[1] targets (shown in below table) for each reference oil.

| | Target | |
|---|---|---|
| Oil | FEI1 | FEI2 |
| 542-2 (n=7) | 2.18 | 1.49 |
| 1011 (n=6) | 1.50 | 1.47 |
| 543 (n=8) | 1.85 | 2.23 |



*Note 1: FEI1 and FEI2 LSMeans were based on the n = 21 EngHr adj result data with Oil, Lab, and Eng(Lab) in the model*

# How are Yi's Calculated?

- For the denominator part of the $Y_i$ equation, the standard deviations of the engine hour adjusted FEI results by reference oil (shown in below table) will be used for the calculation

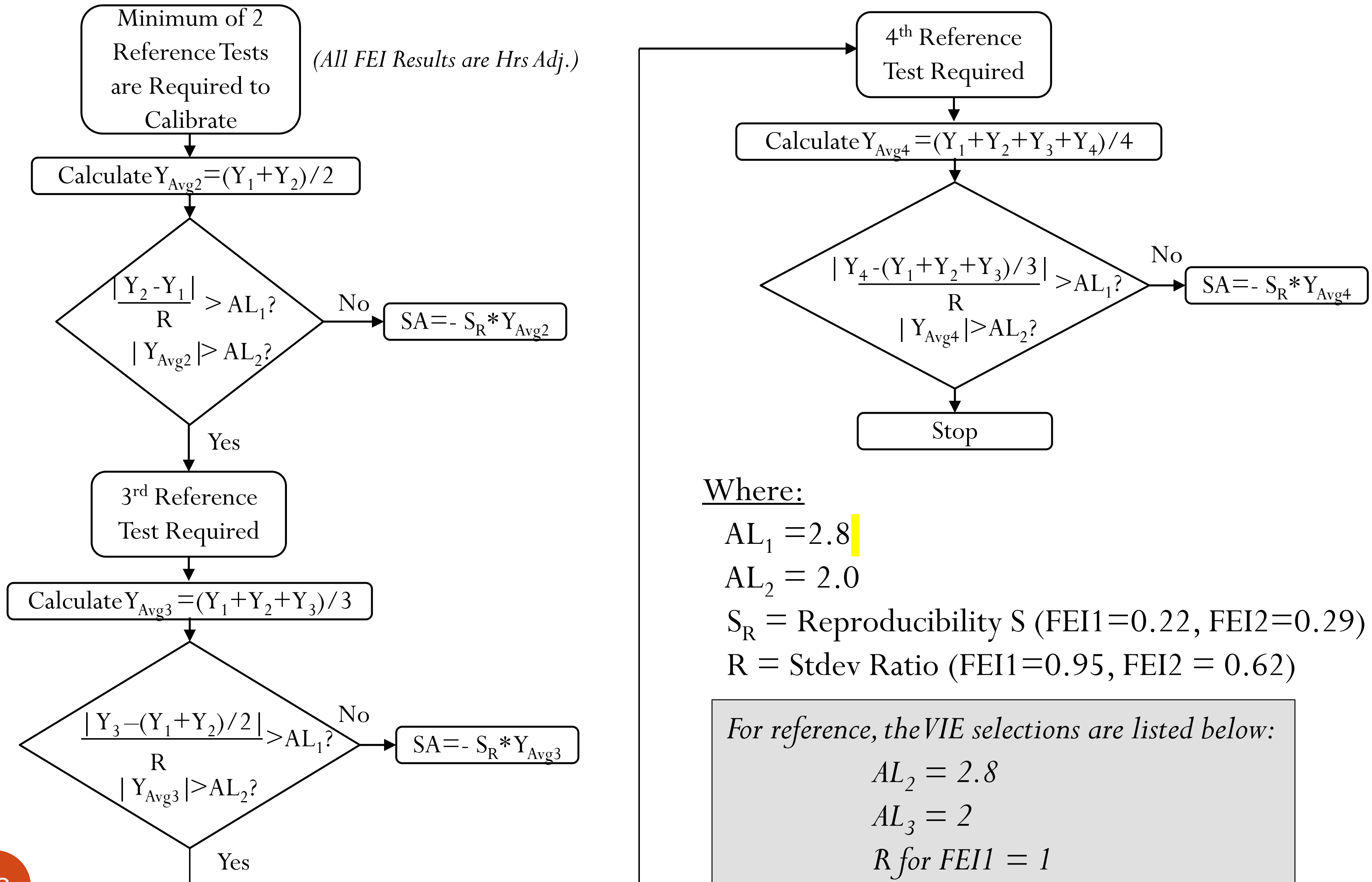
| | Standard Deviation | |
|---|---|---|
| Oil | FEI1 | FEI2 |
| 542-2 (n=7) | 0.20 | 0.18 |
| 1011 (n=6) | 0.17 | 0.36 |
| 543 (n=8) | 0.26 | 0.32 |

- Note that severity adjustment calculation will be based on $S_R$ (reproducibility standard deviation) rather than the individual standard deviation for the oil.
  - FEI1 $S_R = 0.22$
  - FEI2 $S_R = 0.29$



*Note: Oil standard deviations were based on EngHr adjusted data*

# VIF LTMS Flow Chart




<u>Where:</u>

$AL_1 = 2.8$

$AL_2 = 2.0$

$S_R$ = Reproducibility S (FEI1=0.22, FEI2=0.29)

R = Stdev Ratio (FEI1=0.95, FEI2 = 0.62)

*For reference, the VIE selections are listed below:*

*$AL_2 = 2.8$*

*$AL_3 = 2$*

*R for FEI1 = 1*

*R for FEI2 = 0.48*

# VIE Severity - Data Review

Statistics Group

Date: Feb 22, 2017

# Statistics Group

- Arthur Andrews, ExxonMobil
- Doyle Boese, Infineum
- Jo Martinez, Chevron Oronite
- Kevin O'Malley, Lubrizol
- Martin Chadwick, Intertek
- Richard Grundza, TMC
- Lisa Dingwell, Afton
- Todd Dvorak, Afton
- Travis Kostan, SwRI

# Summary

- Analysis of FEI1Yi and FEI2Yi data indicates a severity shift has occurred post matrix for the VIE.
- Analysis of data suggests that the post matrix severity shift is Severity shift is approximately 0.7 and 1.0 Standard deviations severe for FEI1Yi and FEI2Yi, respectively.
- No single factor in the data can be connected with the severity shift.

## - Part 1-

## VIE – Matrix & Postmatrix Analysis

*Includes Chartable =Y*

# VIE Severity - Data Review

- Available VIE data for analysis:
  - N=71 total data points
  - N=29 data points - Matrix
    - 1st run n = 7
    - 2nd run n = 8
    - 3rd run n = 7
    - 4th run n = 7
  - N = 42 data points – Post Matrix
    - 1st run n = 42

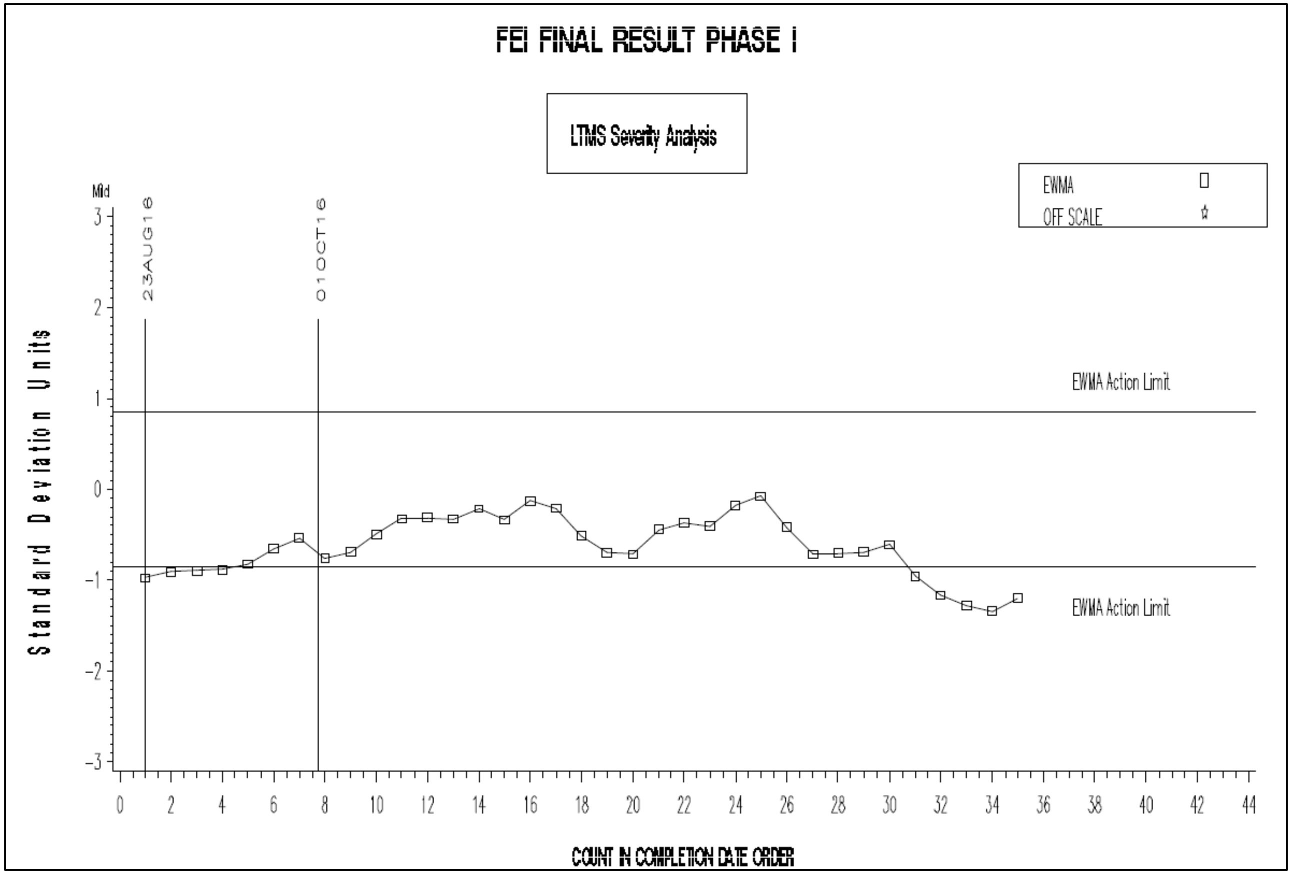


[1] *Note: Post matrix chartable data has no repeat data for the engine within the same lab – thus Stand(Lab) factor selected for analysis.*

# VIE - FEI1Data Review

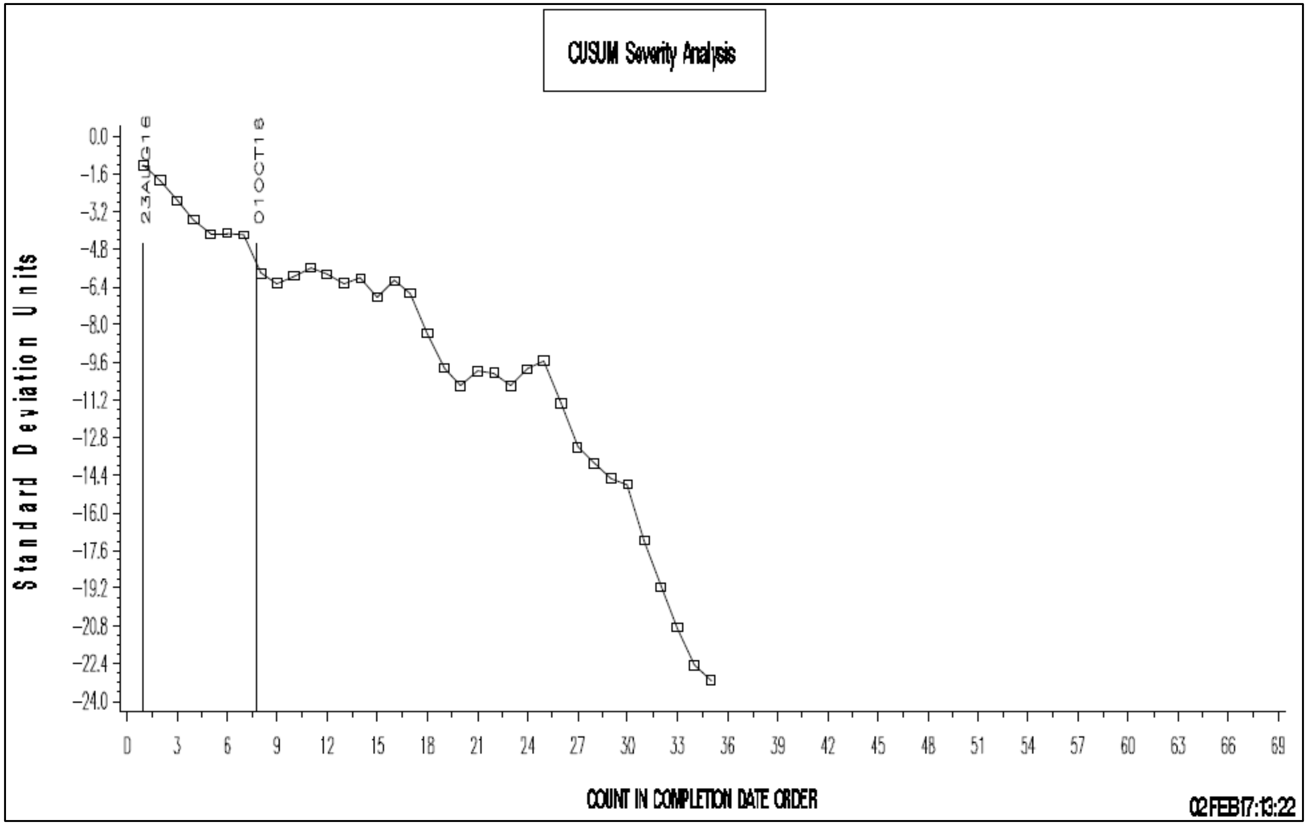
# VIE Severity - Data Review

- Post Matrix, the EWMA chart of the LTMS FEI1 data suggest that the test has been running severe.



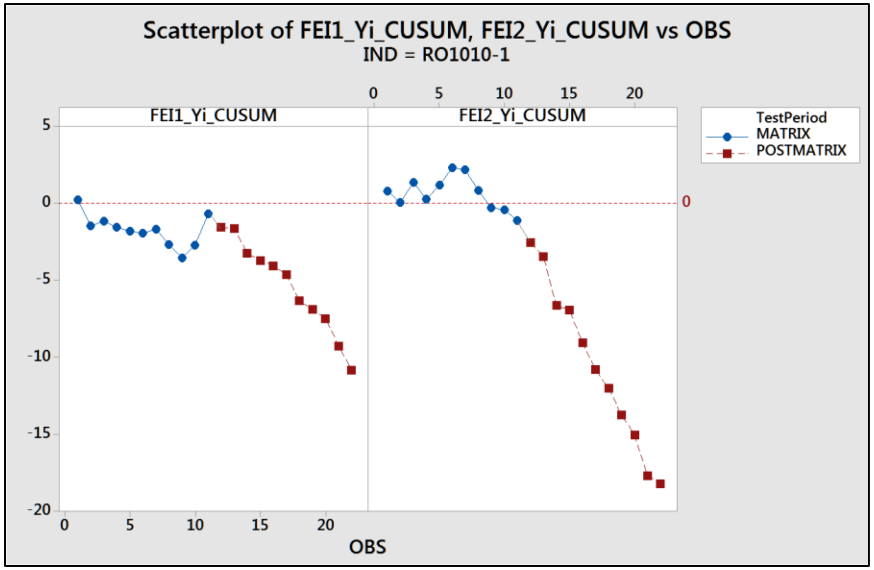
# VIE Severity - Data Review

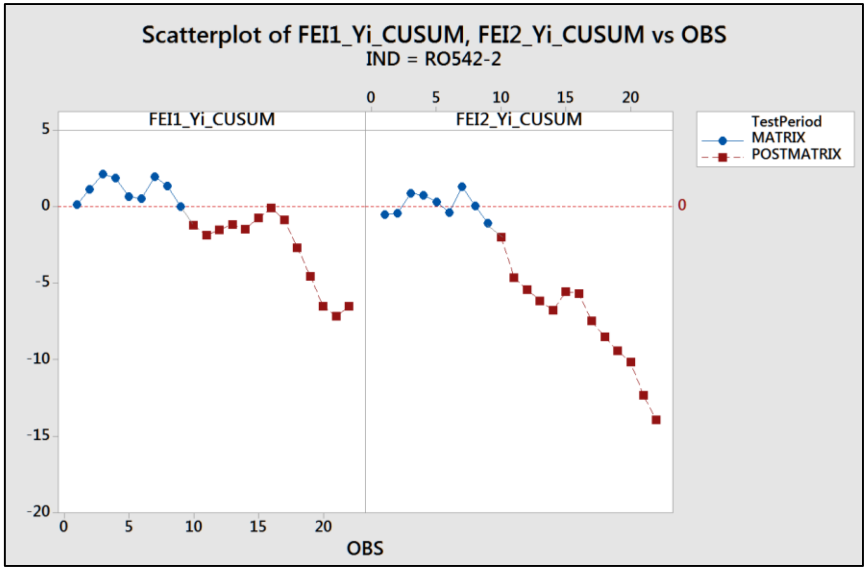
- Post Matrix, the CUSUM chart of the FEI1 LTMS data also suggest that the test has been running severe.

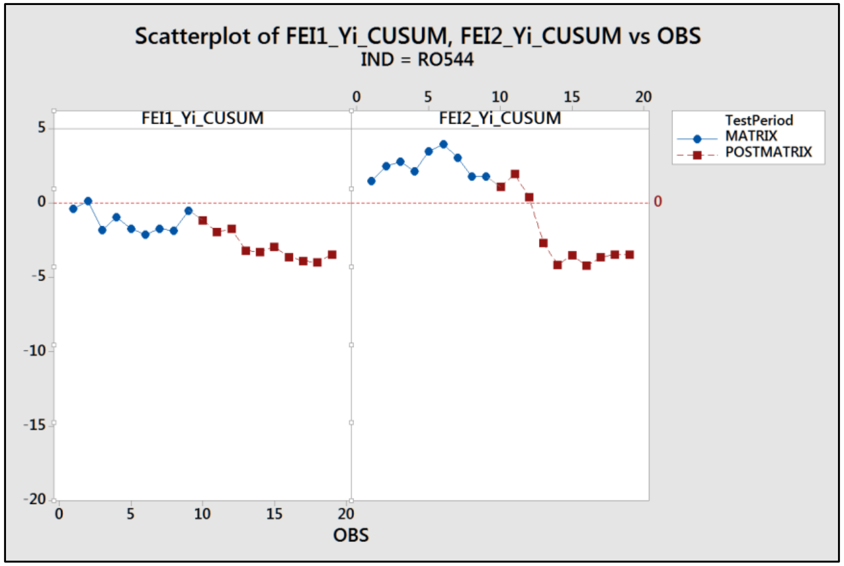


# VIE Severity - Data Review

- CUSUM by Reference oil

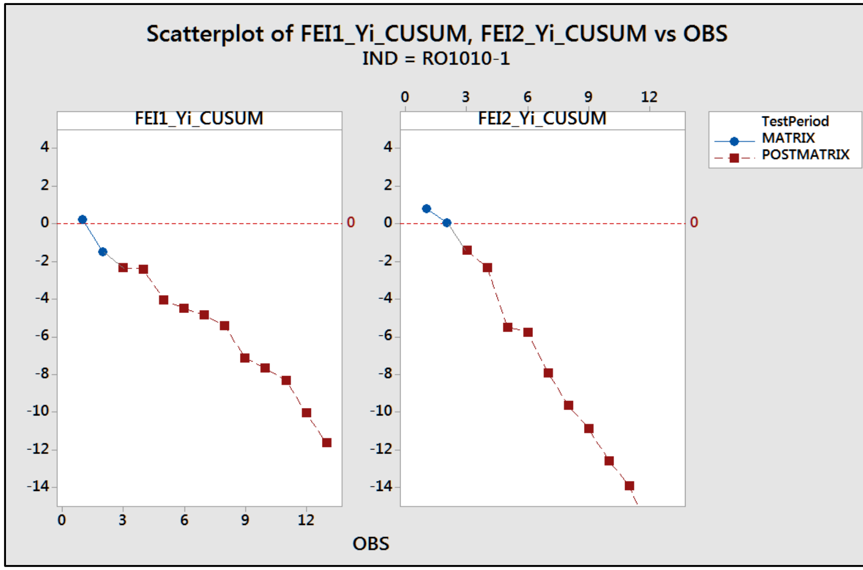


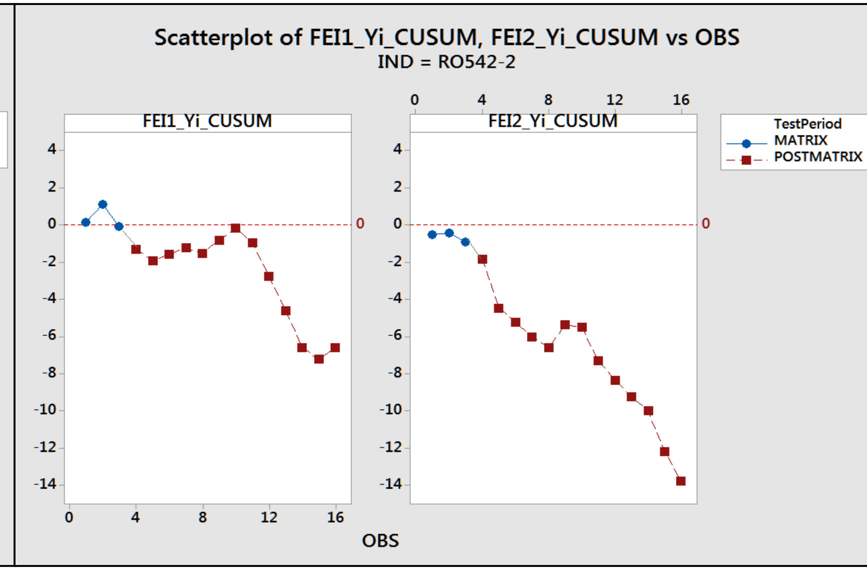



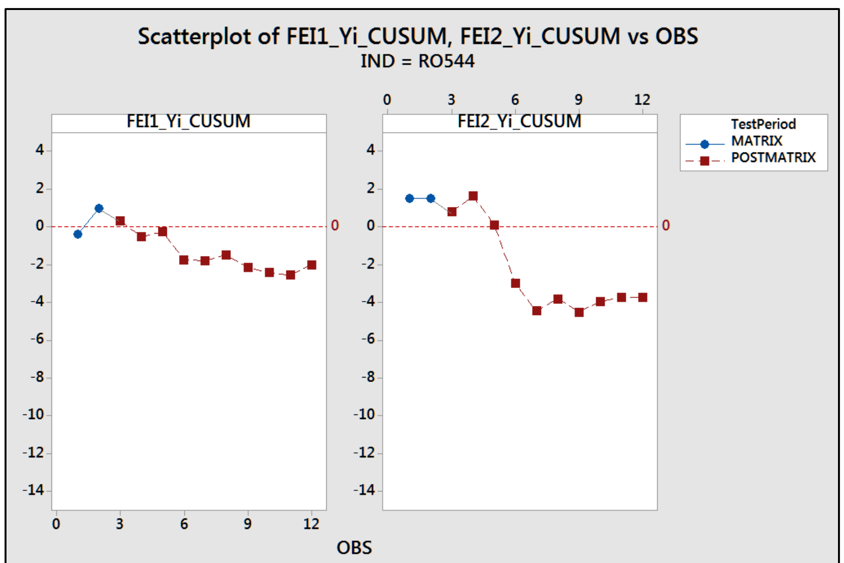



# VIE Severity - Data Review

- CUSUM by Reference oil – first run exclusively



# VIE Severity - Data Review

- Analysis of $Y_i$ data for FEI1 – valid Matrix and Post Matrix
  - Factors for analysis: EngHrs, Lab, Stand(Lab)[1], RefOil, Matrix_Group
  - Analysis suggests that Lab and Stand(Lab) are significant
  - Matrix vs. Post Matrix effect is significant (LSMeans indicate 0.7 StDev severe)
  - No evidence of Oil*Matrix interaction

**Response FEI1_Yi**

**Whole Model**

Actual by Predicted Plot

Summary of Fit

Analysis of Variance

Lack Of Fit

**Parameter Estimates**

| Term | Estimate | Std Error | t Ratio | Prob>\|t\| |
|---|---|---|---|---|
| Intercept | -0.146854 | 0.382765 | -0.38 | 0.7030 |
| LTMSLAB [A] | -0.913105 | 0.252046 | -3.62 | 0.0007* |
| LTMSLAB [B] | 0.7063642 | 0.39554 | 1.79 | 0.0809 |
| LTMSLAB [C] | 0.4113309 | 0.325489 | 1.26 | 0.2128 |
| LTMSLAB [D] | 0.1086434 | 0.230103 | 0.47 | 0.6391 |
| LTMSLAB [F] | -0.440009 | 0.395389 | -1.11 | 0.2717 |
| LTMSLAB [A]:LTMSAPP[10] | 0.2944824 | 0.455256 | 0.65 | 0.5210 |
| LTMSLAB [A]:LTMSAPP[11] | 1.213776 | 0.547544 | 2.22 | 0.0317* |
| LTMSLAB [A]:LTMSAPP[2] | 0.2642025 | 0.48302 | 0.55 | 0.5871 |
| LTMSLAB [A]:LTMSAPP[3] | -0.600231 | 0.461864 | -1.30 | 0.2004 |
| LTMSLAB [A]:LTMSAPP[6] | -1.099441 | 0.722567 | -1.52 | 0.1351 |
| LTMSLAB [A]:LTMSAPP[8] | 0.4461298 | 0.58165 | 0.77 | 0.4471 |
| LTMSLAB [B]:LTMSAPP[1] | -0.560303 | 0.478237 | -1.17 | 0.2475 |
| LTMSLAB [D]:LTMSAPP[1] | 0.3464108 | 0.300534 | 1.15 | 0.2551 |
| LTMSLAB [D]:LTMSAPP[2] | -0.092413 | 0.27468 | -0.34 | 0.7381 |
| LTMSLAB [G]:LTMSAPP[1] | -1.108007 | 0.442508 | -2.50 | 0.0160* |
| LTMSLAB [G]:LTMSAPP[2] | -0.264172 | 0.356272 | -0.74 | 0.4622 |
| LTMSLAB [G]:LTMSAPP[4] | 0.2137108 | 0.461601 | 0.46 | 0.6456 |
| LTMSLAB [G]:LTMSAPP[5] | 0.4405048 | 0.737069 | 0.60 | 0.5531 |
| LTMSLAB [G]:LTMSAPP[6] | 0.7415904 | 0.735131 | 1.01 | 0.3185 |
| RefOil[RO1010-1] | -0.0749 | 0.151765 | -0.49 | 0.6240 |
| RefOil[RO542-2] | 0.0664886 | 0.149874 | 0.44 | 0.6594 |
| Matrix_PostMatrix[MATRIX] | 0.3669047 | 0.183892 | 2.00 | 0.0521 |
| RefOil[RO1010-1]*Matrix_PostMatrix[MATRIX] | 0.1152698 | 0.148762 | 0.77 | 0.4425 |
| RefOil[RO542-2]*Matrix_PostMatrix[MATRIX] | -0.101457 | 0.147009 | -0.69 | 0.4936 |
| ENHREND | -7.874e-5 | 0.000666 | -0.12 | 0.9064 |

LTMSLAB | LTMSAPP[LTMSLAB] | RefOil

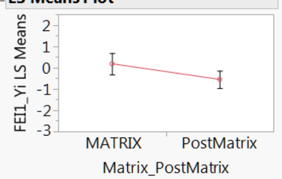
**Matrix_PostMatrix**

Leverage Plot

**Least Squares Means Table**

| Level | Least Sq Mean | Std Error | Mean |
|---|---|---|---|
| MATRIX | 0.1807201 | 0.25075111 | -0.04150 |
| PostMatrix | -0.5530893 | 0.20175099 | -0.67853 |

**LS Means Plot**




**RefOil*Matrix_PostMatrix**

Leverage Plot

**Least Squares Means Table**

| Level | Least Sq Mean | Std Error |
|---|---|---|
| RO1010-1, MATRIX | 0.2210901 | 0.31988145 |
| RO1010-1,PostMatrix | -0.7432590 | 0.28538506 |
| RO542-2, MATRIX | 0.1457519 | 0.32570959 |
| RO542-2,PostMatrix | -0.3851440 | 0.27100833 |
| RO544, MATRIX | 0.1753184 | 0.34630703 |
| RO544,PostMatrix | -0.5308650 | 0.33989415 |

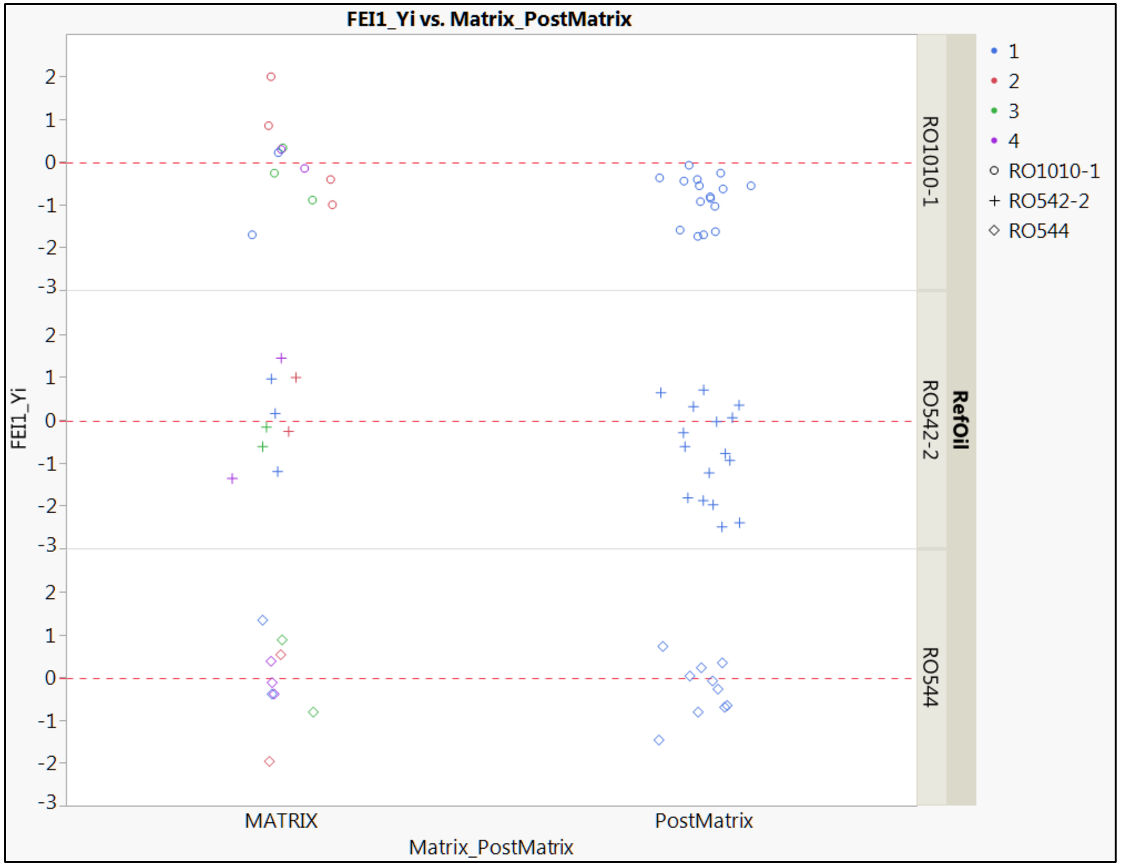
**LS Means Plot**


ENHREND

[1]*Note: Post matrix chartable data has no repeat data for the engine within the same lab – thus Stand(Lab) factor selected for analysis.*

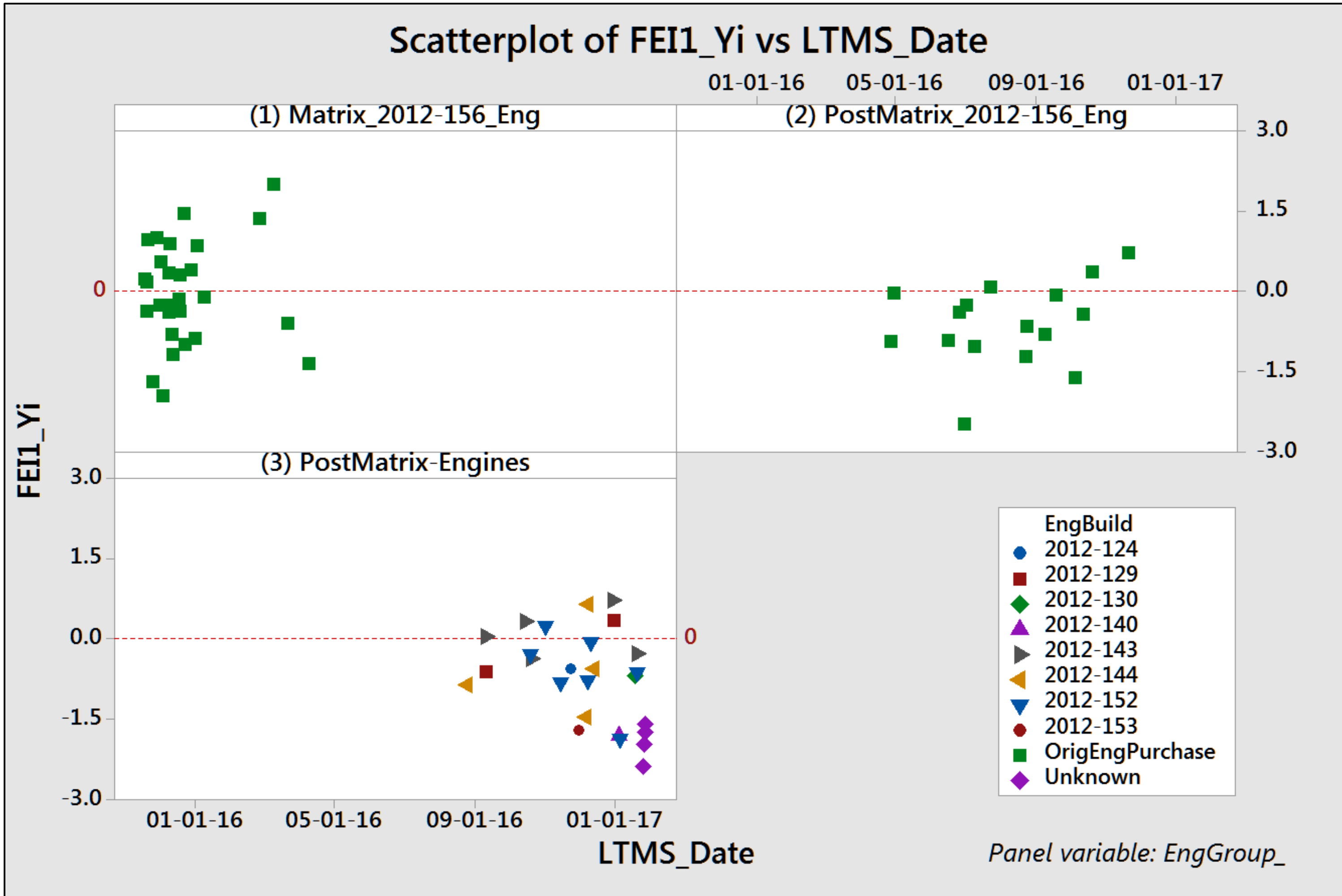
# VIE Severity - Data Review

- Raw data plot of FEI1 Yi data – Matrix and Post Matrix
  - 1st Run post matrix data is generally more severe as compared to matrix data
  - Even though oil*Matrix is not significant, data below suggests that the effect of the severity shift is unequal for the 3 reference oils



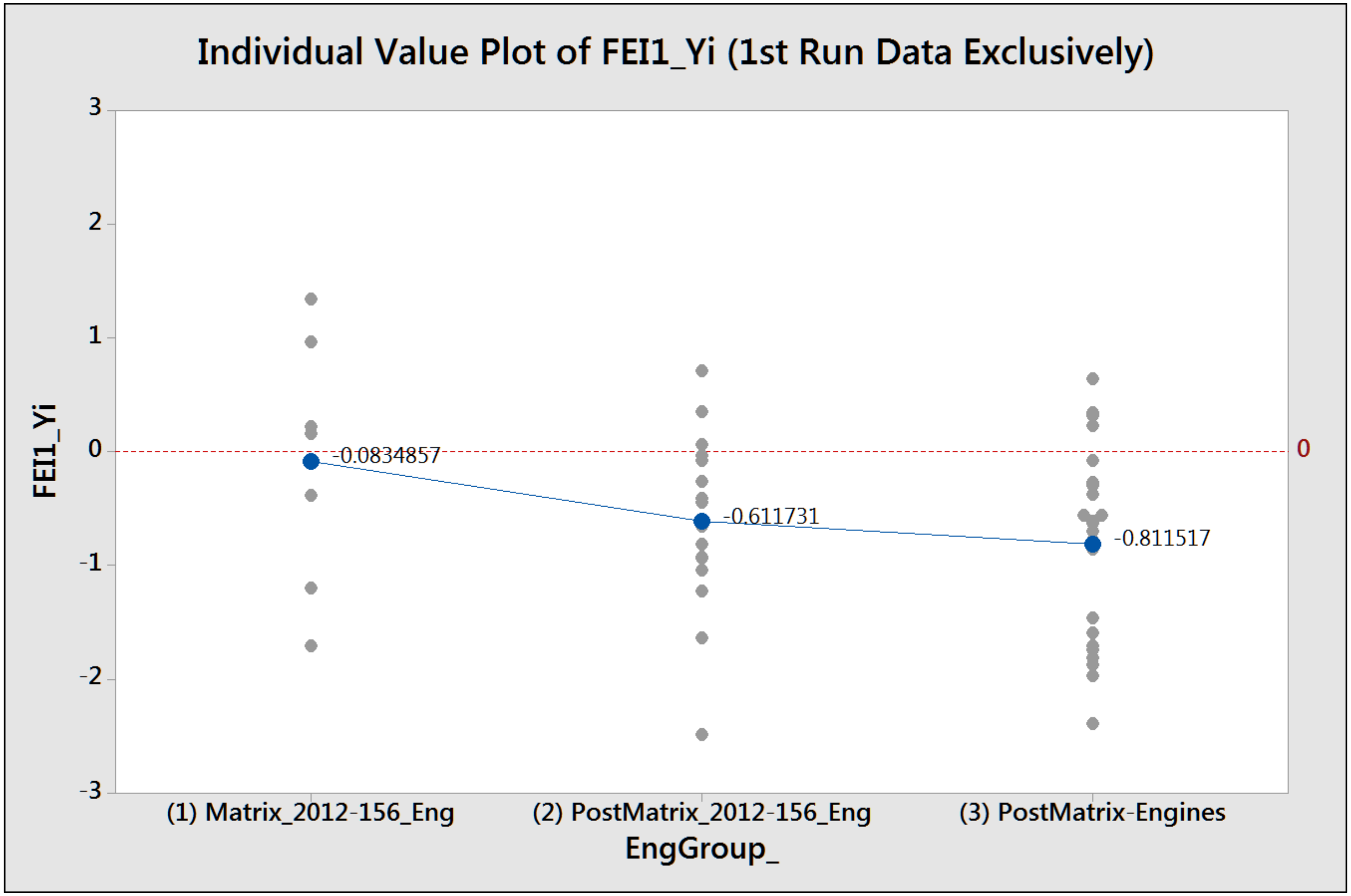
# VIE Severity - Data Review

- Comparison of original matrix engines vs. follow-on purchase for FEI1 $Y_i$



# VIE Severity - Data Review

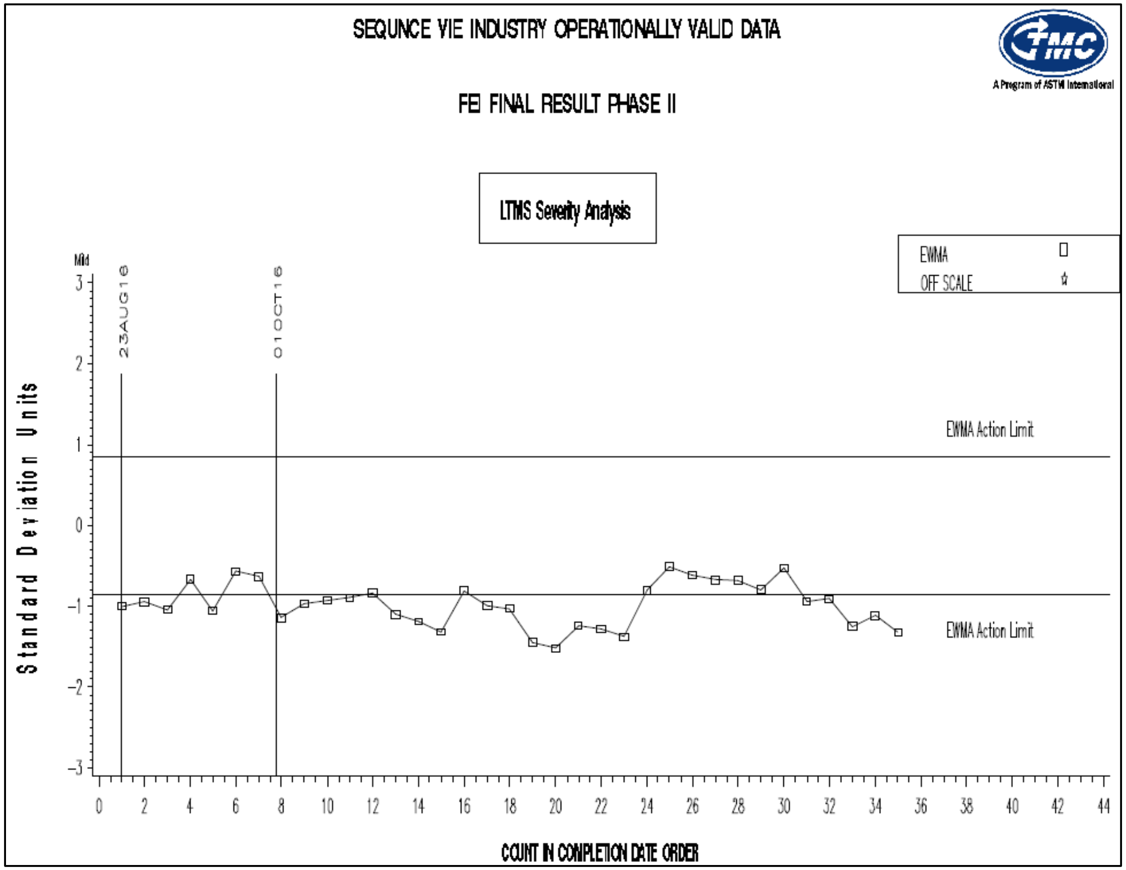
- Comparison of original matrix engines vs. follow-on purchase *(engine run = 1, exclusively)* for FEI1 $Y_i$



# VIE – FEI2 Data Review

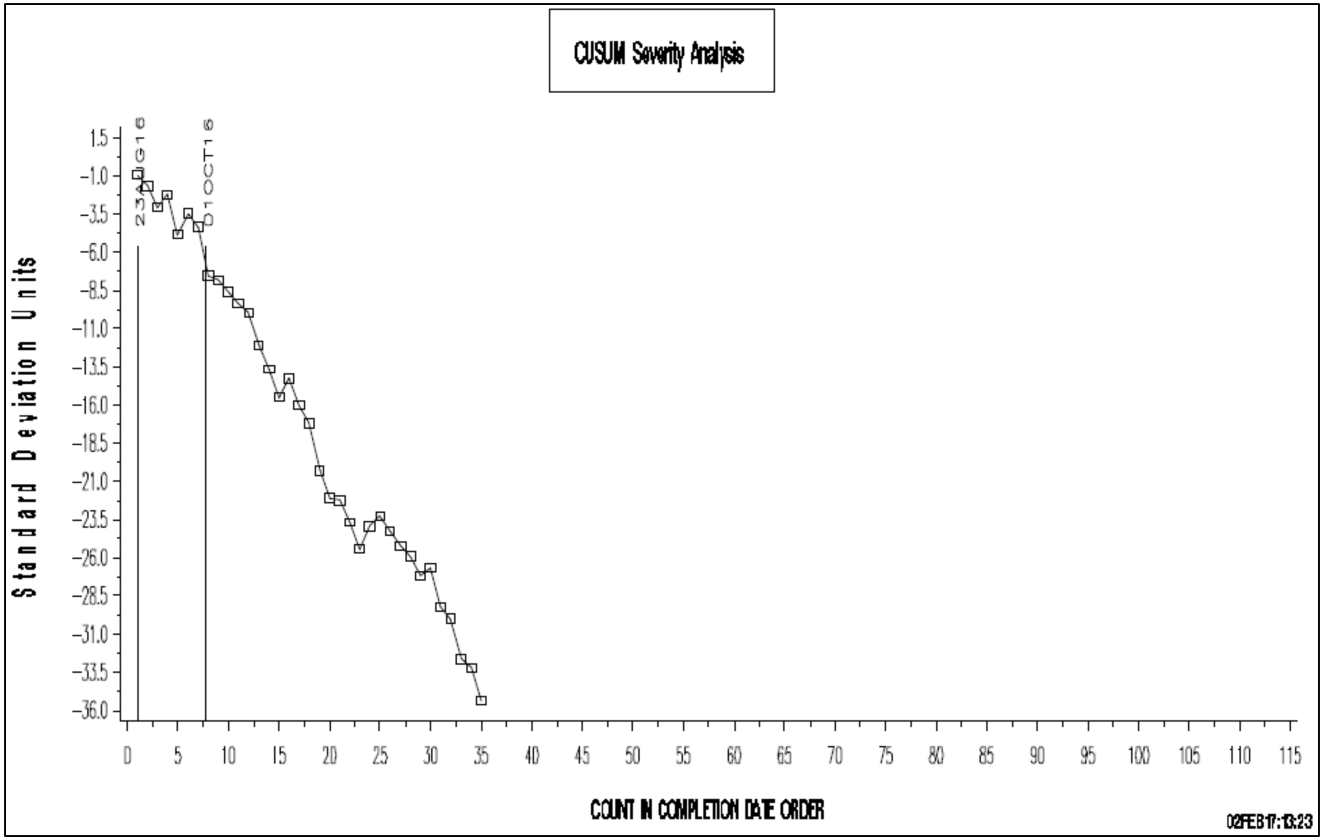
# VIE Severity - Data Review

- Post Matrix, the EWMA chart of the LTMS FEI2 data suggest that the test has been running severe.



# VIE Severity - Data Review

- Post Matrix, the CUSUM chart of the FEI2 LTMS data also suggest that the test has been running severe.



# VIE Severity - Data Review

- Analysis of Yi data for FEI2 – Matrix and Post Matrix
  - Factors for analysis: EngHrs, Lab, Stand(Lab)[1], RefOil, Matrix_Group
  - Analysis suggests that Lab and Stand(Lab) are significant
  - Matrix vs. Post Matrix effect is significant (LS means suggest a 1 StDev severity shift)
  - Evidence of Oil*Matrix interaction

**Response FEI2_Yi**

**Whole Model**

- Actual by Predicted Plot
- Summary of Fit
- Analysis of Variance
- Lack Of Fit
- Parameter Estimates

| Term | Estimate | Std Error | t Ratio | Prob>\|t\| |
|---|---|---|---|---|
| Intercept | -0.247265 | 0.439259 | -0.56 | 0.5763 |
| LTMSLAB [A] | -1.133992 | 0.289247 | -3.92 | 0.0003* |
| LTMSLAB [B] | 1.0179085 | 0.45392 | 2.24 | 0.0299* |
| LTMSLAB [C] | -0.597096 | 0.373529 | -1.60 | 0.1169 |
| LTMSLAB [D] | -0.083371 | 0.264065 | -0.32 | 0.7537 |
| LTMSLAB [F] | 0.6483887 | 0.453747 | 1.43 | 0.1599 |
| LTMSLAB [A]:LTMSAPP[10] | 0.0379226 | 0.52245 | 0.07 | 0.9425 |
| LTMSLAB [A]:LTMSAPP[11] | 0.7347999 | 0.628359 | 1.17 | 0.2484 |
| LTMSLAB [A]:LTMSAPP[2] | -0.115187 | 0.554311 | -0.21 | 0.8363 |
| LTMSLAB [A]:LTMSAPP[3] | -1.159525 | 0.530032 | -2.19 | 0.0339* |
| LTMSLAB [A]:LTMSAPP[6] | -1.178238 | 0.829214 | -1.42 | 0.1622 |
| LTMSLAB [A]:LTMSAPP[8] | 1.2915908 | 0.667498 | 1.93 | 0.0593 |
| LTMSLAB [B]:LTMSAPP[1] | -0.840169 | 0.548823 | -1.53 | 0.1328 |
| LTMSLAB [D]:LTMSAPP[1] | 0.1427553 | 0.344891 | 0.41 | 0.6809 |
| LTMSLAB [D]:LTMSAPP[2] | -0.070995 | 0.315221 | -0.23 | 0.8228 |
| LTMSLAB [G]:LTMSAPP[1] | -1.524173 | 0.507819 | -3.00 | 0.0044* |
| LTMSLAB [G]:LTMSAPP[2] | -0.245533 | 0.408856 | -0.60 | 0.5512 |
| LTMSLAB [G]:LTMSAPP[4] | -0.684766 | 0.52973 | -1.29 | 0.2027 |
| LTMSLAB [G]:LTMSAPP[5] | 1.6257134 | 0.845856 | 1.92 | 0.0610 |
| LTMSLAB [G]:LTMSAPP[6] | 0.8904581 | 0.843632 | 1.06 | 0.2968 |
| RefOil[RO1010-1] | -0.308151 | 0.174164 | -1.77 | 0.0836 |
| RefOil[RO542-2] | 0.1366406 | 0.171995 | 0.79 | 0.4311 |
| Matrix_PostMatrix[MATRIX] | 0.4992174 | 0.211034 | 2.37 | 0.0224* |
| RefOil[RO1010-1]*Matrix_PostMatrix[MATRIX] | 0.3760736 | 0.170719 | 2.20 | 0.0328* |
| RefOil[RO542-2]*Matrix_PostMatrix[MATRIX] | -0.258004 | 0.168706 | -1.53 | 0.1332 |
| ENHREND | 0.0001755 | 0.000764 | 0.23 | 0.8194 |

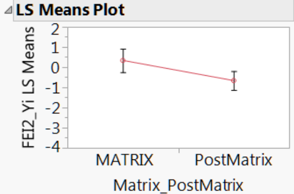
LTMSLAB | LTMSAPP[LTMSLAB] | RefOil

**Matrix_PostMatrix**

- Leverage Plot
- Least Squares Means Table

| Level | Least Sq Mean | Std Error | Mean |
|---|---|---|---|
| MATRIX | 0.3396268 | 0.28776056 | -0.0107 |
| PostMatrix | -0.6588080 | 0.23152830 | -1.0491 |

- LS Means Plot

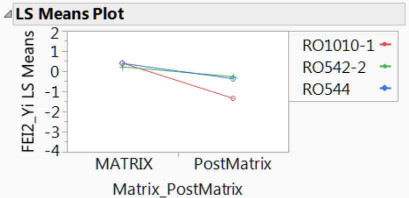



**RefOil*Matrix_PostMatrix**

- Leverage Plot
- Least Squares Means Table

| Level | Least Sq Mean | Std Error |
|---|---|---|
| RO1010-1, MATRIX | 0.407549 | 0.36709415 |
| RO1010-1,PostMatrix | -1.343033 | 0.32750628 |
| RO542-2, MATRIX | 0.218264 | 0.37378248 |
| RO542-2,PostMatrix | -0.264164 | 0.31100763 |
| RO544, MATRIX | 0.393068 | 0.39741999 |
| RO544,PostMatrix | -0.369228 | 0.39006060 |

- LS Means Plot

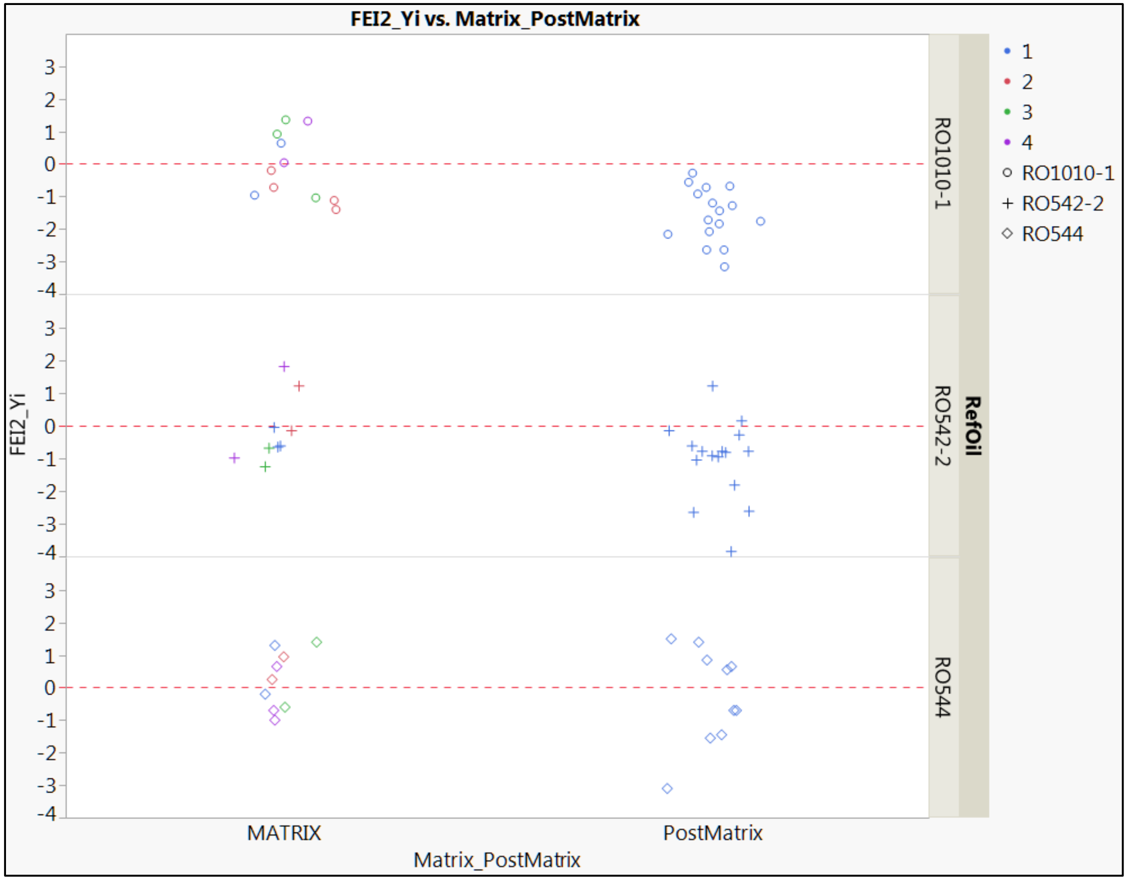



ENHREND

[1] *Note: Post matrix chartable data has no repeat data for the engine within the same lab – thus Stand(Lab) factor selected for analysis.*

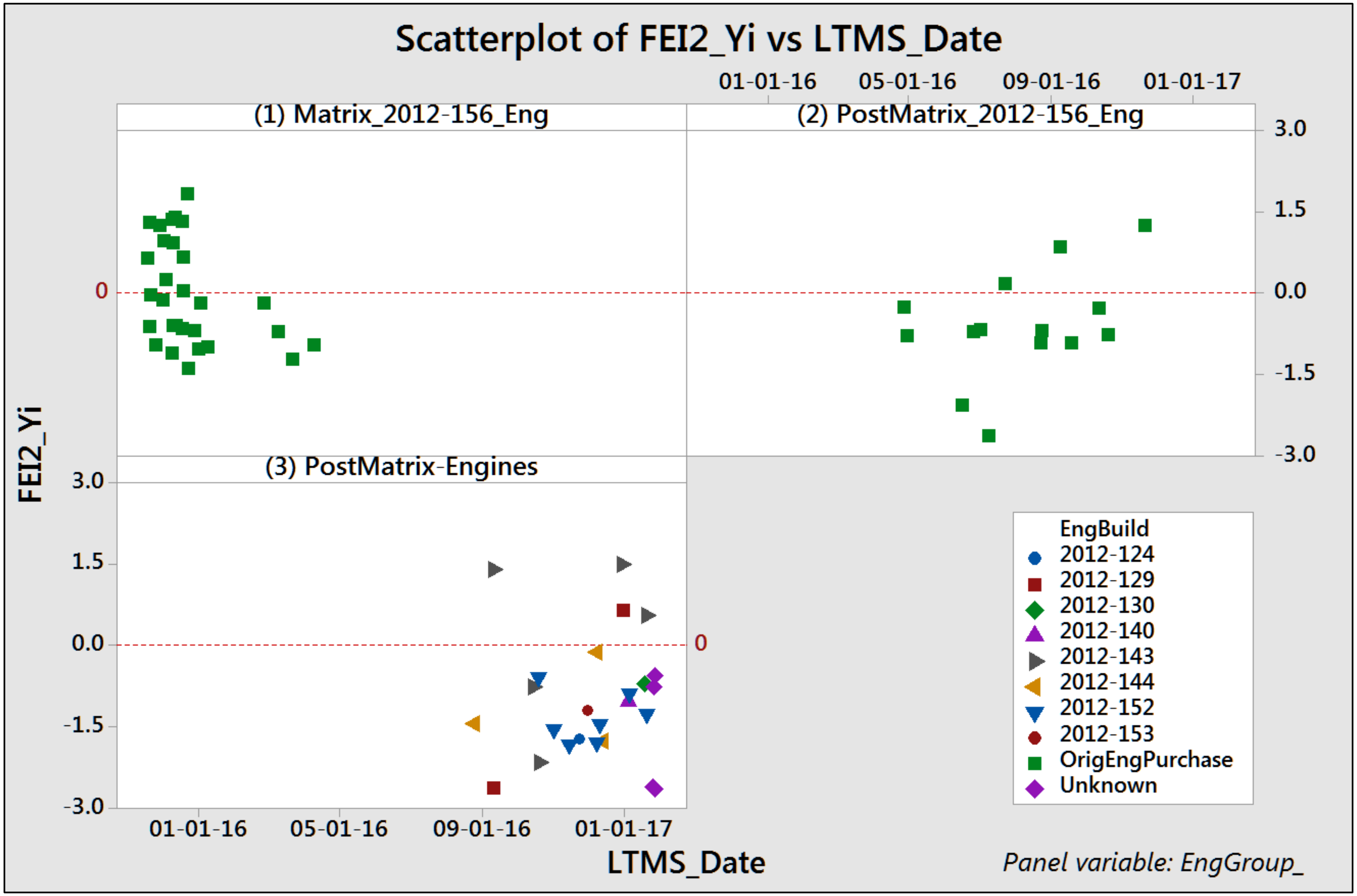
# VIE Severity - Data Review

- Raw data plot of FEI2 Yi data – Matrix and Post Matrix
  - 1st Run post matrix data is generally more severe as compared to matrix data
  - Even though oil*Matrix is not significant, data below suggests that the effect of the severity shift is unequal for the 3 reference oils



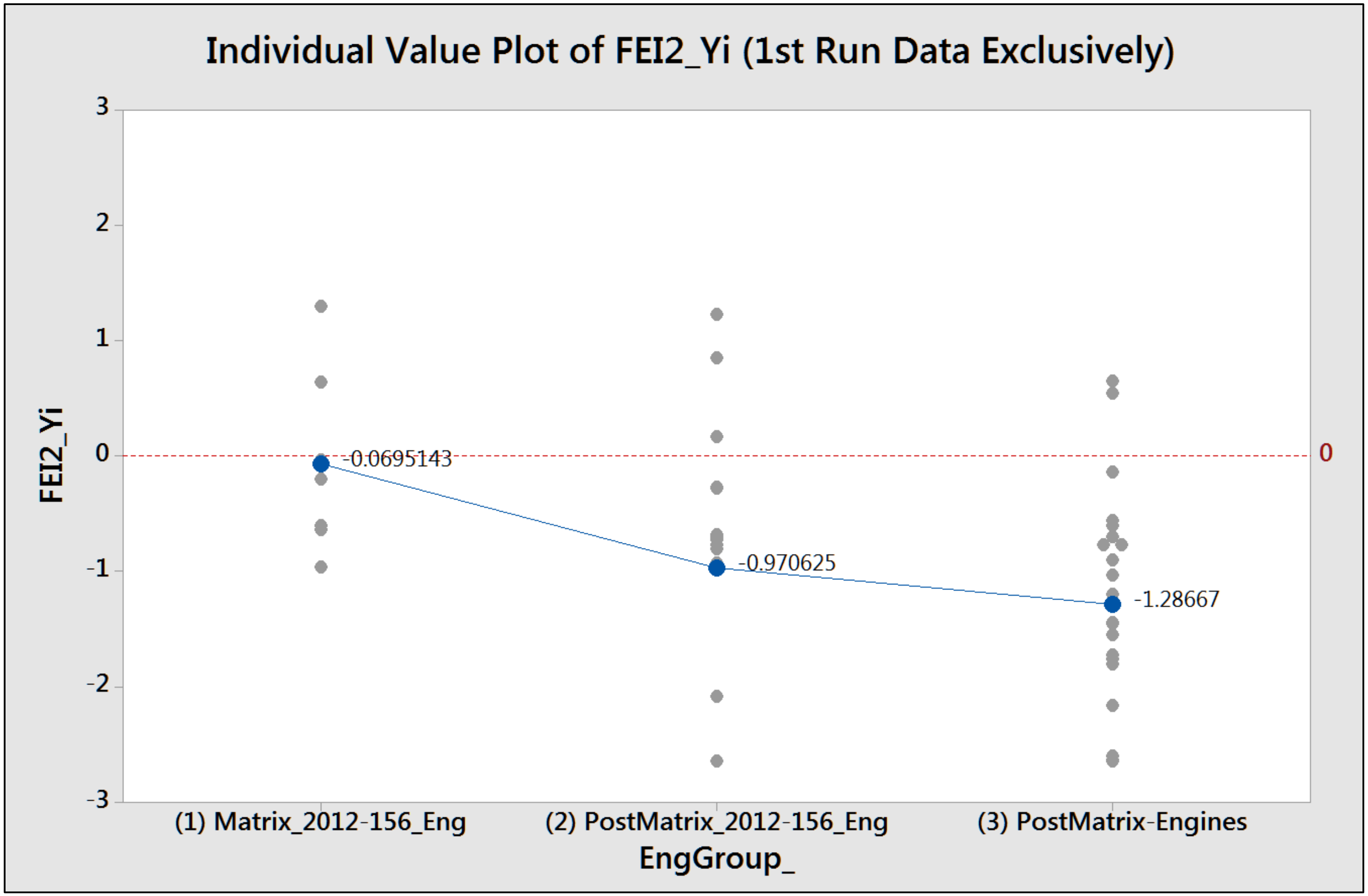
# VIE Severity - Data Review

- Comparison of original matrix engines vs. follow-on for FEI2$Y_i$



# VIE Severity - Data Review

- Comparison of original matrix engines vs. follow-on purchase *(engine run = 1, exclusively)* for FEI2 $Y_i$



## - Part 2-

## VIE – Matrix & Postmatrix Analysis

*Includes Chartable =Y & N*

# Summary

## FEI 1

- Post-precision matrix data is estimated to be about 0.5 standard deviations more severe than in precision matrix, on average.
- Oil 544 has seen the smallest change is severity, but this difference is not statistically significantly different from the other two oils.
- OHT-2 engines average approx. 0.25 standard deviations more severe than OHT-1 engines, though this difference is not consistent across oils, nor statistically different from zero.
- Current coefficient used in the engine hour correction may be too steep.

## FEI 2

- Post-precision matrix data is estimated to be about 1.0 standard deviations more severe than in precision matrix, on average, though 1010-1 has statistically shifted more severe than the other two oils, with a change in severity of 1.45 standard deviations.
- OHT-2 engines average approx. 0.25 standard deviations more severe than OHT-1 engines, though this difference is not statistically different from zero.
- Oils do not discriminate post-precision matrix.
- Engine hour correction appears to be appropriate.

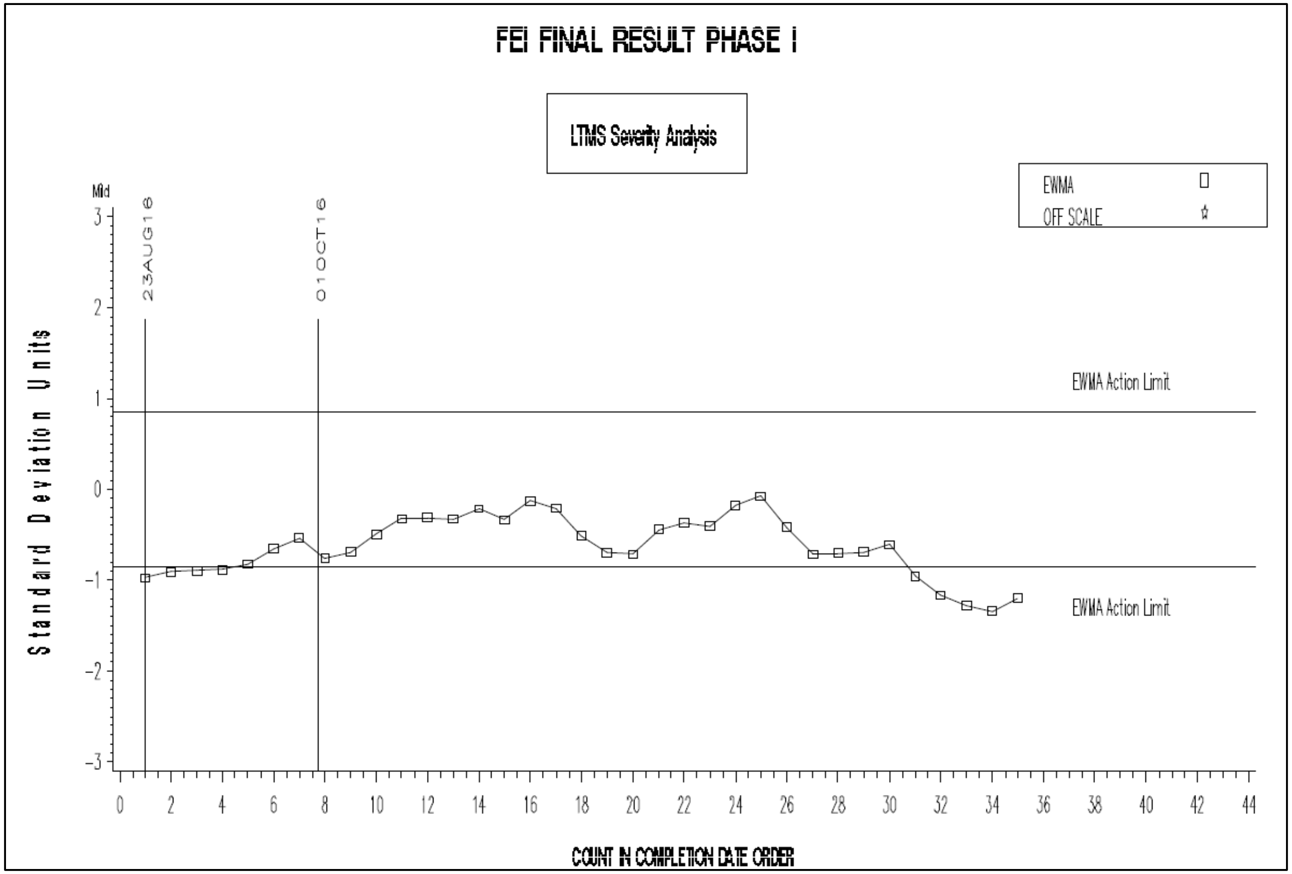
# VIE Severity - Data Review

- Available VIE data for analysis:
  - N=71 total data points
  - N=29 data points - Matrix
    - $1^{st}$ run n = 7
    - $2^{nd}$ run n = 8
    - $3^{rd}$ run n = 7
    - $4^{th}$ run n = 7
  - N = 54 data points – Post Matrix
    - $1^{st}$ run n = 45 (346 < ENHREND < 586)
      - 8 data points with VAL = "NN" during period immediately following precision matrix.
      - 3 data points from abandoned engines
    - $2^{nd}$ run n = 2 (585 < ENHREND < 678)
      - Both from abandoned engines
    - $5^{th}$ run n = 7 (1161 < ENHREND < 1252)
      - *This data is not included unless stated.

# VIE - FEI1Data Review

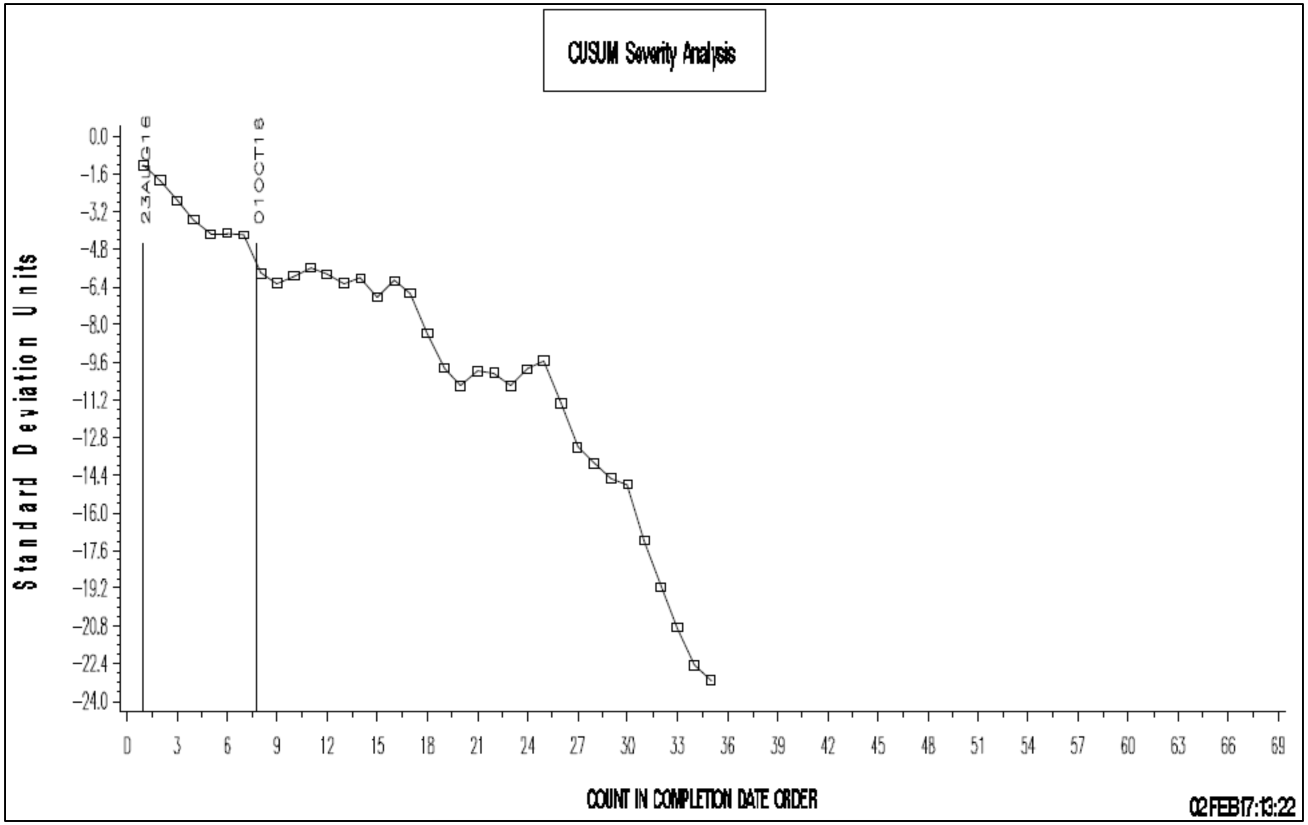
# VIE Severity - Data Review

- Post Matrix, the EWMA chart of the LTMS FEI1 data suggest that the test has been running severe.



# VIE Severity - Data Review

- Post Matrix, the CUSUM chart of the FEI1 LTMS data also suggest that the test has been running severe.



# VIE Severity - Data Review

- Analysis of $Y_i$ data for FEI1 – valid Matrix and Post Matrix **(Full Model)**
  - Model: EngHrs, Lab, Stand(Lab)[1], Oil, Matrix_Group, Matrix_Group*Oil
  - Analysis suggests that Lab term is significant.
  - Matrix vs. Post Matrix term is marginally significant
  - No evidence of Oil*Matrix interaction

**Parameter Estimates**

| Term | Estimate | Std Error | t Ratio | Prob>\|t\| | VIF |
|---|---|---|---|---|---|
| Intercept | -0.465213 | 0.26258 | -1.77 | 0.0819 | . |
| IND[1010-1] | -0.03901 | 0.153097 | -0.25 | 0.7998 | 1.6584193 |
| IND[542-2] | 0.0440368 | 0.152889 | 0.29 | 0.7744 | 1.5791737 |
| LTMSLAB[ A] | -0.938678 | 0.245209 | -3.83 | 0.0003* | 3.6174443 |
| LTMSLAB[ B] | 0.6753073 | 0.419594 | 1.61 | 0.1131 | 6.4929264 |
| LTMSLAB[ C] | 0.4633799 | 0.349728 | 1.32 | 0.1906 | 4.2776511 |
| LTMSLAB[ D] | 0.103154 | 0.234859 | 0.44 | 0.6622 | 3.3185252 |
| LTMSLAB[ F] | -0.389023 | 0.423284 | -0.92 | 0.3620 | 5.5661436 |
| LTMSLAB[ A]:LTMSAPP[1] | 0.3485818 | 0.643617 | 0.54 | 0.5902 | 3.3042117 |
| LTMSLAB[ A]:LTMSAPP[2] | 0.3300329 | 0.506914 | 0.65 | 0.5177 | 2.7550128 |
| LTMSLAB[ A]:LTMSAPP[3] | -0.534893 | 0.491105 | -1.09 | 0.2807 | 2.2587215 |
| LTMSLAB[ A]:LTMSAPP[6] | -1.001276 | 0.791875 | -1.26 | 0.2113 | 4.1107959 |
| LTMSLAB[ A]:LTMSAPP[8] | 0.4753931 | 0.538164 | 0.88 | 0.3808 | 2.7123412 |
| LTMSLAB[ A]:LTMSAPP[9] | -0.420197 | 0.791896 | -0.53 | 0.5978 | 4.1110138 |
| LTMSLAB[ A]:LTMSAPP[10] | 0.3477402 | 0.492354 | 0.71 | 0.4829 | 2.2702239 |
| LTMSLAB[ B]:LTMSAPP[1] | -0.504746 | 0.509005 | -0.99 | 0.3256 | 2.3259762 |
| LTMSLAB[ D]:LTMSAPP[1] | 0.3611862 | 0.294649 | 1.23 | 0.2254 | 1.2784731 |
| LTMSLAB[ D]:LTMSAPP[2] | -0.026573 | 0.268376 | -0.10 | 0.9215 | 1.4188356 |
| LTMSLAB[ G]:LTMSAPP[1] | -1.297437 | 0.426479 | -3.04 | 0.0036* | 1.8443425 |
| LTMSLAB[ G]:LTMSAPP[2] | 0.0676404 | 0.37521 | 0.18 | 0.8576 | 1.891294 |
| LTMSLAB[ G]:LTMSAPP[4] | 0.0257212 | 0.449693 | 0.06 | 0.9546 | 1.3256962 |
| LTMSLAB[ G]:LTMSAPP[5] | 0.4449461 | 0.784615 | 0.57 | 0.5729 | 1.6500893 |
| LTMSLAB[ G]:LTMSAPP[6] | 0.7928279 | 0.784558 | 1.01 | 0.3166 | 1.6498493 |
| MatrixGroup[Matrix] | 0.2671708 | 0.159474 | 1.68 | 0.0994 | 2.57227 |
| ENHREND | 0.0004784 | 0.000383 | 1.25 | 0.2173 | 1.2025656 |
| MatrixGroup[Matrix]*IND[1010-1] | 0.0854444 | 0.152215 | 0.56 | 0.5768 | 1.6633092 |
| MatrixGroup[Matrix]*IND[542-2] | -0.066601 | 0.152034 | -0.44 | 0.6630 | 1.561559 |

**Effect Tests**

| Source | Nparm | DF | Sum of Squares | F Ratio | Prob > F |
|---|---|---|---|---|---|
| IND | 2 | 2 | 0.080525 | 0.0540 | 0.9475 |
| LTMSLAB | 5 | 5 | 15.442425 | 4.1391 | 0.0029* |
| LTMSAPP[LTMSLAB] | 15 | 15 | 14.272079 | 1.2751 | 0.2485 |
| MatrixGroup | 1 | 1 | 2.094281 | 2.8067 | 0.0994 |
| ENHREND | 1 | 1 | 1.161892 | 1.5571 | 0.2173 |
| MatrixGroup*IND | 2 | 2 | 0.283289 | 0.1898 | 0.8276 |

**Least Squares Means Table**

| Level | Least Sq Mean | Std Error | Mean |
|---|---|---|---|
| Matrix | 0.0698997 | 0.23015411 | -0.04150 |
| PostMatrix | -0.4644418 | 0.19340254 | -0.69679 |

**Least Squares Means Table**

| Level | Least Sq Mean |
|---|---|
| Matrix,1010-1 | 0.1163337 |
| Matrix,542-2 | 0.0473355 |
| Matrix,544 | 0.0460300 |
| PostMatrix,1010-1 | -0.5888966 |
| PostMatrix,542-2 | -0.3538039 |
| PostMatrix,544 | -0.4506248 |



[1]*Note: Post matrix chartable data has no repeat data for the engine within the same lab – thus Stand(Lab) factor selected for analysis.*

# VIE Severity - Data Review

- Analysis of $Y_i$ data for FEI1 – valid Matrix and Post Matrix **(Significant Terms Only)**
  - Model: FEI1_Yi ~ Lab, Matrix_Group
  - Analysis suggests FEI1 data post-precision matrix is approx. 0.45 standard deviations more severe than in the precision matrix.

**Parameter Estimates**

| Term | Estimate | Std Error | t Ratio | Prob>\|t\| | VIF |
|---|---|---|---|---|---|
| Intercept | -0.265379 | 0.123055 | -2.16 | 0.0342* | . |
| LTMSLAB[ A] | -0.73195 | 0.214106 | -3.42 | 0.0010* | 2.632764 |
| LTMSLAB[ B] | 0.3978742 | 0.299514 | 1.33 | 0.1880 | 3.1582132 |
| LTMSLAB[ C] | 0.6047716 | 0.327599 | 1.85 | 0.0688 | 3.5830737 |
| LTMSLAB[ D] | 0.129845 | 0.214106 | 0.61 | 0.5460 | 2.632764 |
| LTMSLAB[ F] | -0.234407 | 0.397426 | -0.59 | 0.5571 | 4.6841352 |
| MatrixGroup[Matrix] | 0.2259367 | 0.116665 | 1.94 | 0.0565 | 1.3141521 |

**Effect Tests**

| Source | Nparm | DF | Sum of Squares | F Ratio | Prob > F |
|---|---|---|---|---|---|
| LTMSLAB | 5 | 5 | 13.509689 | 3.4567 | 0.0072* |
| MatrixGroup | 1 | 1 | 2.931580 | 3.7505 | 0.0565 |

**Least Squares Means Table**

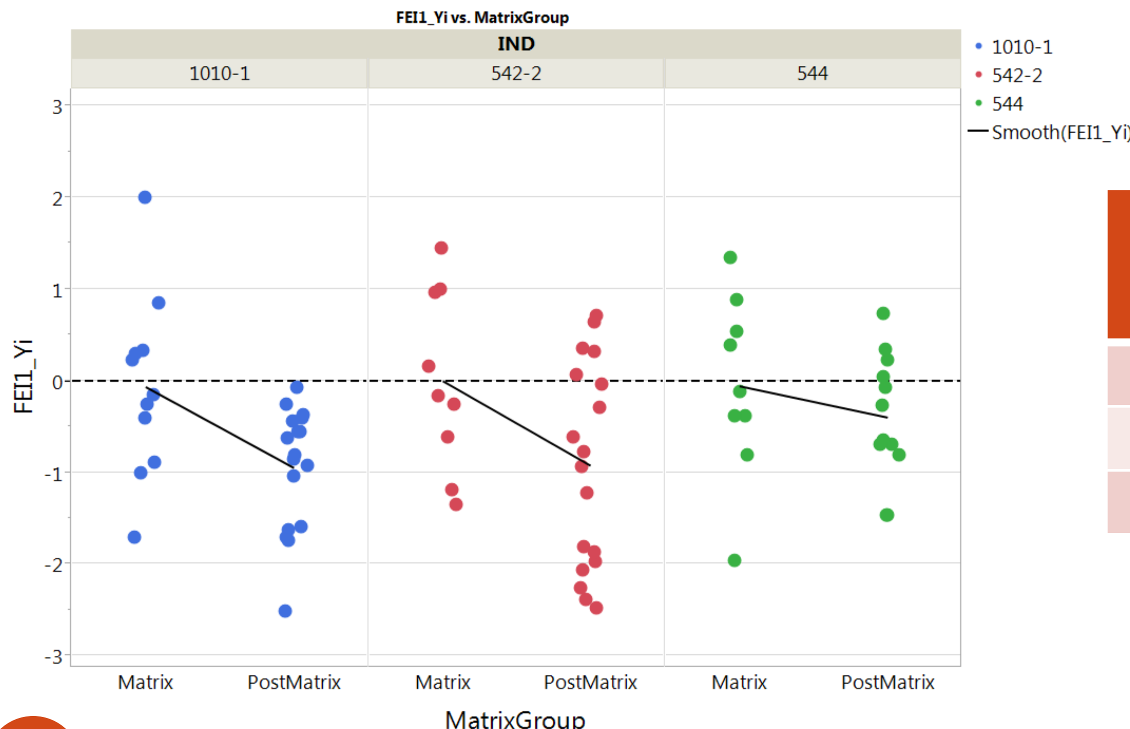
| Level | Least Sq Mean | Std Error | Mean |
|---|---|---|---|
| A | -0.9973296 | 0.20600263 | -1.1372 |
| B | 0.1324948 | 0.33457631 | 0.1648 |
| C | 0.3393922 | 0.36921991 | 0.4900 |
| D | -0.1355344 | 0.20600263 | -0.2754 |
| F | -0.4997867 | 0.45718915 | -0.2738 |
| G | -0.4315128 | 0.18460996 | -0.5068 |

**Least Squares Means Table**

| Level | Least Sq Mean | Std Error | Mean |
|---|---|---|---|
| Matrix | -0.0394427 | 0.16635219 | -0.04150 |
| PostMatrix | -0.4913162 | 0.17272372 | -0.69679 |

# VIE Severity - Data Review

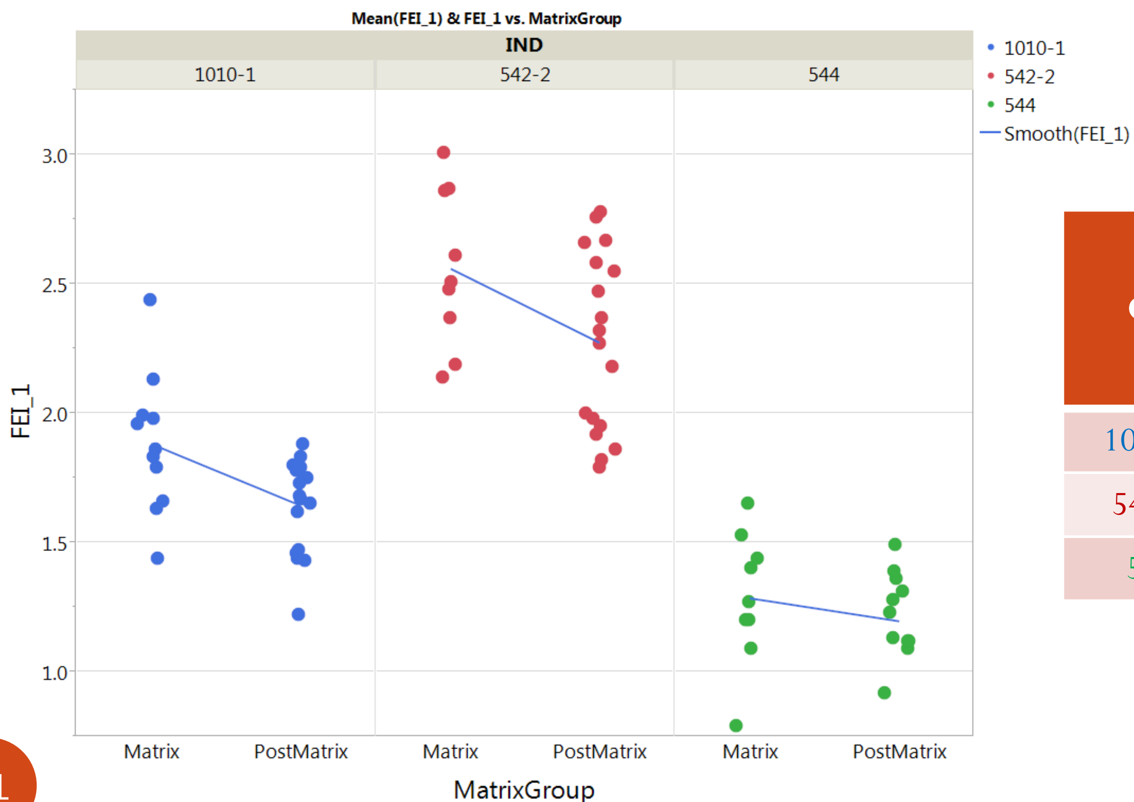
- Plot of FEI1 Yi data by Oil, Matrix Group
  - Matrix and Post Matrix where ENRUN <= 4
  - Post-matrix data is generally more severe as compared to matrix data
  - On average, oil 544 has not seen as large of a severity shift, though it was seen previously that these differences in shift magnitude are not statistically significantly different.




| Oil | Matrix Avg. Yi | Post-Matrix Avg. Yi | Delta in Avg. Yi's. |
|---|---|---|---|
| 1010-1 | -0.06 | -0.95 | -0.89 |
| 542-2 | 0.00 | -0.92 | -0.92 |
| 544 | -0.06 | -0.40 | -0.34 |

# VIE Severity - Data Review

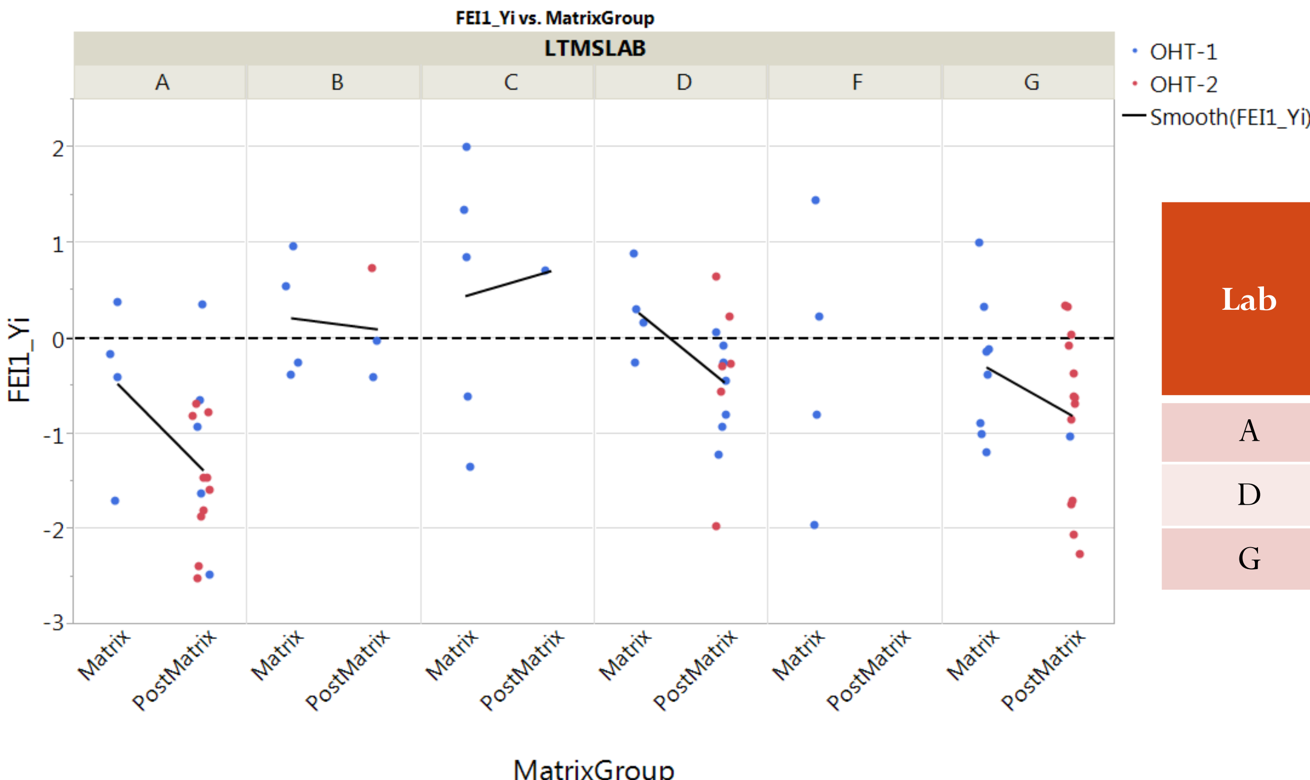
- Plot of FEI1 data by Oil, Matrix Group
  - Matrix and Post Matrix where ENRUN <= 4
  - Post-matrix data is generally more severe as compared to matrix data
  - On average, oil 544 has not seen as large of a severity shift, though it was seen previously that these differences in shift magnitude are not statistically significantly different.




| Oil | Matrix Avg. FEI1 | Post-Matrix Avg. FEI1 | Delta in Avg. FEI1 |
|---|---|---|---|
| 1010-1 | 1.88 | 1.64 | -0.24 |
| 542-2 | 2.56 | 2.27 | -0.29 |
| 544 | 1.29 | 1.20 | -0.09 |

# VIE Severity - Data Review

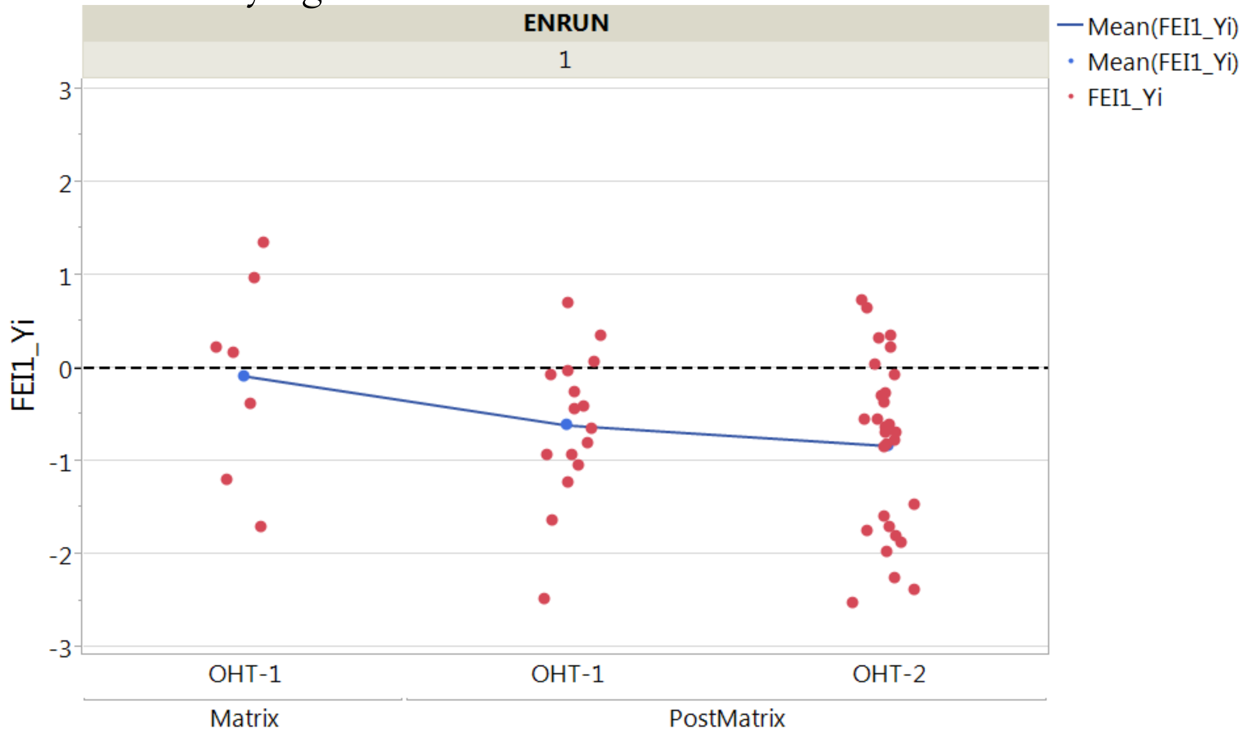
- Plot of FEI1 Yi data by Lab, Matrix Group, Colored by Engine Batch
- The 3 labs with the most data (A, D, and G) have all experienced a similar shift post-matrix in FEI1 Yi, from 0.51 to 0.91 standard deviations more severe.
- Data looks similar for OHT-1 and OHT-2 engines post-matrix in labs A and D where multiple data points are available for comparison.




| Lab | Matrix Avg. FEI1 Yi | Post-Matrix Avg. FEI1 Yi | Delta in Avg. FEI1 Yi |
|---|---|---|---|
| A | -0.47 | -1.38 | -0.91 |
| D | 0.27 | -0.46 | -0.73 |
| G | -0.30 | -0.81 | -0.51 |

# VIE Severity - Data Review

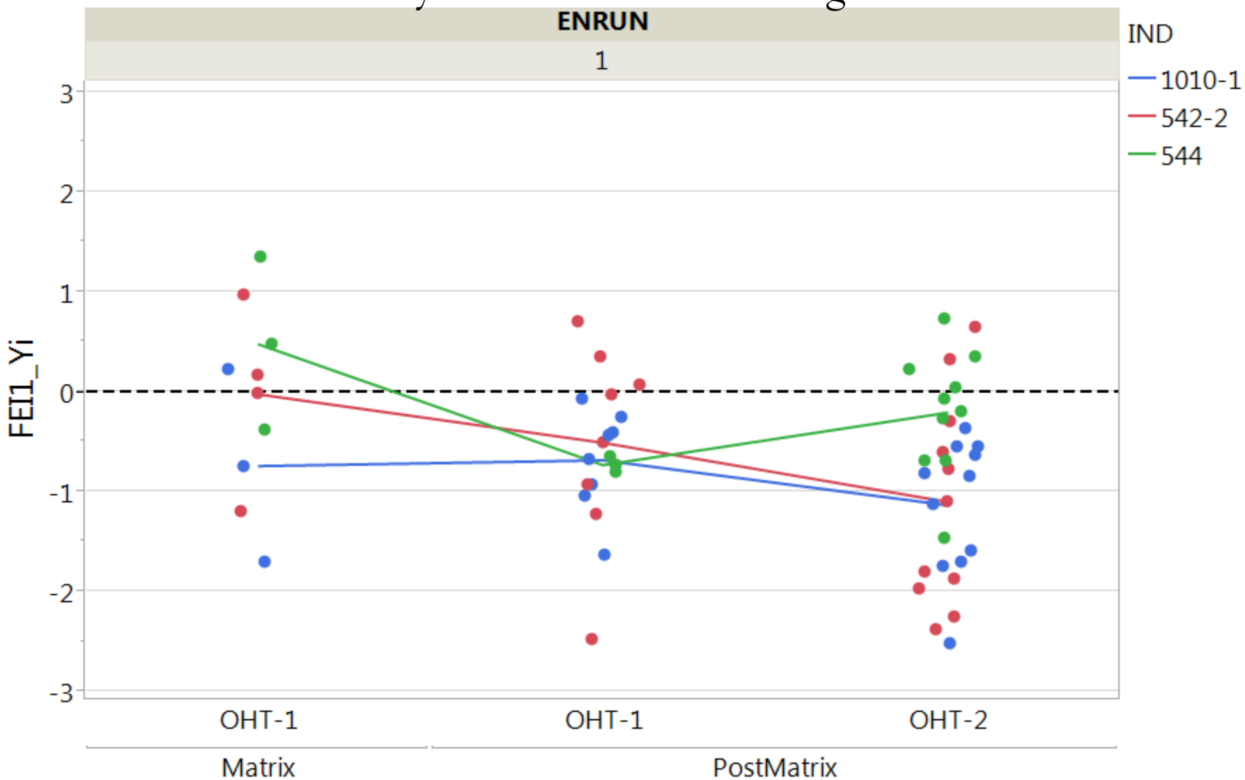
- Comparison of original matrix engines vs. follow-on purchase for FEI1 $Y_i$
- 1st run data only
- OHT-2 engines are approx. 0.22 standard deviations more severe on average post-matrix. This difference is not statistically significant.




| MatrixGroup/EngineBatch | Average FEI1 Yi |
|---|---|
| Matrix/OHT-1 | -0.08 |
| Post-Matrix/OHT-1 | -0.61 |
| Post-Matrix/OHT-2 | -0.83 |

# VIE Severity - Data Review

- Comparison of original matrix engines vs. follow-on purchase for FEI1 $Y_i$
- 1st run data only
- Oil 544 has not seen a similar severity shift on the OHT-2 engines




| Oil | Matrix/OHT-1 Avg.Yi | Post-Matrix/OHT-1 Avg.Yi | Post-Matrix/OHT-2 Avg.Yi |
|---|---|---|---|
| 1010-1 | -0.74 | -0.68 | -1.13 |
| 542-2 | -0.02 | -0.51 | -1.10 |
| 544 | 0.48 | -0.73 | -0.21 |

# VIE Severity - Data Review

- Post-matrix data only
- Original Model was FEI_1 ~ Oil, Lab, Stand(Lab), Engine Batch, Engine Batch * Oil
- Model shown is FEI_1 ~ Oil, Lab (terms with p-value > 0.05 excluded)
- Analysis of post-matrix data only indicates that there is still good oil discrimination between all three reference oils.

**Response FEI_1**

**Whole Model**

**Actual by Predicted Plot**

**Summary of Fit**

| | |
|---|---|
| RSquare | 0.837301 |
| RSquare Adj | 0.812896 |
| Root Mean Square Error | 0.218001 |
| Mean of Response | 1.771064 |
| Observations (or Sum Wgts) | 47 |

**Analysis of Variance**

**Lack Of Fit**

**Parameter Estimates**

| Term | Estimate | Std Error | t Ratio | Prob>\|t\| | VIF |
|---|---|---|---|---|---|
| Intercept | 1.8404049 | 0.055299 | 33.28 | <.0001* | . |
| IND[1010-1] | -0.06938 | 0.045154 | -1.54 | 0.1323 | 1.2213451 |
| IND[542-2] | 0.5651004 | 0.04512 | 12.52 | <.0001* | 1.2522945 |
| LTMSLAB[ A] | -0.302092 | 0.069611 | -4.34 | <.0001* | 2.9547176 |
| LTMSLAB[ B] | 0.1029284 | 0.112084 | 0.92 | 0.3640 | 3.813325 |
| LTMSLAB[ C] | 0.3744946 | 0.180651 | 2.07 | 0.0447* | 7.8312502 |
| LTMSLAB[ D] | -0.030552 | 0.071229 | -0.43 | 0.6703 | 2.9892303 |

**Effect Tests**

| Source | Nparm | DF | Sum of Squares | F Ratio | Prob > F |
|---|---|---|---|---|---|
| IND | 2 | 2 | 8.2057454 | 86.3317 | <.0001* |
| LTMSLAB | 4 | 4 | 0.9989259 | 5.2548 | 0.0017* |

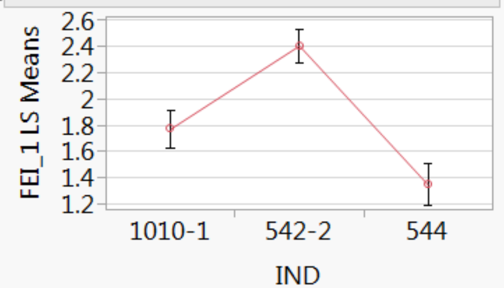
**IND**

**Leverage Plot**

**Least Squares Means Table**

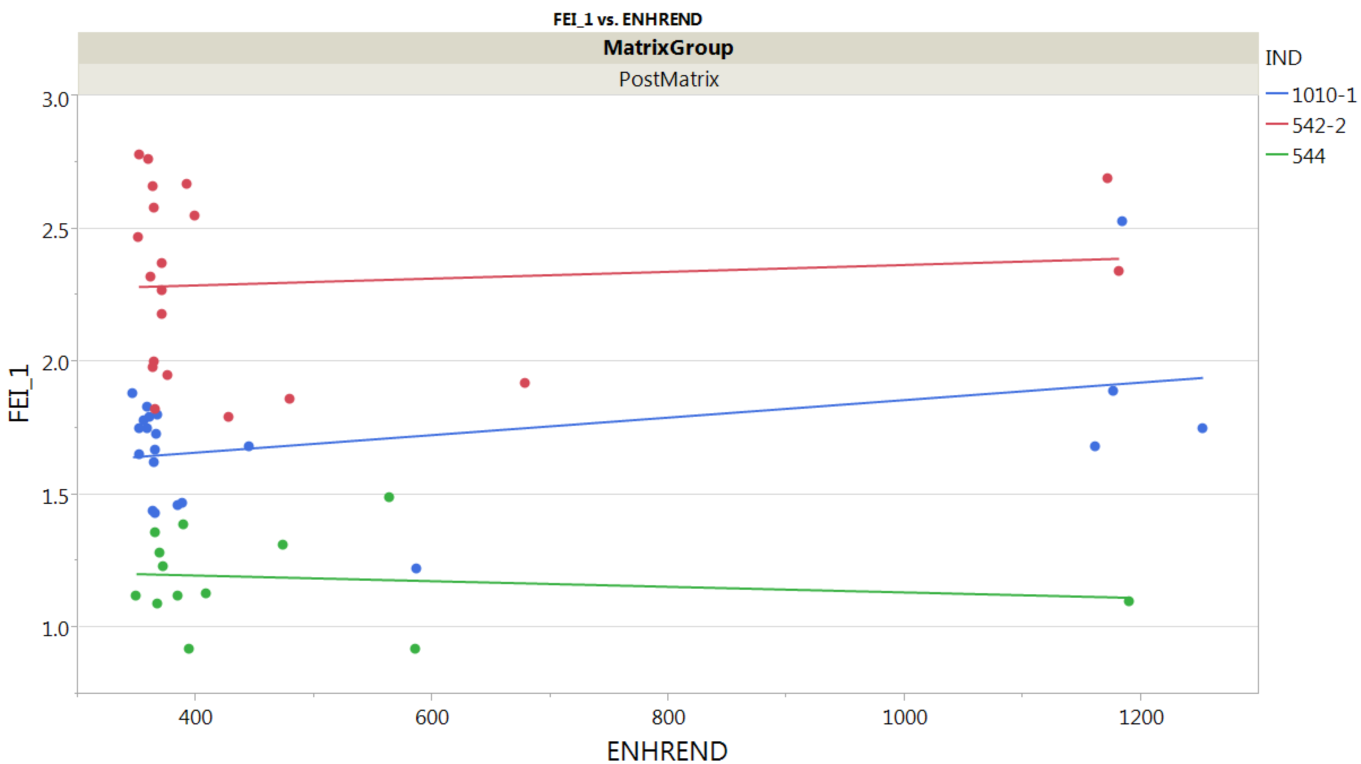
| Level | Least Sq Mean | Std Error | Mean |
|---|---|---|---|
| 1010-1 | 1.7710251 | 0.07250095 | 1.64412 |
| 542-2 | 2.4055054 | 0.06418846 | 2.27389 |
| 544 | 1.3446843 | 0.07917368 | 1.19667 |

**LS Means Plot**



# VIE Severity - Data Review

- 5th run data included here to evaluate engine hour adjustment.
- It is difficult to say with limited data if the small slopes observed are indicative of a problem, or just normal variability. The upward slope seen in oil 1010-1 is largely affected by one mild result.
- The oils appear to discriminate at ENRUN = 5, though some overlap exists.



# VIE Severity - Data Review

- $5^{th}$ run data included here to evaluate engine hour adjustment.
- Model is FEI1 ~ Oil, Lab, and EngHours (Insignificant terms removed)
- On average, $5^{th}$ run results are close to target, making them milder than $1^{st}$ and $2^{nd}$ run results.
- The ENHREND term is marginally significant, and suggests the current slope may be steeper than is should be, based on this limited data set.

**Summary of Fit**

| | |
|---|---|
| RSquare | 0.808258 |
| RSquare Adj | 0.77908 |
| Root Mean Square Error | 0.240316 |
| Mean of Response | 1.80037 |
| Observations (or Sum Wgts) | 54 |

**Analysis of Variance**

**Lack Of Fit**

**Parameter Estimates**

| Term | Estimate | Std Error | t Ratio | Prob>\|t\| | VIF |
|---|---|---|---|---|---|
| Intercept | 1.7468698 | 0.082103 | 21.28 | <.0001* | . |
| IND[1010-1] | -0.045028 | 0.046074 | -0.98 | 0.3335 | 1.2061747 |
| IND[542-2] | 0.5733242 | 0.047198 | 12.15 | <.0001* | 1.2379269 |
| LTMSLAB[ A] | -0.302649 | 0.074643 | -4.05 | 0.0002* | 3.1818516 |
| LTMSLAB[ B] | 0.0915194 | 0.123257 | 0.74 | 0.4616 | 4.1748544 |
| LTMSLAB[ C] | 0.3759777 | 0.198964 | 1.89 | 0.0651 | 8.7967801 |
| LTMSLAB[ D] | -0.041719 | 0.075383 | -0.55 | 0.5827 | 3.2452567 |
| ENHREND | 0.0002381 | 0.00012 | 1.98 | 0.0539 | 1.0190676 |

**Effect Tests**

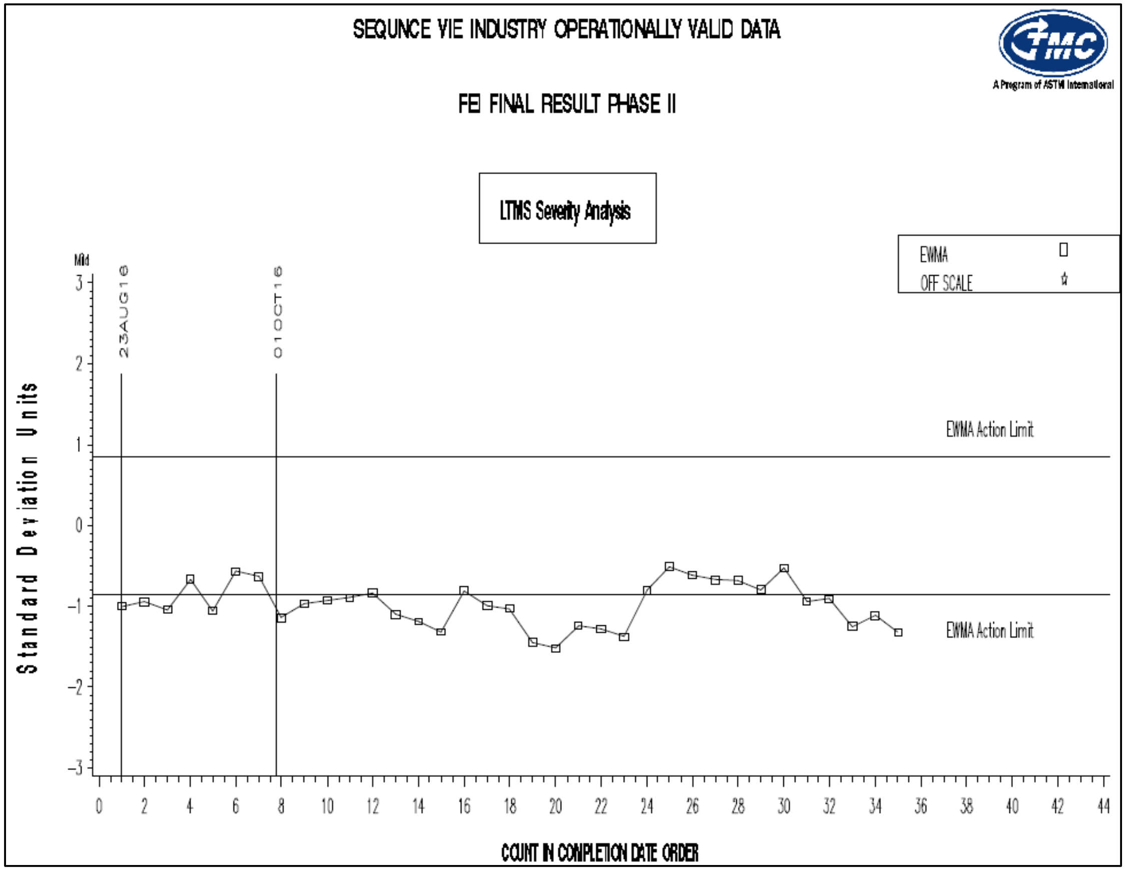
| Source | Nparm | DF | Sum of Squares | F Ratio | Prob > F |
|---|---|---|---|---|---|
| IND | 2 | 2 | 9.4557995 | 81.8657 | <.0001* |
| LTMSLAB | 4 | 4 | 1.0346453 | 4.4788 | 0.0039* |
| ENHREND | 1 | 1 | 0.2261135 | 3.9153 | 0.0539 |

| Engine Run | Sample size | Avg. FEI1 Yi |
|---|---|---|
| 1 | 45 | -0.75 |
| 2 | 2 | -1.76 |
| 5 | 7 | -0.02 |

# VIE – FEI2 Data Review

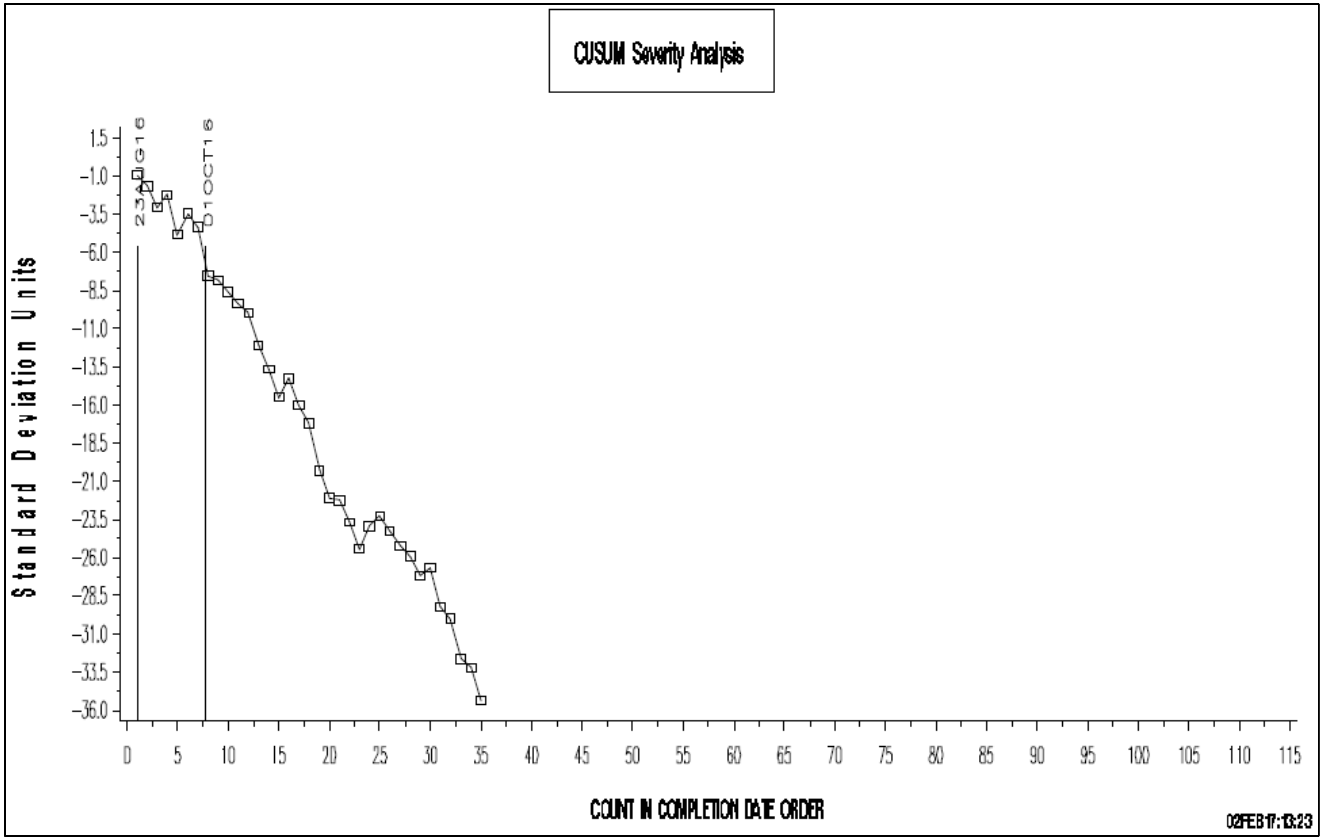
# VIE Severity - Data Review

- Post Matrix, the EWMA chart of the LTMS FEI2 data suggest that the test has been running severe.



# VIE Severity - Data Review

- Post Matrix, the CUSUM chart of the FEI2 LTMS data also suggest that the test has been running severe.



# VIE Severity - Data Review

- Analysis of $Y_i$ data for FEI2 – valid Matrix and Post Matrix **(Full Model)**
  - Model: FEI2_Yi ~EngHrs, Lab, Stand(Lab)[1], Oil, Matrix_Group, Matrix_Group*Oil
  - Analysis suggests that Lab and Matrix Group terms are significant.
  - Marginally significant stand differences
  - Marginally significant Oil * Matrix interaction.

**Parameter Estimates**

| Term | Estimate | Std Error | t Ratio | Prob>\|t\| | VIF |
|---|---|---|---|---|---|
| Intercept | -0.084211 | 0.420231 | -0.20 | 0.8420 | . |
| IND[1010-1] | -0.317721 | 0.16414 | -1.94 | 0.0587 | 1.6083459 |
| IND[542-2] | 0.1639894 | 0.165228 | 0.99 | 0.3258 | 1.6018155 |
| LTMSLAB[ A] | -1.241327 | 0.260449 | -4.77 | <.0001* | 3.4235928 |
| LTMSLAB[ B] | 1.0512737 | 0.442479 | 2.38 | 0.0215* | 6.2939952 |
| LTMSLAB[ C] | -0.563803 | 0.366997 | -1.54 | 0.1309 | 4.0956849 |
| LTMSLAB[ D] | -0.096072 | 0.257229 | -0.37 | 0.7104 | 3.2502557 |
| LTMSLAB[ F] | 0.7015268 | 0.443068 | 1.58 | 0.1198 | 5.2680009 |
| LTMSLAB[ A]:LTMSAPP[1] | -0.413018 | 0.682005 | -0.61 | 0.5476 | 2.8635841 |
| LTMSLAB[ A]:LTMSAPP[2] | 0.0387722 | 0.533137 | 0.07 | 0.9423 | 2.4517003 |
| LTMSLAB[ A]:LTMSAPP[3] | -1.075009 | 0.514967 | -2.09 | 0.0421* | 1.9643517 |
| LTMSLAB[ A]:LTMSAPP[6] | -1.166577 | 0.829571 | -1.41 | 0.1660 | 3.3536921 |
| LTMSLAB[ A]:LTMSAPP[8] | 1.3767877 | 0.647982 | 2.12 | 0.0387* | 2.5850008 |
| LTMSLAB[ A]:LTMSAPP[9] | 0.3999966 | 0.829602 | 0.48 | 0.6318 | 3.3539449 |
| LTMSLAB[ A]:LTMSAPP[10] | 0.1154926 | 0.516524 | 0.22 | 0.8240 | 1.9762455 |
| LTMSLAB[ B]:LTMSAPP[1] | -0.829306 | 0.536597 | -1.55 | 0.1287 | 2.3713717 |
| LTMSLAB[ D]:LTMSAPP[1] | 0.1317837 | 0.338193 | 0.39 | 0.6985 | 1.26895 |
| LTMSLAB[ D]:LTMSAPP[2] | -0.06835 | 0.308905 | -0.22 | 0.8258 | 1.4926981 |
| LTMSLAB[ G]:LTMSAPP[1] | -1.409513 | 0.4484 | -3.14 | 0.0028* | 1.8681938 |
| LTMSLAB[ G]:LTMSAPP[2] | -0.230458 | 0.400978 | -0.57 | 0.5681 | 1.8177981 |
| LTMSLAB[ G]:LTMSAPP[4] | -0.741686 | 0.51618 | -1.44 | 0.1571 | 1.2984293 |
| LTMSLAB[ G]:LTMSAPP[5] | 1.6208004 | 0.82623 | 1.96 | 0.0555 | 1.6855452 |
| LTMSLAB[ G]:LTMSAPP[6] | 0.8601804 | 0.824402 | 1.04 | 0.3019 | 1.6780957 |
| MatrixGroup[Matrix] | 0.4951737 | 0.194102 | 2.55 | 0.0139* | 3.3366679 |
| ENHREND | -0.000126 | 0.000724 | -0.17 | 0.8620 | 1.9965033 |
| MatrixGroup[Matrix]*IND[1010-1] | 0.385698 | 0.162586 | 2.37 | 0.0216* | 1.5952155 |
| MatrixGroup[Matrix]*IND[542-2] | -0.269445 | 0.163969 | -1.64 | 0.1067 | 1.5774815 |

**Effect Tests**

| Source | Nparm | DF | Sum of Squares | F Ratio | Prob > F |
|---|---|---|---|---|---|
| IND | 2 | 2 | 3.098655 | 1.9127 | 0.1585 |
| LTMSLAB | 5 | 5 | 23.892986 | 5.8994 | 0.0002* |
| LTMSAPP[LTMSLAB] | 15 | 15 | 22.599866 | 1.8600 | 0.0523 |
| MatrixGroup | 1 | 1 | 5.271624 | 6.5081 | 0.0139* |
| ENHREND | 1 | 1 | 0.024717 | 0.0305 | 0.8620 |
| MatrixGroup*IND | 2 | 2 | 5.147712 | 3.1776 | 0.0504 |

**Least Squares Means Table**

| Level | Least Sq Mean | Std Error | Mean |
|---|---|---|---|
| Matrix | 0.3474576 | 0.27278584 | -0.0133 |
| PostMatrix | -0.6428898 | 0.21515357 | -1.0922 |

**Least Squares Means Table**

| Level | Least Sq Mean |
|---|---|
| Matrix,1010-1 | 0.415435 |
| Matrix,542-2 | 0.242001 |
| Matrix,544 | 0.384936 |
| PostMatrix,1010-1 | -1.346309 |
| PostMatrix,542-2 | -0.209455 |
| PostMatrix,544 | -0.372906 |



[1] *Note: Post matrix chartable data has no repeat data for the engine within the same lab – thus Stand(Lab) factor selected for analysis.*

# VIE Severity - Data Review

- Analysis of $Y_i$ data for FEI2 – valid Matrix and Post Matrix **(Significant Terms Only)**
  - Model: FEI2_Yi ~Lab, Stand(Lab)[1], Oil, Matrix_Group, Matrix_Group*Oil
  - Analysis suggests FEI2 data post-precision matrix is approx. 0.95 standard deviations more severe than in the precision matrix.

**Parameter Estimates**

| Term | Estimate | Std Error | t Ratio | Prob>\|t\| | VIF |
|---|---|---|---|---|---|
| Intercept | -0.152942 | 0.146146 | -1.05 | 0.3004 | . |
| IND[1010-1] | -0.31685 | 0.162466 | -1.95 | 0.0568 | 1.6068623 |
| IND[542-2] | 0.164877 | 0.163541 | 1.01 | 0.3182 | 1.6003004 |
| LTMSLAB[ A] | -1.24186 | 0.257894 | -4.82 | <.0001* | 3.423123 |
| LTMSLAB[ B] | 1.0409505 | 0.434243 | 2.40 | 0.0203* | 6.1817229 |
| LTMSLAB[ C] | -0.560427 | 0.362918 | -1.54 | 0.1288 | 4.0843285 |
| LTMSLAB[ D] | -0.091606 | 0.253462 | -0.36 | 0.7193 | 3.218152 |
| LTMSLAB[ F] | 0.7053195 | 0.438224 | 1.61 | 0.1138 | 5.2553508 |
| LTMSLAB[ A]:LTMSAPP[1] | -0.424361 | 0.672293 | -0.63 | 0.5308 | 2.8376236 |
| LTMSLAB[ A]:LTMSAPP[2] | 0.040537 | 0.527848 | 0.08 | 0.9391 | 2.4508199 |
| LTMSLAB[ A]:LTMSAPP[3] | -1.073373 | 0.509866 | -2.11 | 0.0403* | 1.9637022 |
| LTMSLAB[ A]:LTMSAPP[6] | -1.16038 | 0.820737 | -1.41 | 0.1636 | 3.3475585 |
| LTMSLAB[ A]:LTMSAPP[8] | 1.3748541 | 0.641576 | 2.14 | 0.0370* | 2.5842465 |
| LTMSLAB[ A]:LTMSAPP[9] | 0.4063203 | 0.820737 | 0.50 | 0.6227 | 3.3475585 |
| LTMSLAB[ A]:LTMSAPP[10] | 0.1202649 | 0.510776 | 0.24 | 0.8148 | 1.9707168 |
| LTMSLAB[ B]:LTMSAPP[1] | -0.817828 | 0.527371 | -1.55 | 0.1273 | 2.3358158 |
| LTMSLAB[ D]:LTMSAPP[1] | 0.1318672 | 0.334898 | 0.39 | 0.6954 | 1.2689475 |
| LTMSLAB[ D]:LTMSAPP[2] | -0.069334 | 0.305845 | -0.23 | 0.8216 | 1.4922018 |
| LTMSLAB[ G]:LTMSAPP[1] | -1.415263 | 0.442833 | -3.20 | 0.0024* | 1.8581262 |
| LTMSLAB[ G]:LTMSAPP[2] | -0.225742 | 0.396171 | -0.57 | 0.5714 | 1.809559 |
| LTMSLAB[ G]:LTMSAPP[4] | -0.736679 | 0.510362 | -1.44 | 0.1551 | 1.2944252 |
| LTMSLAB[ G]:LTMSAPP[5] | 1.611156 | 0.816352 | 1.97 | 0.0540 | 1.6780187 |
| LTMSLAB[ G]:LTMSAPP[6] | 0.861156 | 0.816352 | 1.05 | 0.2965 | 1.6780187 |
| MatrixGroup[Matrix] | 0.4769025 | 0.161916 | 2.95 | 0.0049* | 2.3677518 |
| MatrixGroup[Matrix]*IND[1010-1] | 0.3862998 | 0.160966 | 2.40 | 0.0202* | 1.5944993 |
| MatrixGroup[Matrix]*IND[542-2] | -0.267207 | 0.161875 | -1.65 | 0.1051 | 1.5678477 |

**Effect Tests**

| Source | Nparm | DF | Sum of Squares | F Ratio | Prob > F |
|---|---|---|---|---|---|
| IND | 2 | 2 | 3.087395 | 1.9435 | 0.1539 |
| LTMSLAB | 5 | 5 | 23.871033 | 6.0105 | 0.0002* |
| LTMSAPP[LTMSLAB] | 15 | 15 | 22.591499 | 1.8961 | 0.0466* |
| MatrixGroup | 1 | 1 | 6.890730 | 8.6752 | 0.0049* |
| MatrixGroup*IND | 2 | 2 | 5.140582 | 3.2359 | 0.0477* |

**Least Squares Means Table**

| Level | Least Sq Mean | Std Error | Mean |
|---|---|---|---|
| Matrix | 0.3239605 | 0.23500301 | -0.0133 |
| PostMatrix | -0.6298444 | 0.19981108 | -1.0922 |

**Least Squares Means Table**

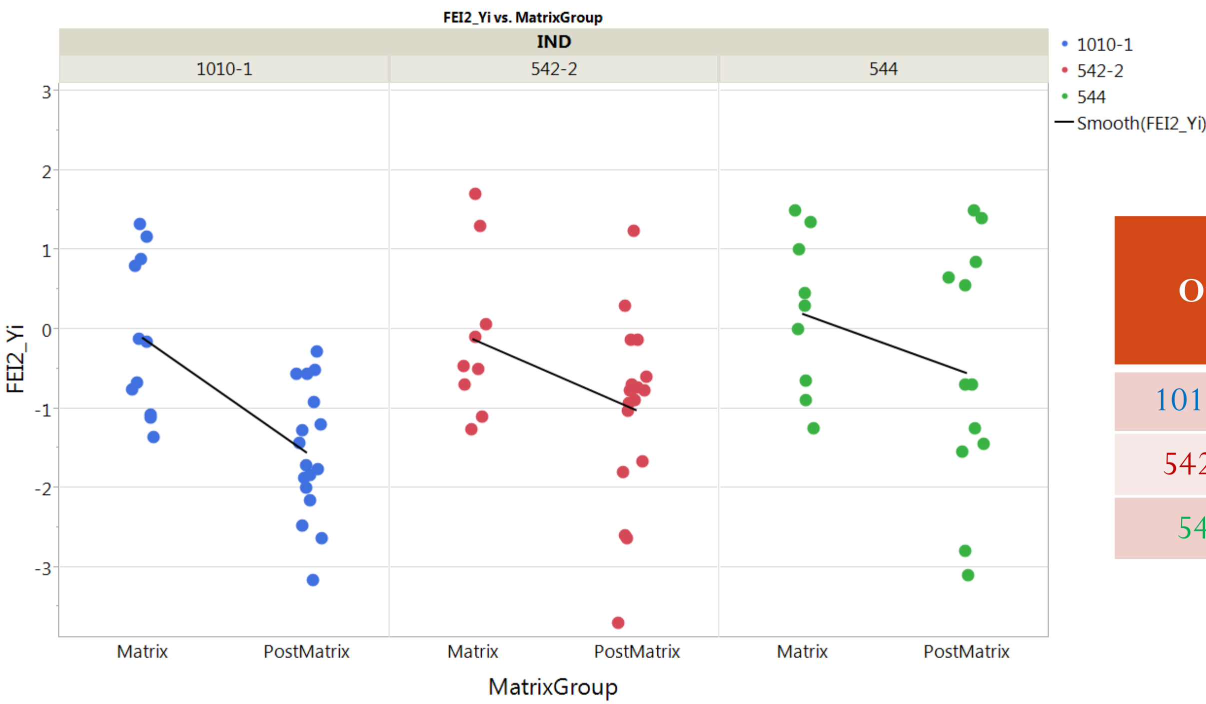
| Level | Least Sq Mean |
|---|---|
| Matrix,1010-1 | 0.393410 |
| Matrix,542-2 | 0.221630 |
| Matrix,544 | 0.356841 |
| PostMatrix,1010-1 | -1.332994 |
| PostMatrix,542-2 | -0.197760 |
| PostMatrix,544 | -0.358779 |



[1]*Note: Post matrix chartable data has no repeat data for the engine within the same lab – thus Stand(Lab) factor selected for analysis.*

# VIE Severity - Data Review

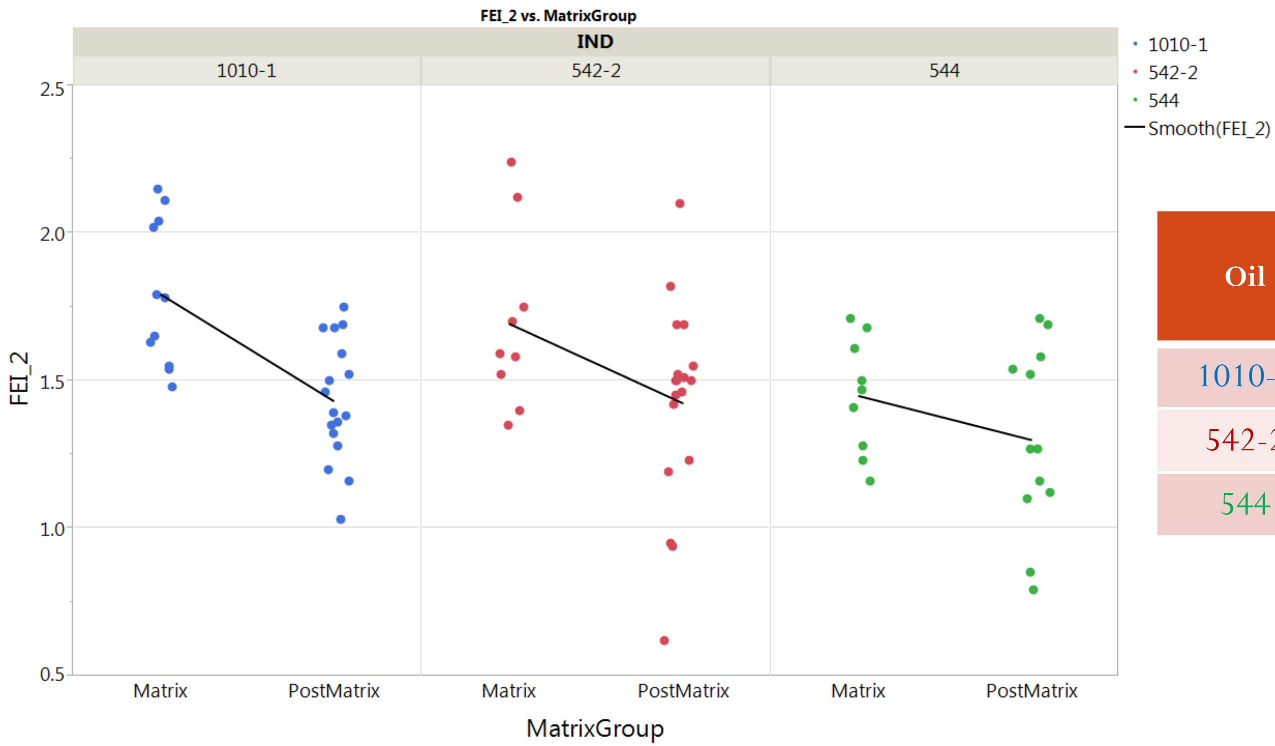
- Plot of FEI2 Yi data by Oil, Matrix Group
  - Matrix and Post Matrix where ENRUN <= 4
  - Post-matrix data is generally more severe as compared to matrix data
  - On average, oil 1010-1 has shifted 0.50 to 0.75 standard deviations more severe than the other two oils, and this difference is statistically significant.




| Oil | Matrix Avg. Yi | Post-Matrix Avg. Yi | Delta in Avg. Yi's. |
|---|---|---|---|
| 1010-1 | -0.10 | -1.55 | -1.45 |
| 542-2 | -0.12 | -1.02 | -0.90 |
| 544 | 0.20 | -0.55 | -0.75 |

# VIE Severity - Data Review

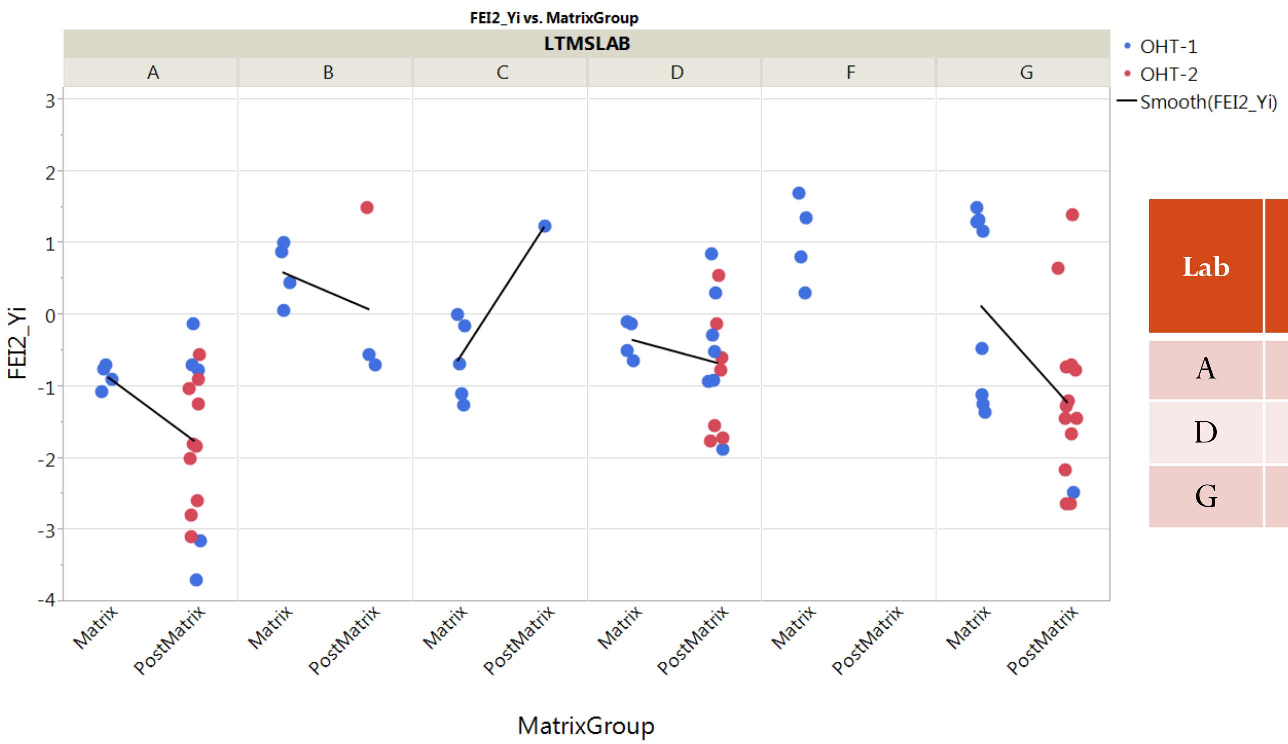
- Plot of FEI2 data by Oil, Matrix Group
  - Matrix and Post Matrix where ENRUN <= 4
  - Oil do not appear to separate post-matrix.




| Oil | Matrix Avg. FEI2 | Post-Matrix Avg. FEI2 | Delta in Avg. FEI2 |
|---|---|---|---|
| 1010-1 | 1.79 | 1.43 | -0.36 |
| 542-2 | 1.69 | 1.42 | -0.27 |
| 544 | 1.45 | 1.30 | -0.15 |

# VIE Severity - Data Review

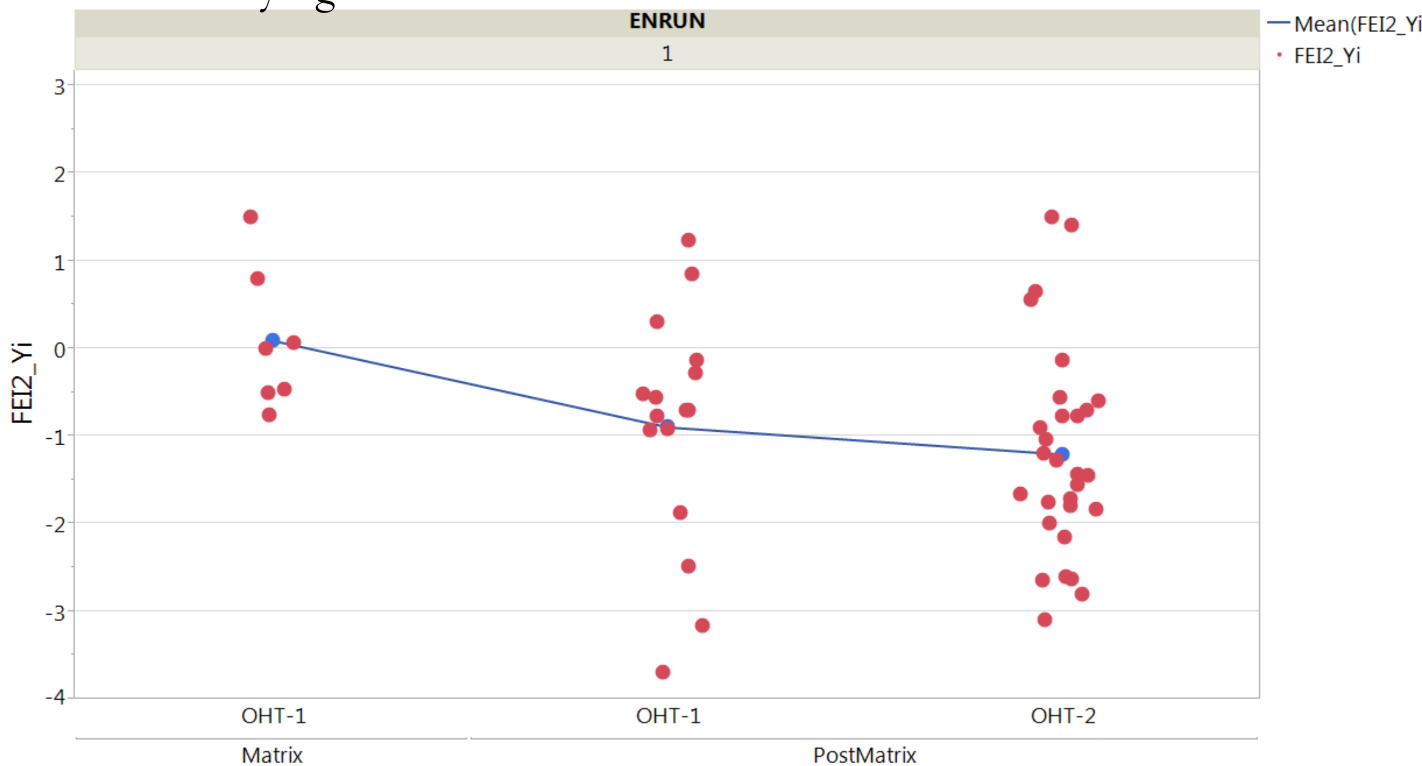
- Plot of FEI2 Yi data by Lab, Matrix Group, Colored by Engine Batch
- Looking at the 3 labs with the most data (A, D, and G), Lab A and G appear to have observed a larger shift in FEI2 Yi than Lab D, though all are directionally the same.
- Data looks similar for OHT-1 and OHT-2 engines post-matrix for labs A and D where multiple data points are available for comparison.




| Lab | Matrix Avg. FEI2 Yi | Post-Matrix Avg. FEI2 Yi | Delta in Avg. FEI2 Yi |
|---|---|---|---|
| A | -0.47 | -1.38 | -0.91 |
| D | 0.27 | -0.46 | -0.73 |
| G | -0.30 | -0.81 | -0.51 |

# VIE Severity - Data Review

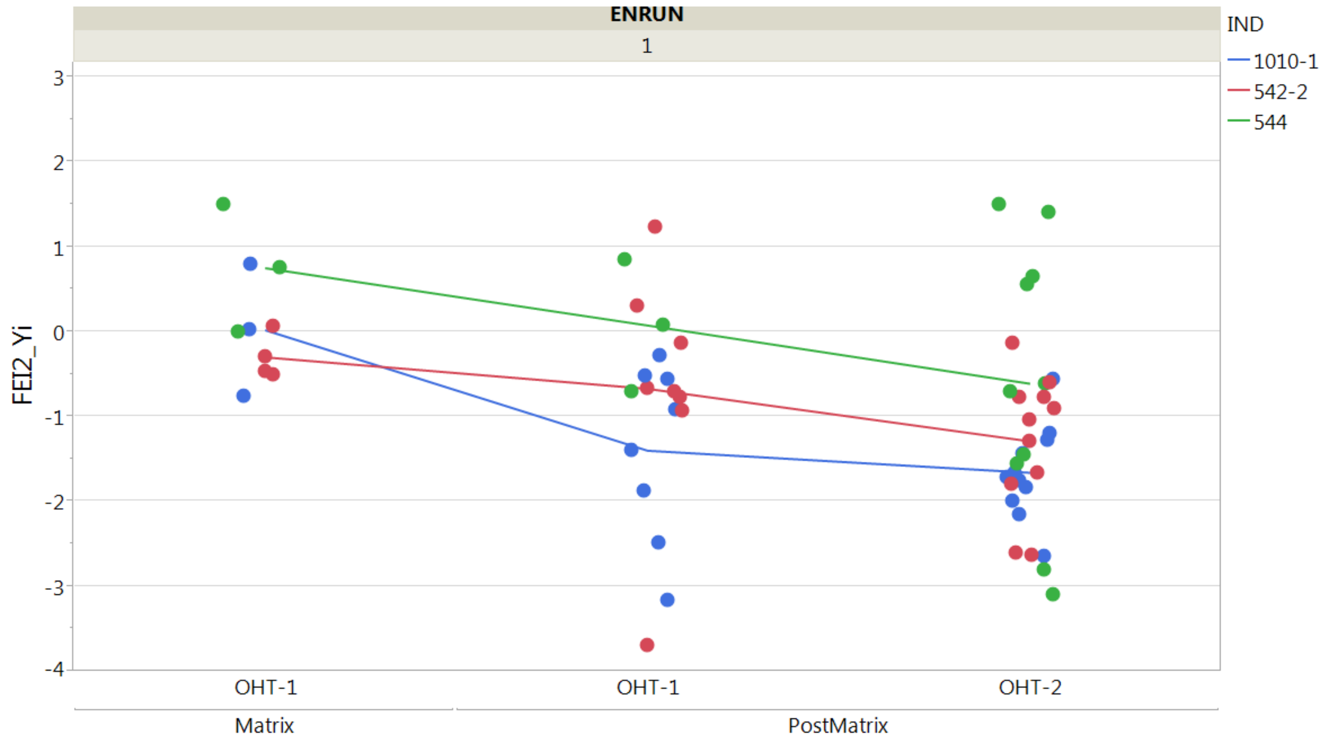
- Comparison of original matrix engines vs. follow-on purchase for FEI2$Y_i$
- 1st run data only
- OHT-2 engines are approx. 0.31 standard deviations more severe on average post-matrix. This difference is not statistically significant.




| MatrixGroup/EngineBatch | Average FEI2Yi |
| --- | --- |
| Matrix/OHT-1 | 0.09 |
| Post-Matrix/OHT-1 | -0.90 |
| Post-Matrix/OHT-2 | -1.21 |

# VIE Severity - Data Review

- Comparison of original matrix engines vs. follow-on purchase for FEI2$Y_i$
- 1st run data only
- Post-matrix changing from OHT-1 to OHT-2 engines, Oils 544 and 542-2 shifted approx. 0.5 standard deviations more severe, while 1010-1 shifted approx. 0.25 standard deviations severe, on average.




| Oil | Matrix/OHT-1 Avg. Yi | Post-Matrix/OHT-1 Avg. Yi | Post-Matrix/OHT-2 Avg. Yi |
|---|---|---|---|
| 1010-1 | 0.02 | -1.40 | -1.66 |
| 542-2 | -0.30 | -0.67 | -1.29 |
| 544 | 0.75 | 0.08 | -0.61 |

# VIE Severity - Data Review

- Post-matrix data only
- Original Model was FEI_2 ~ Oil, Lab, Stand(Lab), Engine Batch, Engine Batch * Oil
- Model shown is FEI_2 ~ Oil, Lab (terms with p-value > 0.05 excluded)
- Analysis of post-matrix data only indicates that there is no longer oil discrimination between any of the oils.

**Response FEI_2**

**Whole Model**

**Actual by Predicted Plot**

**Summary of Fit**

| | |
|---|---|
| RSquare | 0.384696 |
| RSquare Adj | 0.292401 |
| Root Mean Square Error | 0.244397 |
| Mean of Response | 1.395319 |
| Observations (or Sum Wgts) | 47 |

**Analysis of Variance**

**Lack Of Fit**

**Parameter Estimates**

| Term | Estimate | Std Error | t Ratio | Prob>\|t\| | VIF |
|---|---|---|---|---|---|
| Intercept | 1.5564731 | 0.061995 | 25.11 | <.0001* | . |
| IND[1010-1] | 0.0409079 | 0.050622 | 0.81 | 0.4238 | 1.2213451 |
| IND[542-2] | 0.0269332 | 0.050583 | 0.53 | 0.5974 | 1.2522945 |
| LTMSLAB[ A] | -0.342526 | 0.07804 | -4.39 | <.0001* | 2.9547176 |
| LTMSLAB[ B] | 0.0801936 | 0.125656 | 0.64 | 0.5270 | 3.813325 |
| LTMSLAB[ C] | 0.5165937 | 0.202525 | 2.55 | 0.0147* | 7.8312502 |
| LTMSLAB[ D] | -0.043372 | 0.079854 | -0.54 | 0.5900 | 2.9892303 |

**Effect Tests**

| Source | Nparm | DF | Sum of Squares | F Ratio | Prob > F |
|---|---|---|---|---|---|
| IND | 2 | 2 | 0.0928688 | 0.7774 | 0.4664 |
| LTMSLAB | 4 | 4 | 1.3468861 | 5.6374 | 0.0011* |

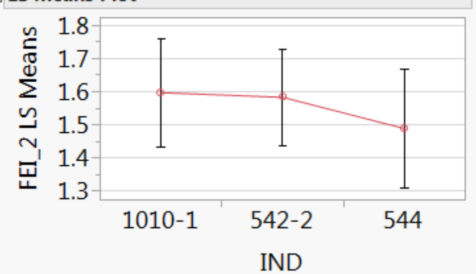
**IND**

**Leverage Plot**

**Least Squares Means Table**

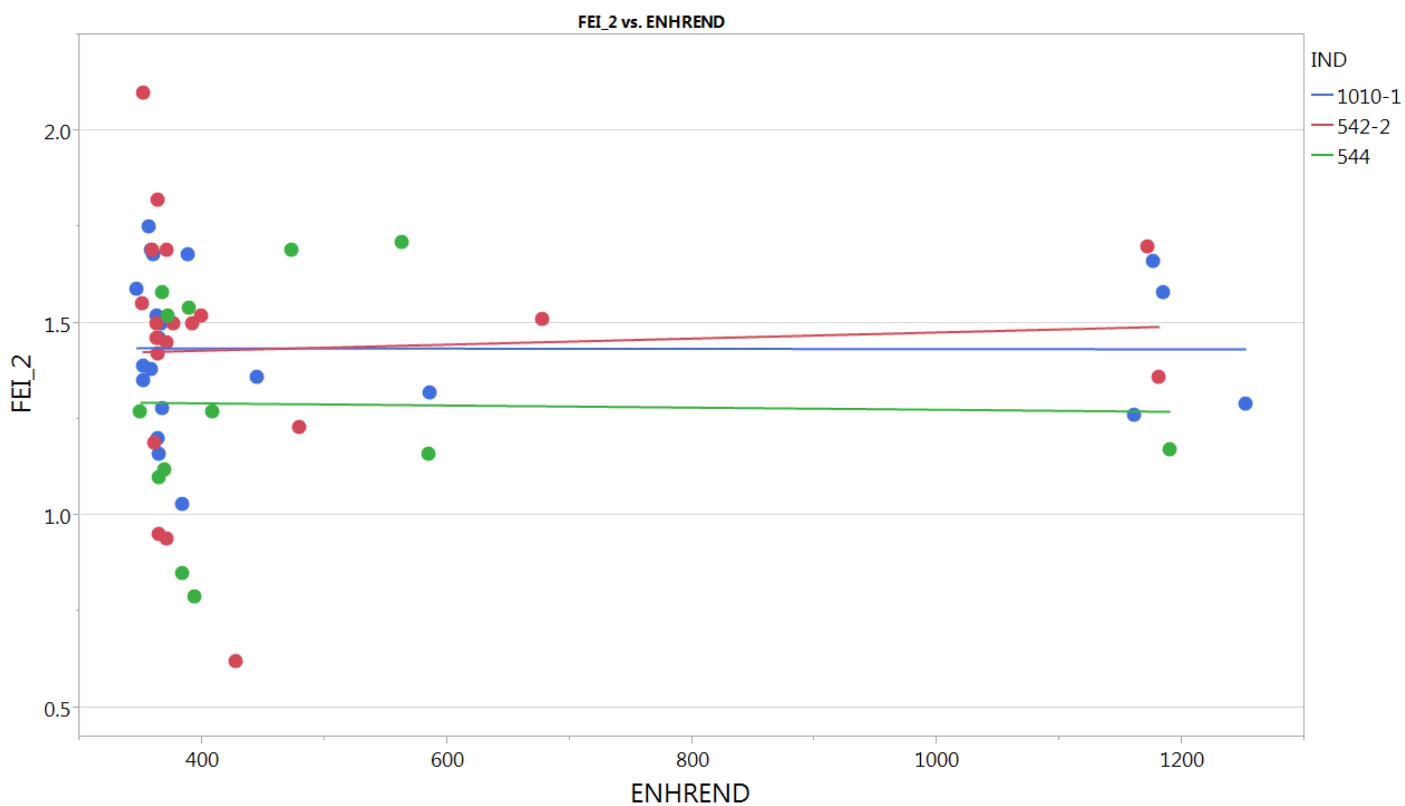
| Level | Least Sq Mean | Std Error | Mean |
|---|---|---|---|
| 1010-1 | 1.5973810 | 0.08127962 | 1.43176 |
| 542-2 | 1.5834063 | 0.07196062 | 1.42444 |
| 544 | 1.4886319 | 0.08876030 | 1.30000 |

**LS Means Plot**



# VIE Severity - Data Review

- 5th run data included here to evaluate engine hour adjustment.
- Current engine hour adjustment seems appropriate, based on the relatively flat line observed in all 3 oils.



# VIE Severity - Data Review

- 5th run data included here to evaluate engine hour adjustment.
- Model is FEI2 ~ Oil, Lab, and EngHours (Insignificant terms removed)
- On average, 5th run results are close to target, making them milder than 1st and 2nd run results.
- The ENHREND term is not significantly different from zero, meaning the current adjustment is still appropriate.

**Summary of Fit**

| | |
|---|---|
| RSquare | 0.385546 |
| RSquare Adj | 0.292042 |
| Root Mean Square Error | 0.235734 |
| Mean of Response | 1.4 |
| Observations (or Sum Wgts) | 54 |

**Analysis of Variance**

**Lack Of Fit**

**Parameter Estimates**

| Term | Estimate | Std Error | t Ratio | Prob>\|t\| | VIF |
|---|---|---|---|---|---|
| Intercept | 1.5278877 | 0.080538 | 18.97 | <.0001* | . |
| IND[1010-1] | 0.0383698 | 0.045195 | 0.85 | 0.4003 | 1.2061747 |
| IND[542-2] | 0.0400624 | 0.046299 | 0.87 | 0.3914 | 1.2379269 |
| LTMSLAB[ A] | -0.33851 | 0.07322 | -4.62 | <.0001* | 3.1818516 |
| LTMSLAB[ B] | 0.0821878 | 0.120907 | 0.68 | 0.5001 | 4.1748544 |
| LTMSLAB[ C] | 0.5108091 | 0.195171 | 2.62 | 0.0120* | 8.7967801 |
| LTMSLAB[ D] | -0.048378 | 0.073946 | -0.65 | 0.5162 | 3.2452567 |
| ENHREND | 6.0343e-5 | 0.000118 | 0.51 | 0.6117 | 1.0190676 |

**Effect Tests**

| Source | Nparm | DF | Sum of Squares | F Ratio | Prob > F |
|---|---|---|---|---|---|
| IND | 2 | 2 | 0.1329808 | 1.1965 | 0.3115 |
| LTMSLAB | 4 | 4 | 1.3954982 | 6.2780 | 0.0004* |
| ENHREND | 1 | 1 | 0.0145173 | 0.2612 | 0.6117 |

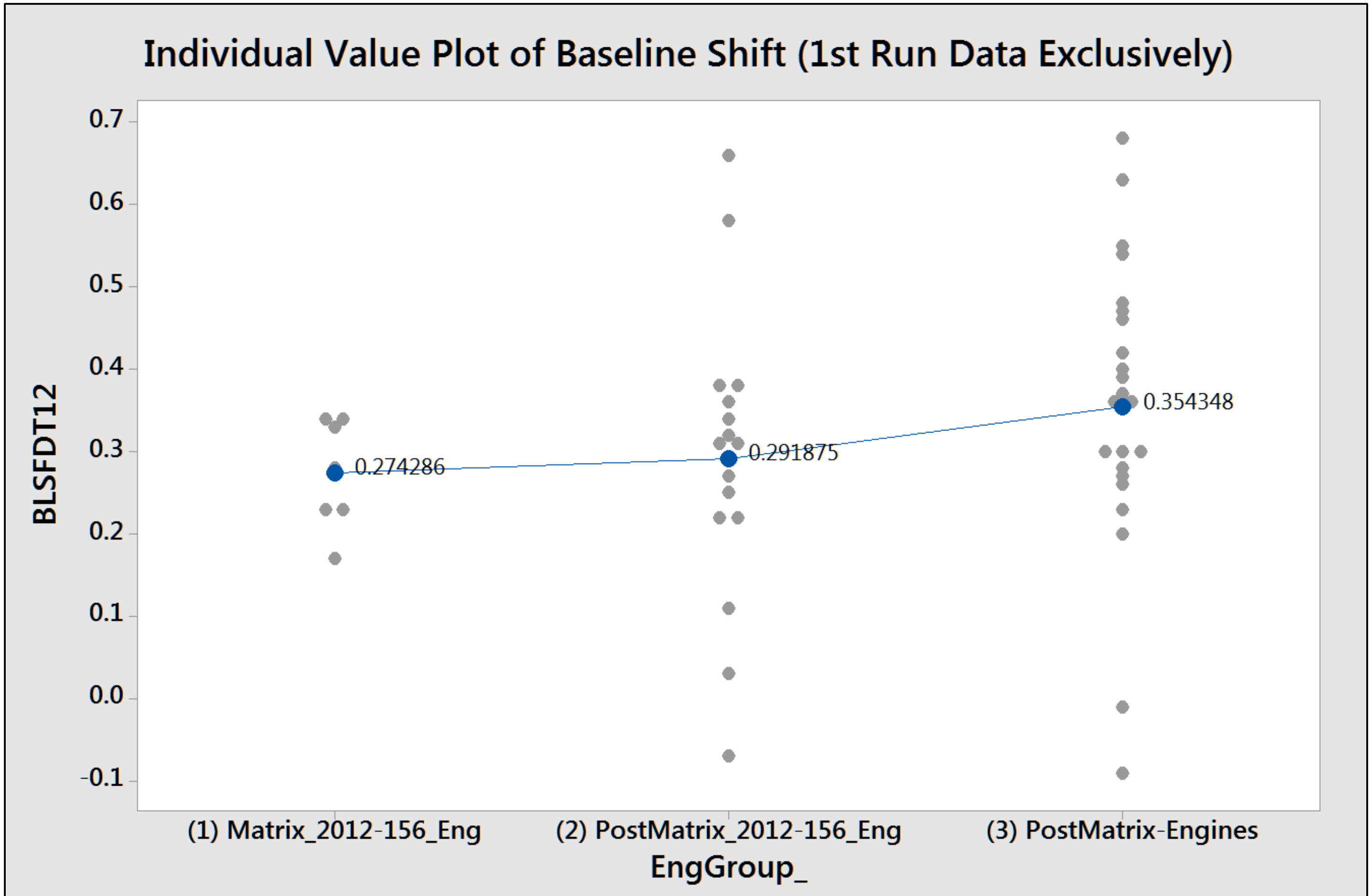
| Engine Run | Sample size | Avg. FEI2Yi |
|---|---|---|
| 1 | 45 | -1.10 |
| 2 | 2 | -0.99 |
| 5 | 7 | -1.21 |

# Appendix

# Appendix

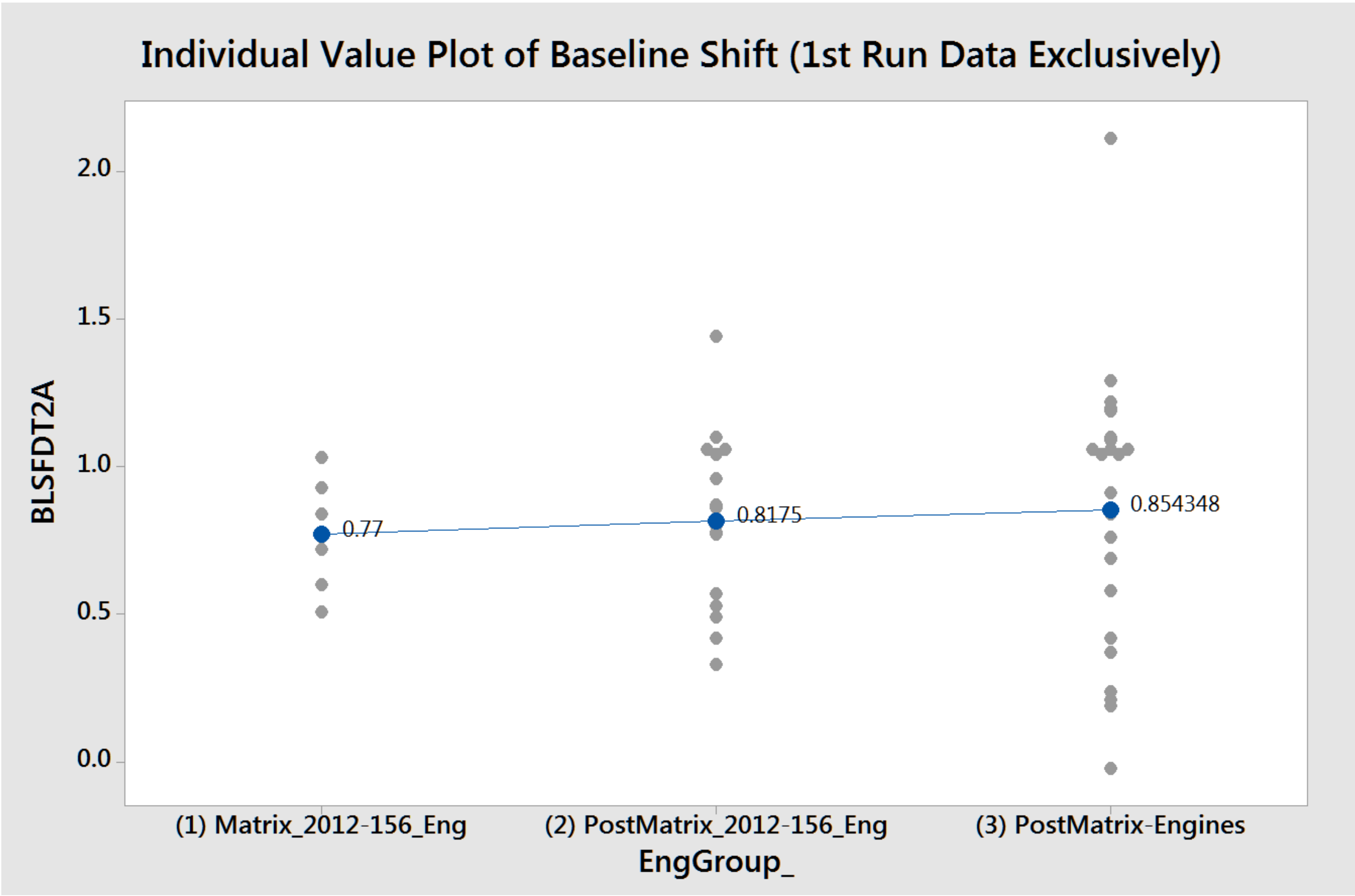
# VIE Severity - Data Review

- Comparison of baseline shift (BLB1 vs. BLB2)
- Post matrix, the variance of baseline shift appears to increasing



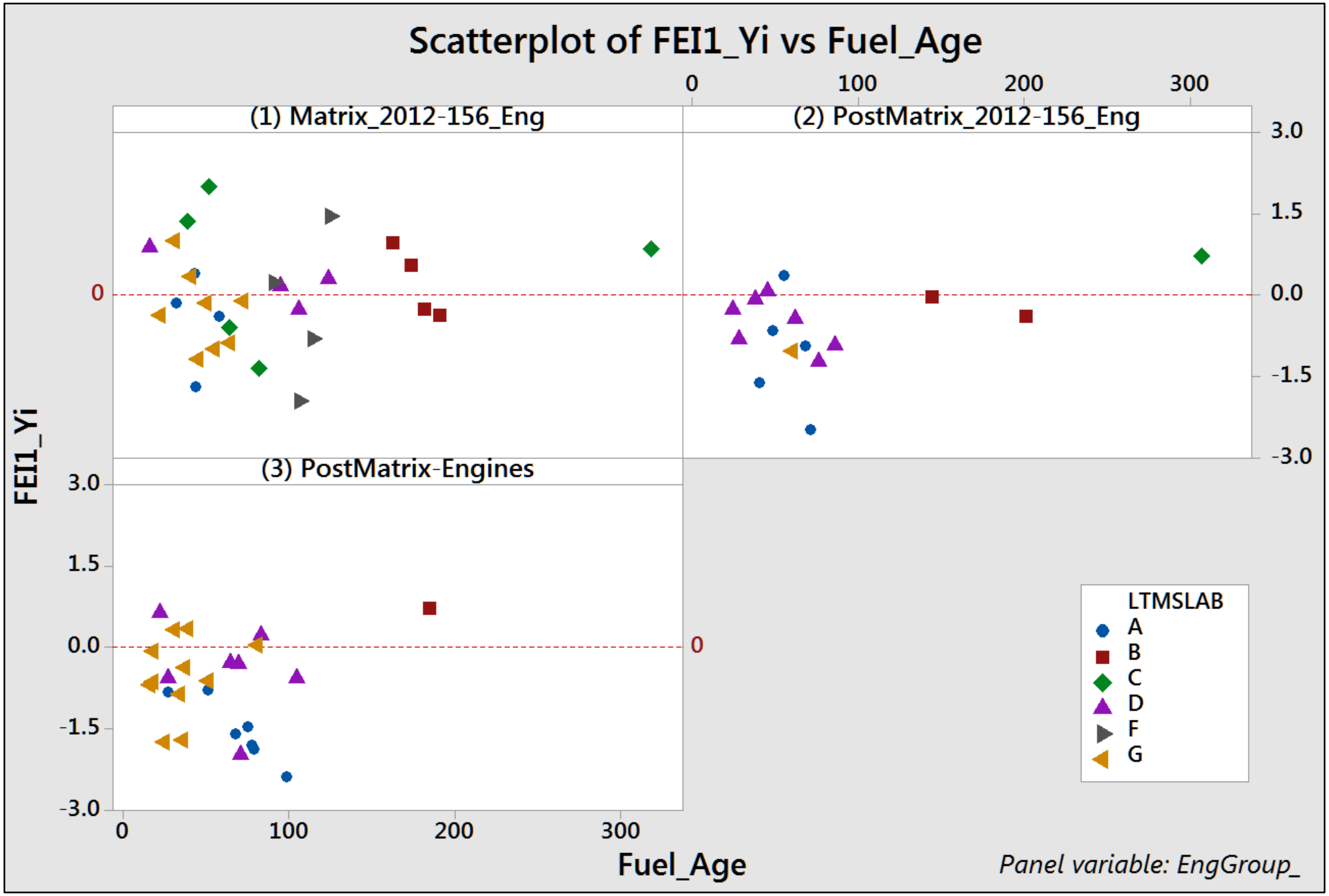
# VIE Severity - Data Review

- Comparison of baseline shift (BLB2 vs. BLA)



# VIE Severity - Data Review

- Estimated Fuel Age (LTMS_Date – Fuel_Production_Date) vs. FEI1_Yi



# VIE Severity - Data Review

- Estimated Fuel Age (LTMS_Date – Fuel_Production_Date) vs. FEI1_Yi