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COMMITTEE D02 ON PETROLEUM PRODUCTS, LIQUID FUELS, AND LUBRICANTS

Issued: Feb. 20, 2017

Reply to: Dan Worcester
Southwest Research Institute
6220 Culebra Rd.
San Antonio, TX 78238
Phone: 210.522.2405
Email: dworcester@swri.org

These are the unapproved minutes of the 02.16.2017 Sequence VI Conference Call.

The meeting was called to order at 9:06 AM Eastern Time by Greg Miranda.

Agenda

An Agenda was not included for this meeting. Discussion is on the VIF Precision Matrix.

1.0 Roll Call

The Attendance list is Attachment 1.

2. The VIF Precision Matrix Analysis

2.1 Jo Martinez gave the presentation, included as Attachment 2.

a. The VIF will move forward. It will use number of runs and engine run limit of 900 hours for the last start and same BL weighting as the VIE test.
b. The review included 18 valid matrix tests.
c. Each engine will run two valid acceptable references, and will gather the 5th run data as is being done on the VIE test.
d. There was some difference in response between labs, and engine G58 showed a different response in the same lab, but is not statistically significant. Bob Campbell asked about how many references tests versus candidates per engine. This will be discussed in the LTMS presentation.
e. There will be new VIF engine hour correction equations:

- $FEI1 = FEI1\_OR + 0.000403*(ENHREND - 700)$
- $FEI2 = FEI2\_OR + 0.000293*(ENHREND - 700)$

3. The VIF LTMS

3.1 Todd Dvorak gave the presentation, included as Attachment 3.

3.2 The reason for two references per engine is the second run may be a milder result, but it may also be that the first test on an engine is more severe. More data is needed.

3.3 The analysis was 4 runs per engine. There was discussion on another analysis using the 5th run data to get additional data.

3.4 During this discussion review moved from the LTMS back to the supplemental pages of Attachment 2. On page 45 is the Executive Summary that discusses number of references and candidate runs per engine.

Motion #1: Recommend the Stat Group re-analyze the VIF data using 5 tests per engine where that data is available.
William Buscher, Katerina Pecinovsky,, second. 8 Yes, 3 Waive, 0 No

4.0 Next Meeting.

4.1 Face-to-face meeting, 02.23.2017
The next meeting will be in San Antonio. IAR volunteered to host the meeting. It will start at 8:00 AM Central Time.

The meetings adjourned at 11:49 AM Eastern Time.

ASTM SEQUENCE VI

Name	Email/Phone	Company	Attend
Adrian Alfonso **Voting Member**	Phone: (210) 838-0431 Adrian.Alfonso@intertek.com	Intertek	ATTEND
Jason Bowden **Voting Member**	Phone: (440) 354-7007 jhbowden@ohtech.com	OHT	ATTEND
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Kaustav Sinha **Voting Member**	Phone: (713) 432-6642 LFNQ@chevron.com	Chevron Oronite	ATTEND
Haiying Tang **Voting Member**	Phone: (248) 512-0593 HT146@Chrysler.com	Chrysler	
Dan Worcester **Voting Member**	Phone: (210) 522-2405 Dan.Worcester@swri.org	SwRI	ATTEND

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Chris Taylor	Chris.Taylor@vpracingfuels.com	VP Racing Fuels	

ASTM SEQUENCE VI

Name	Email/Phone	Company	Attend

MOTION:	**5 RUN REVIEW**			
Adrian Alfonso **Voting Member**	YES			
Jason Bowden **Voting Member**	WAIVE			
Amol Savant **Voting Member**				
Tim Cushing **Voting Member**	YES			
Rich Grundza **Voting Member**	WAIVE			
Jeff Hsu **Voting Member**				
Teri Kowalski **Voting Member**				
Dan Lanctot **Voting Member**	WAIVE			
Greg Miranda **Voting Member**	YES			
Katerina Pecinovsky **Voting Member**	YES			
Brianne Pentz **Voting Member**	YES			
Andy Ritchie **Voting Member**	YES			
Ron Romano **Voting Member**				
Clifford Salvesen **Voting Member**				
Kaustav Sinha **Voting Member**	YES			
Haiying Tang **Voting Member**				
Dan Worcester **Voting Member**	YES			
VOTES	8 YES, 3 WAIVE			

ASTM SEQUENCE VI

Name	Email/Phone	Company	Attend

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

VIF Precision Matrix Analysis

Statistics Group

Date: February 16, 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

- Analyses reflect surveillance panel decisions to:
  - Move forward with the VIF test allowing up to 4 full length tests with the 4th test starting with an engine hour of 900 or less (Motioned on 7-19-16).
  - Include the 18 valid precision matrix tests (Motioned on 11-7-16)
  - 1-17-17 Motion: In the opinion of the SP the VIF should be similar to the VIE and any disagreement between the VIE methods of analyzing the results with the VIF matrix data is caused by the small data set available for analysis. The VIF analysis shall proceed using the same BL weights, engine hour correction calculation methods, run limitations, etc. as the VIE used.
    - Engine reference shall include two tests
    - Gather 5th run data similar to the VIE
    - Revisit assumptions with more data

Executive Summary

- Precision Matrix (PM) Analysis Highlights:
  - Within the shortened engine hours, data support the use of no transformation
  - Oils discriminate for both FEI1 and FEI2:
    - FEI1: 542-2 > 543 > 1011
    - FEI2: 543 > (542-2 & 1011)
  - The difference between labs is not statistically significant
  - Engine differences within labs:
    - FEI1: the differences between the engines are not statistically significant
    - FEI2: G58 < G96; the difference in Lab A engines is not statistically significant
    - An engine-based LTMS system is recommended
  - Oil discrimination may not be consistent across engines (based on limited data)
  - A higher BLB2 to BLA shift correlates with higher FEI2

Executive Summary

- Precision Matrix (PM) Analysis Highlights (continued):
  - Engine hour adjustments (recommended though not statistically significant):
    - FEI1 = FEI1_OR + 0.000403*(ENHREND – 700)
    - FEI2 = FEI2_OR + 0.000293*(ENHREND – 700)
  - Estimated within engine test precision
    - FEI1 s: 0.21; FEI2 s: 0.19
  - Estimated test precision across labs and engines
    - FEI1 s: 0.22; FEI2 s: 0.30
  - LTMS Oil Targets:

	Target		Standard Deviation		RMSE	
Oil	FEI1	FEI2	FEI1	FEI2	FEI1	FEI2
542-2 (n=6)	2.23	1.52	0.18	0.13	0.22	0.30
1011 (n=5)	1.45	1.41	0.14	0.39	0.22	0.30
543 (n=7)	1.88	2.25	0.27	0.34	0.22	0.30

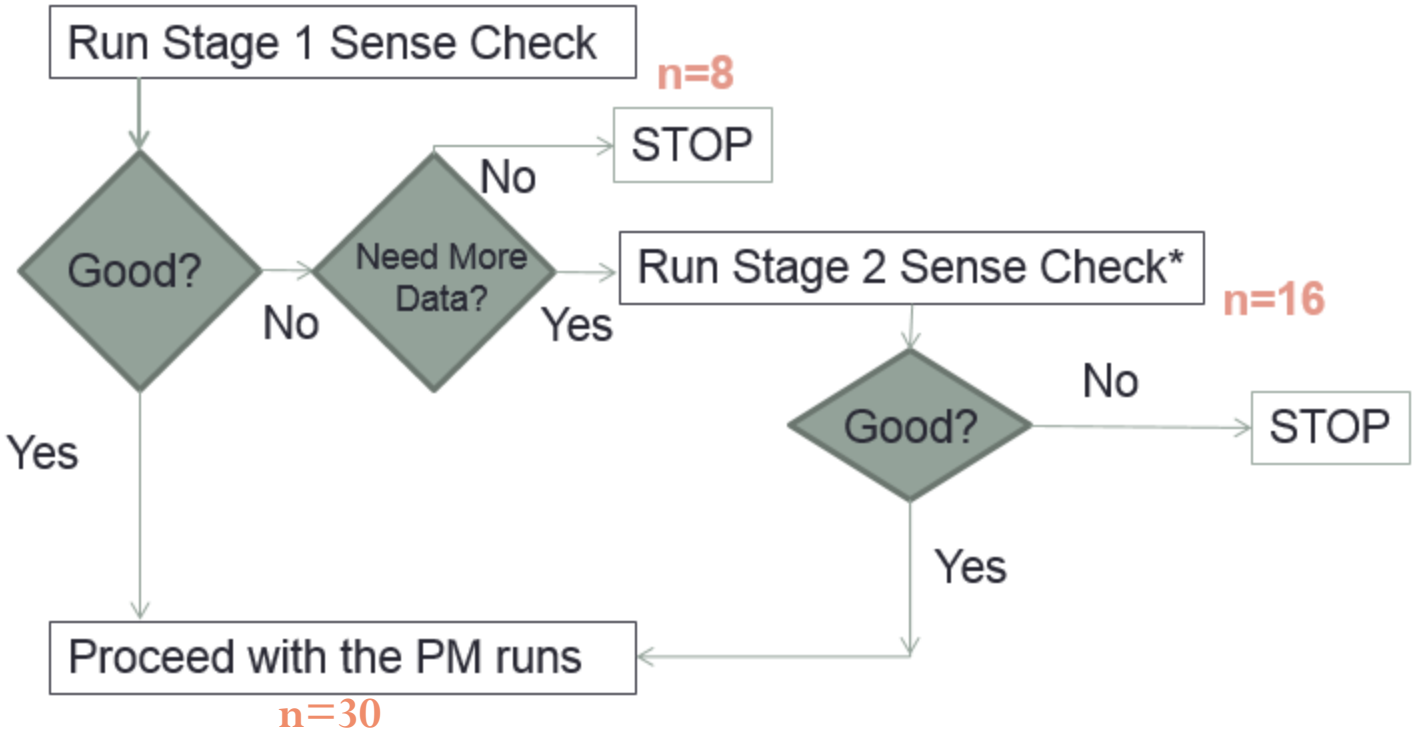
Note: Engine hour adjustment, precision and LTMS targets may change with more data

Review PM Data for Analysis

- Precision Matrix 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; 18 are viable for inclusion in precision matrix analysis and 18 are excluded due to following reasons:
  - 4 were deemed invalid
  - 14 don't meet engine life restriction

Review PM Data for Analysis

- Precision matrix tests were conducted in a stage gate process



*Stage 2 Sense Check can be re-designed based on the outcome of Stage 1 Sense Check

- 4 additional tests were conducted at Lubrizol upon initial matrix review

PM Data for Analysis

- Precision Matrix (PM):
  - On 11-7-16 the surveillance panel passed a motion to include 18 tests in the statistical analysis.

Run Order	EOT Engine Hours	SwRI #1		SwRI #2		IAR #1		IAR #2		LZ	
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	Additional Testing	1011 118268-VIF
2	550		542-2 112951-VIF		542-2 116037-VIF		543 112958-VIF		543 113824-VIF		543 118267-VIF
3	750		542-2 113818-VIF		1011 112954-VIF		543 113823-VIF		1011 112956-VIF		542-2 119631-VIF
4	950		543 113819-VIF		543 113820-VIF		542-2 113822-VIF EBP Calibration Shift		542-2 116030-VIF		1011 119628-VIF
							542-2 113231-VIF				
5	1150	1011 117508-VIF		543 113821-VIF Worn Throttle Controller		1011 116832-VIF		542-2 116031-VIF Baseline Shift			
				543 [illegible]-VIF							
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

Test Reported | Under Review | Invalid

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

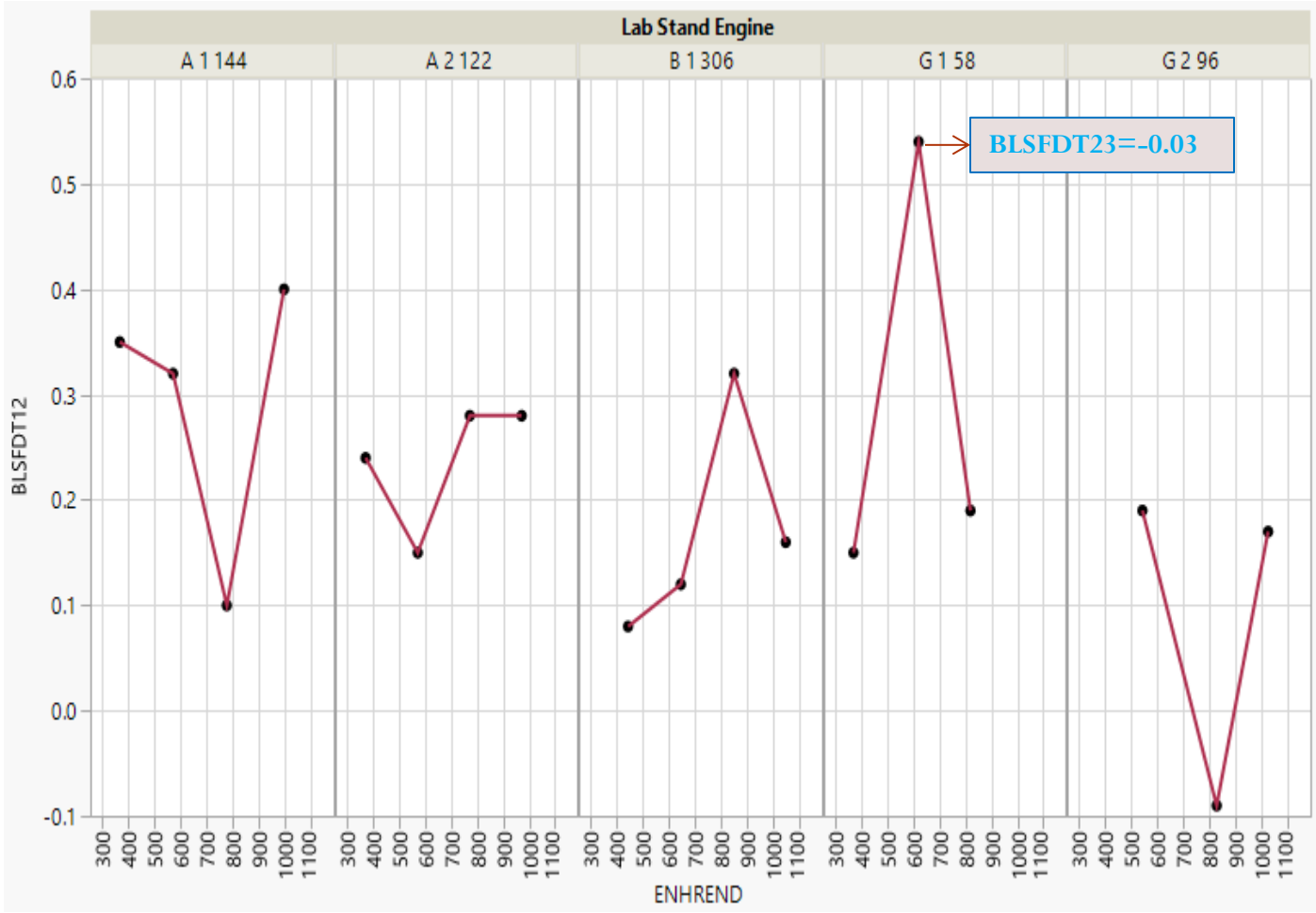
Review PM Data for Analysis

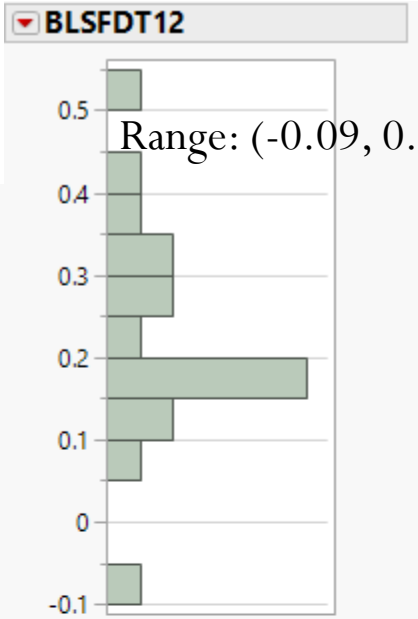
- Average engine hour age[1]:
  - PM Average EngHrs = 700

LTMSLAB	ENGNO	Average ENHREND	Max ENHREND
A	122	673	972
A	144	678	995
G	58	604	820
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





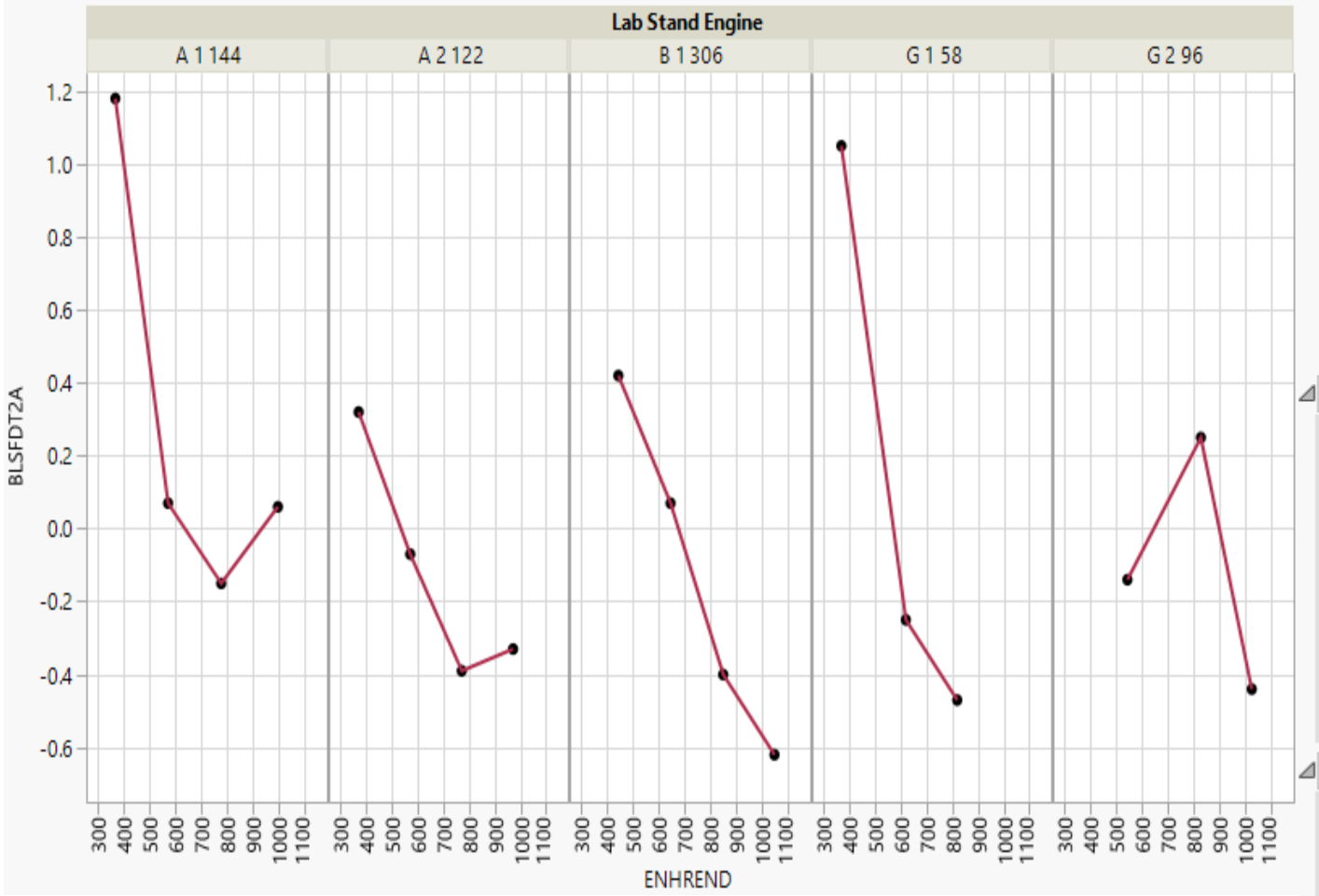
Quantiles

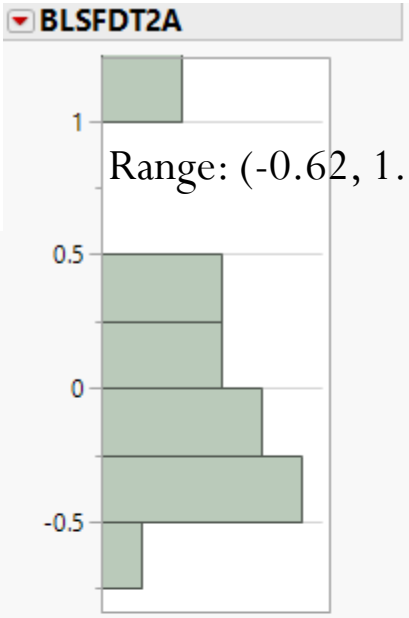
100.0%	maximum	0.54
99.5%		0.54
97.5%		0.54
90.0%		0.414
75.0%	quartile	0.32
50.0%	median	0.19
25.0%	quartile	0.1425
10.0%		0.063
2.5%		-0.09
0.5%		-0.09
0.0%	minimum	-0.09

Summary Statistics

Mean	0.2194444
Std Dev	0.1408158
Std Err Mean	0.0331906
Upper 95% Mean	0.2894705
Lower 95% Mean	0.1494184
N	18

BL SHIFT % DELTA, BLB2 VS BLA





Range: (-0.62, 1.18)

Quantiles

100.0%	maximum	1.18
99.5%		1.18
97.5%		1.18
90.0%		1.063
75.0%	quartile	0.2675
50.0%	median	-0.105
25.0%	quartile	-0.3925
10.0%		-0.485
2.5%		-0.62
0.5%		-0.62
0.0%	minimum	-0.62

Summary Statistics

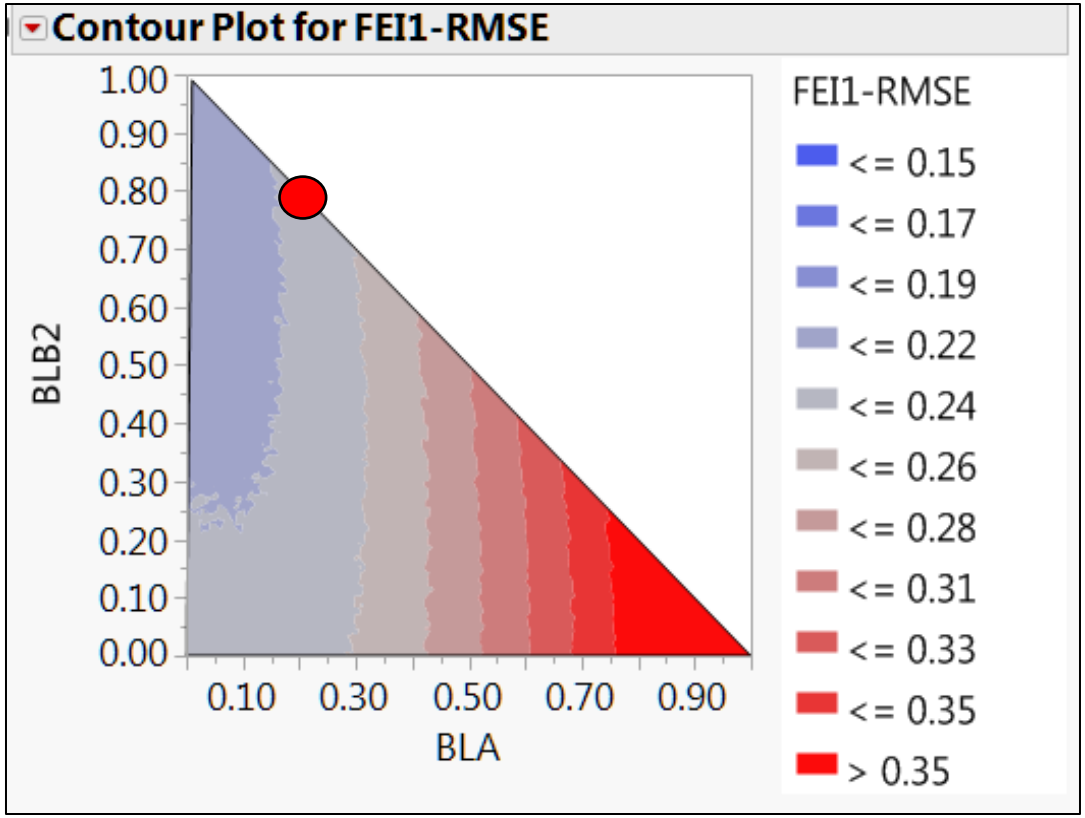
Mean	0.0088889
Std Dev	0.4957216
Std Err Mean	0.1168427
Upper 95% Mean	0.2554054
Lower 95% Mean	-0.237628
N	18

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

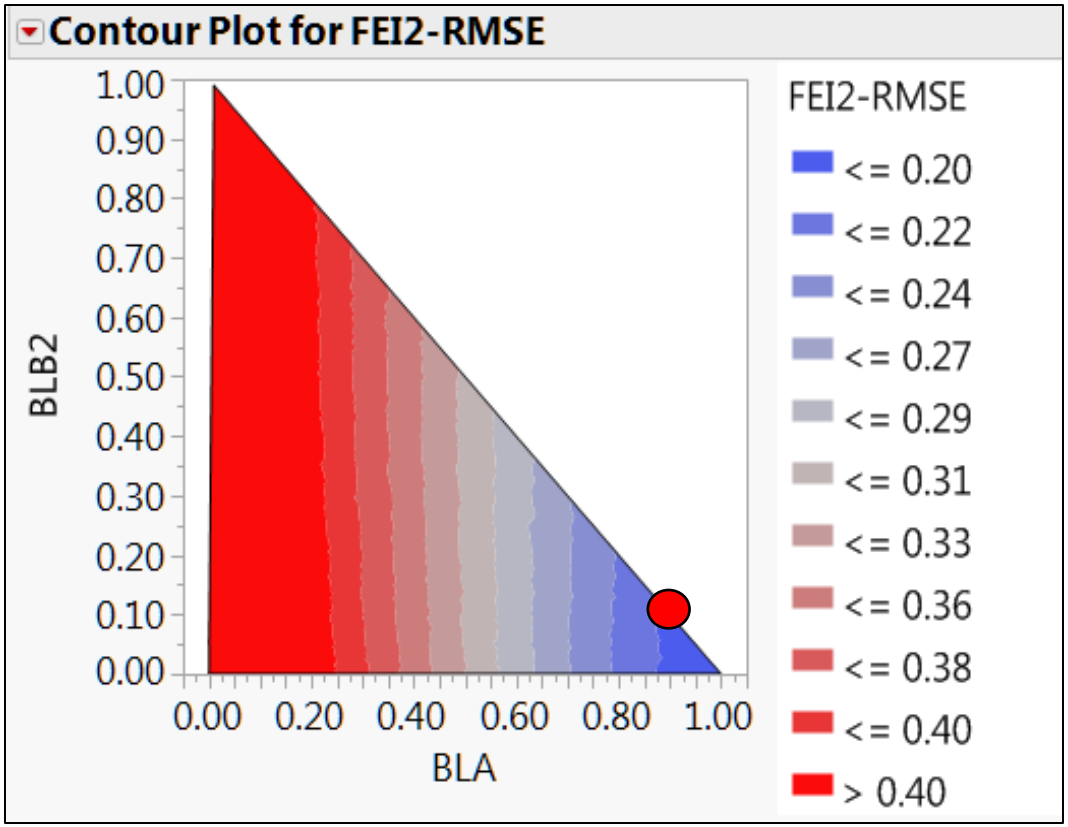
Evaluating Baseline Weight Scenarios

- 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)

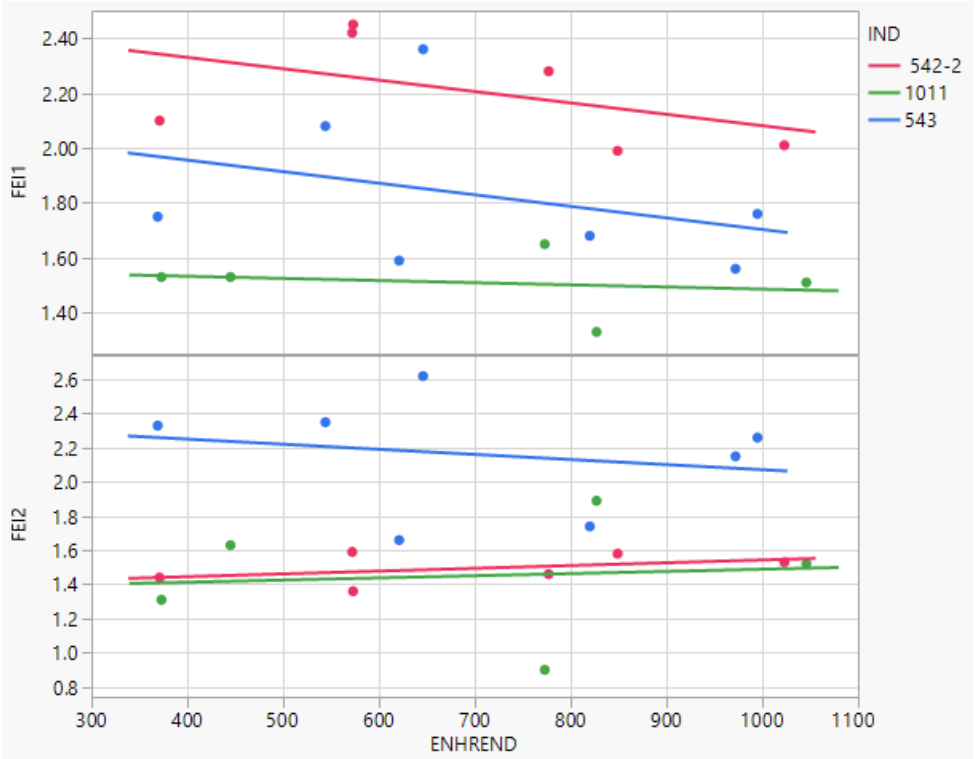


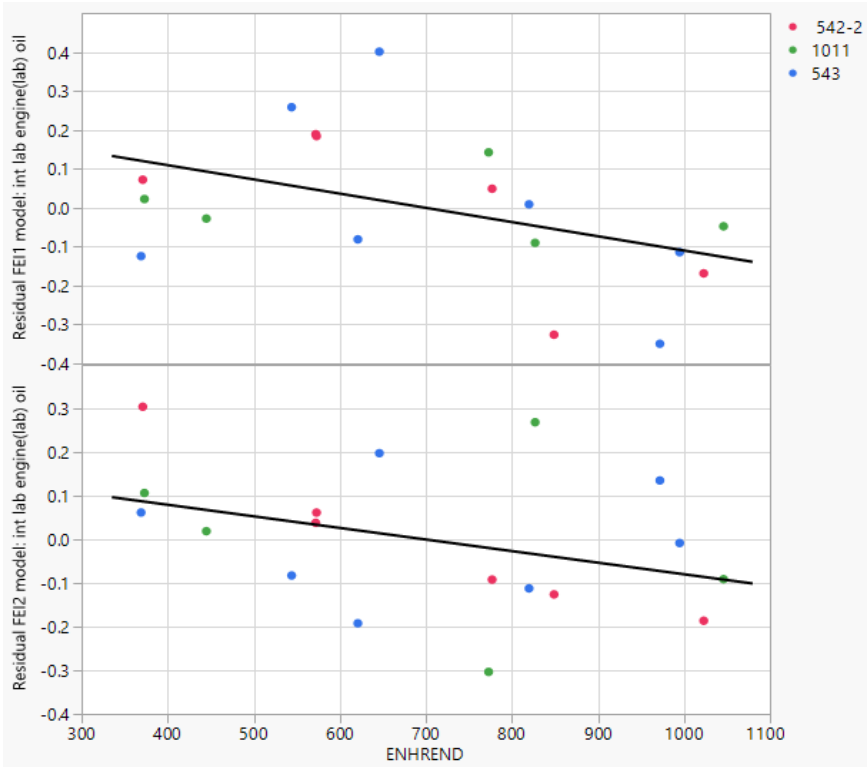
Agenda

- **Evaluating Engine Hour Adjustment**
- Analyzing PM 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



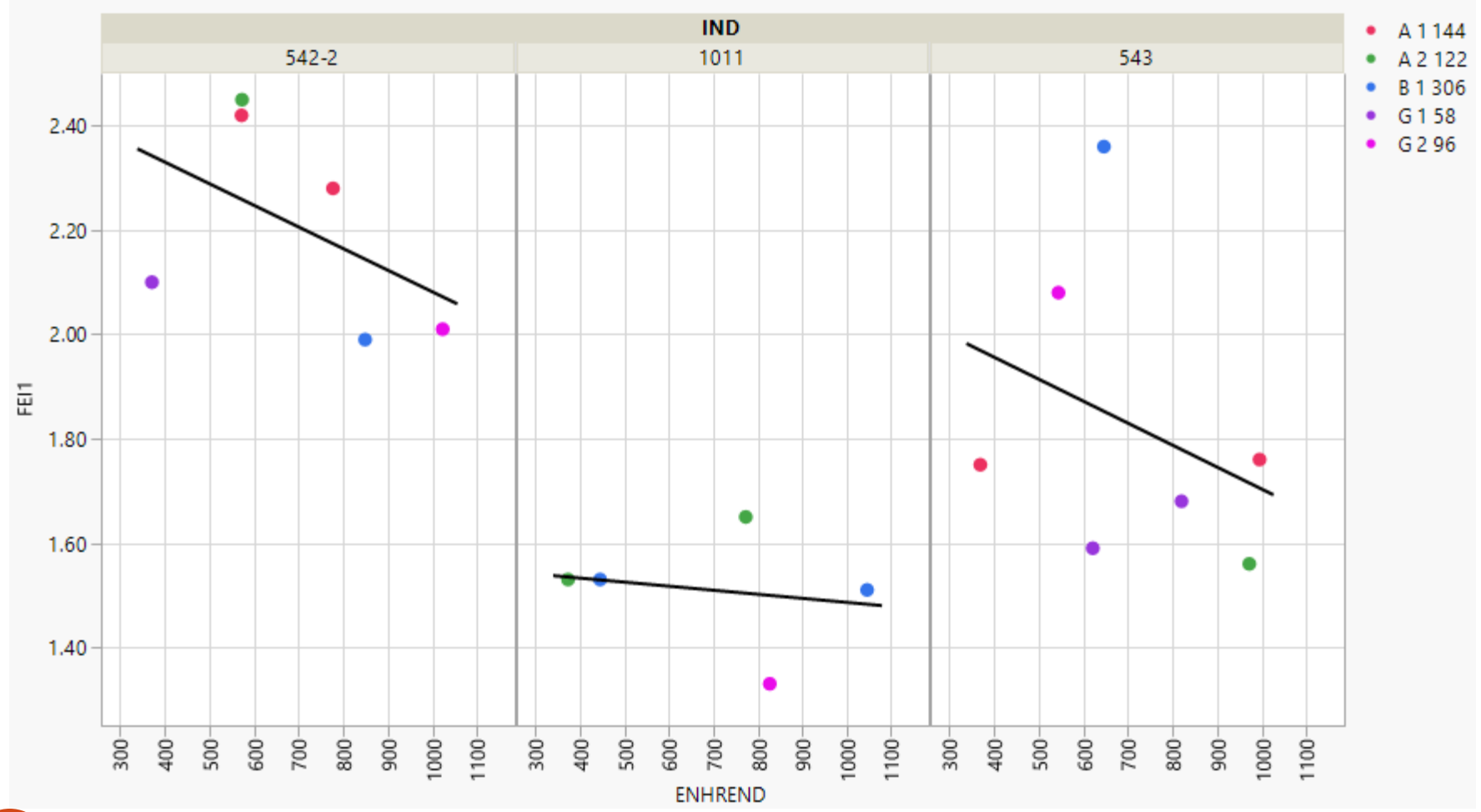


Agenda

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

Analyzing PM Data – FEI1

- Plot of FEI1_OR



Analyzing PM Data – FEI1

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

Summary of Fit

RSquare	0.76592
RSquare Adj	0.602064
Root Mean Square Error	0.222538
Mean of Response	1.865556
Observations (or Sum Wgts)	18

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	7	1.6204138	0.231488	4.6743
Error	10	0.4952307	0.049523	Prob > F
C. Total	17	2.1156444		0.0144*

Parameter Estimates

Term	Estimate	Prob>|t|
Intercept	2.1345341	<.0001*
LTMSLAB[A]	0.0118758	0.8723
LTMSLAB[B]	0.1144656	0.2292
LTMSLAB[A]:ENGNO[122]	0.0229028	0.7949
LTMSLAB[G]:ENGNO[58]	-0.119698	0.2502
IND[542-2]	0.3741418	0.0007*
IND[1011]	-0.404026	0.0013*
ENHREND	-0.000403	0.1323

Effect Tests

Source	DF	Prob > F
LTMSLAB	2	0.3026
ENGNO[LTMSLAB]	2	0.4949
IND	2	0.0014*
ENHREND	1	0.1323

FEI1 Engine Hours Adjustment:

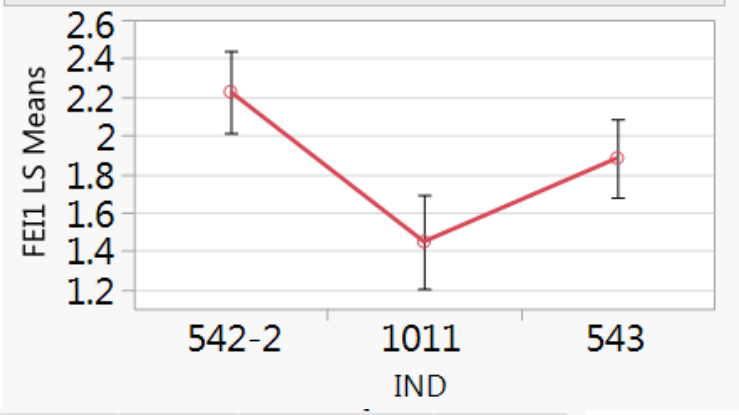
FEI1 = FEI1_OR + 0.000403*(ENHREND – 700)

Analyzing PM Data – FEI1

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

Level	Least Sq Mean
542-2	2.23
1011	1.45
543	1.88

LS Means Plot

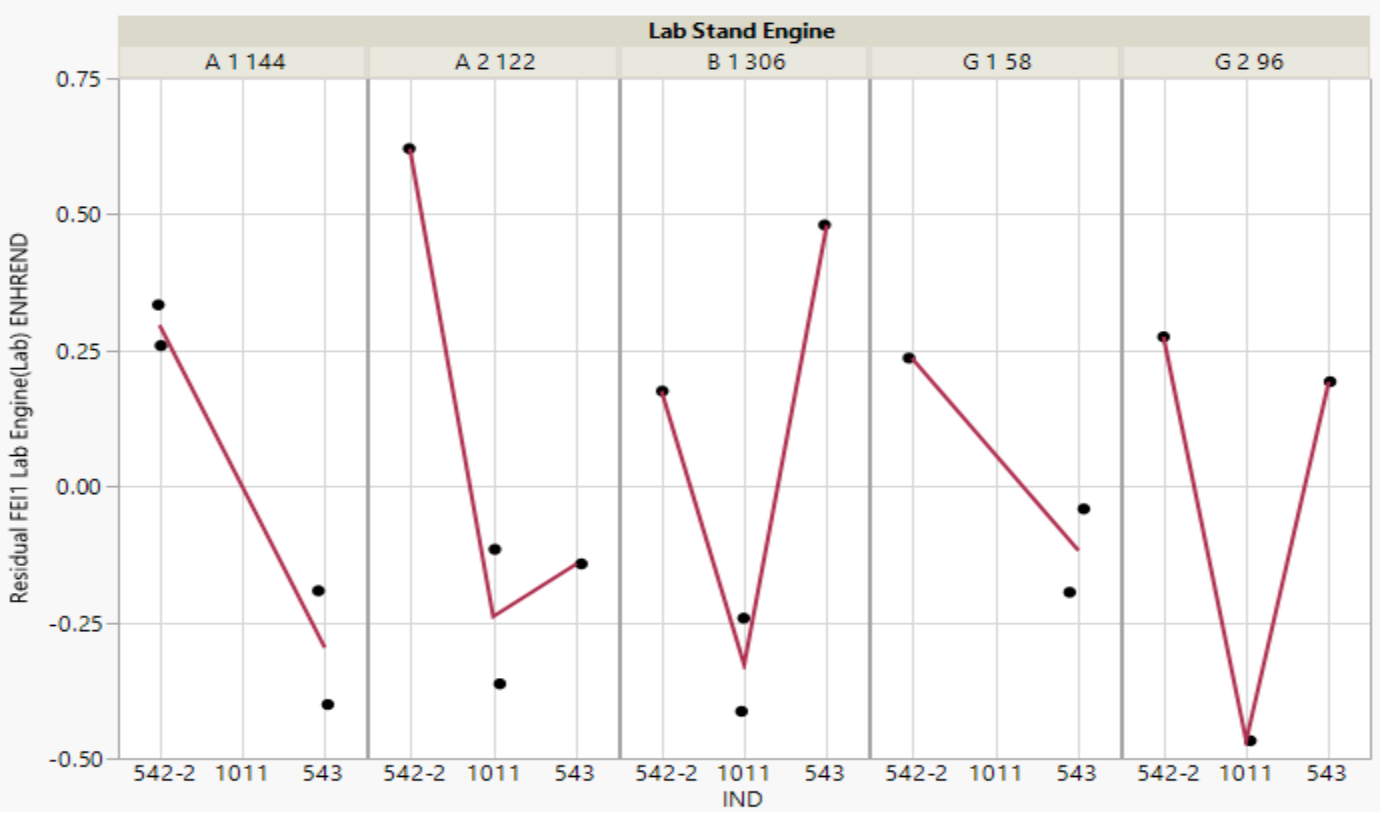


Level	- Level	Difference	p-Value
542-2	1011	0.78	0.00*
543	1011	0.43	0.04*
542-2	543	0.34	0.05*

Ref Oil	VID FEI1 Target	VIE FEI1 Target
542	1.49	2.56

Analyzing PM 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 PM Data – FEI1

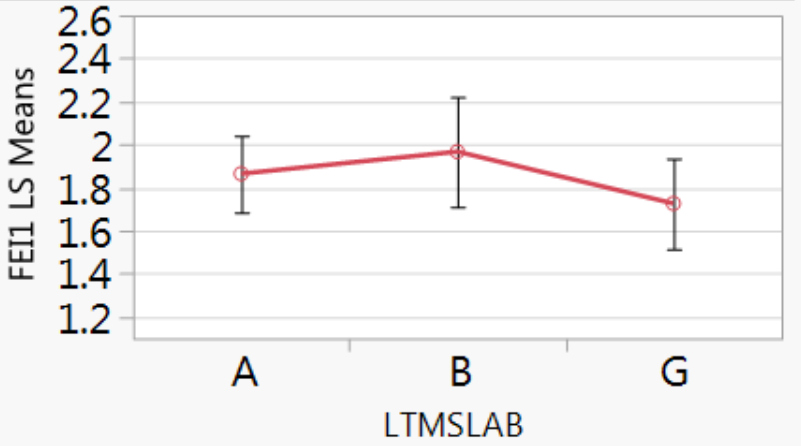
- The difference between labs is not statistically significant

Effect Tests

Source	DF	Prob > F
LTMSLAB	2	0.3026
ENGNO[LTMSLAB]	2	0.4949
IND	2	0.0014*
ENHREND	1	0.1323

Level	Least Sq Mean
A	1.86
B	1.97
G	1.73

LS Means Plot



Level	- Level	Difference	p-Value
B	G	0.24	0.30
A	G	0.14	0.51
B	A	0.10	0.76

Analyzing PM 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

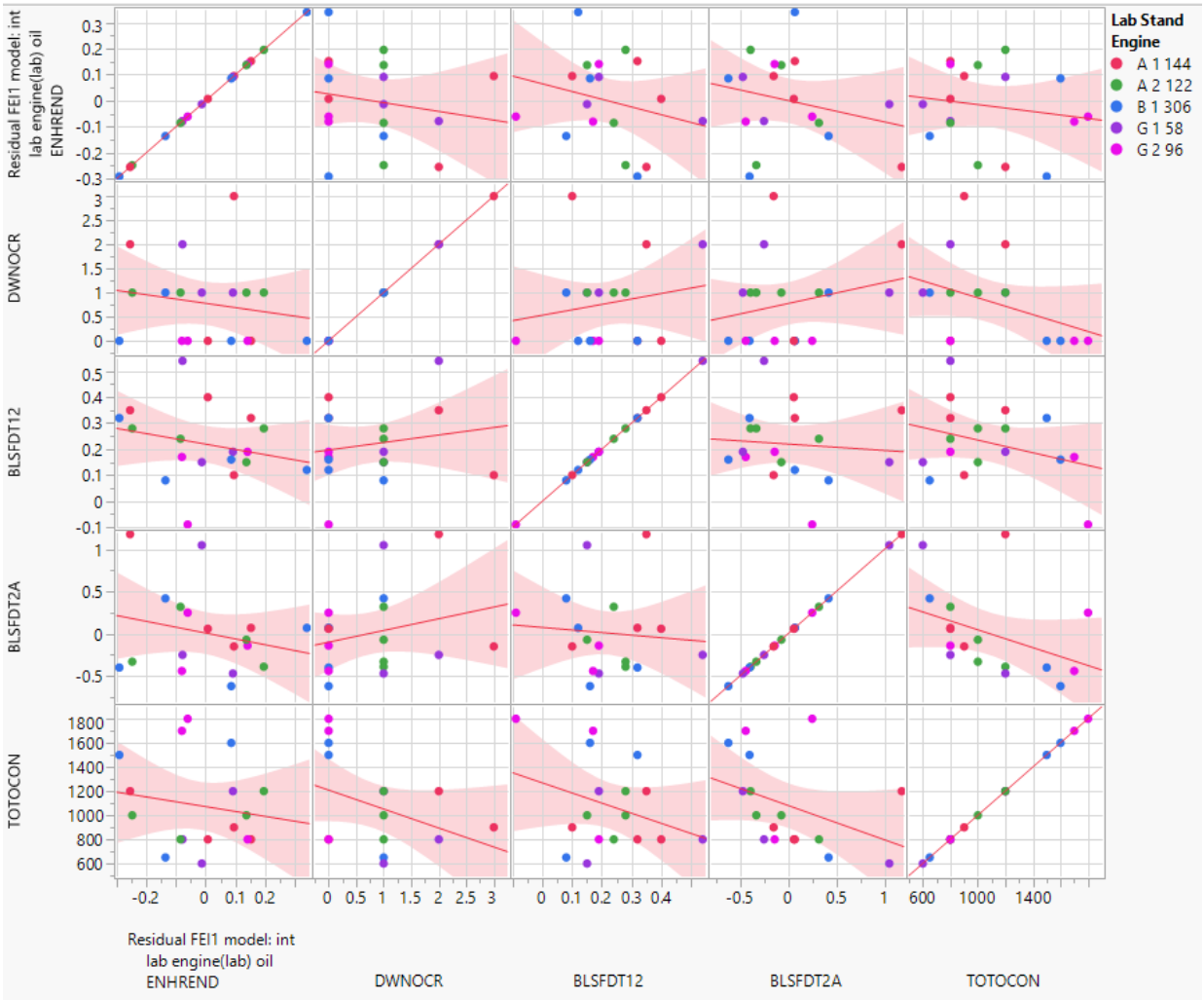
Term	Estimate	Prob>|t|
Intercept	2.1345341	<.0001*
LTMSLAB[A]	0.0118758	0.8723
LTMSLAB[B]	0.1144656	0.2292
LTMSLAB[A]:ENGNO[122]	0.0229028	0.7949
LTMSLAB[G]:ENGNO[58]	-0.119698	0.2502
IND[542-2]	0.3741418	0.0007*
IND[1011]	-0.404026	0.0013*
ENHREND	-0.000403	0.1323

Effect Tests

Source	DF	Prob > F
LTMSLAB	2	0.3026
ENGNO[LTMSLAB]	2	0.4949
IND	2	0.0014*
ENHREND	1	0.1323

Analyzing PM 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 RMSE	Repeatability
• s = 0.21 • VIE Precision Matrix s=0.29 • VID Precision Matrix s=0.14 • VID LTMS s=0.12	• s = 0.21 • r = 0.58

Model: FEI1 Engine hours adjusted vs. Oil

Reproducibility
• s = 0.22 • 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.

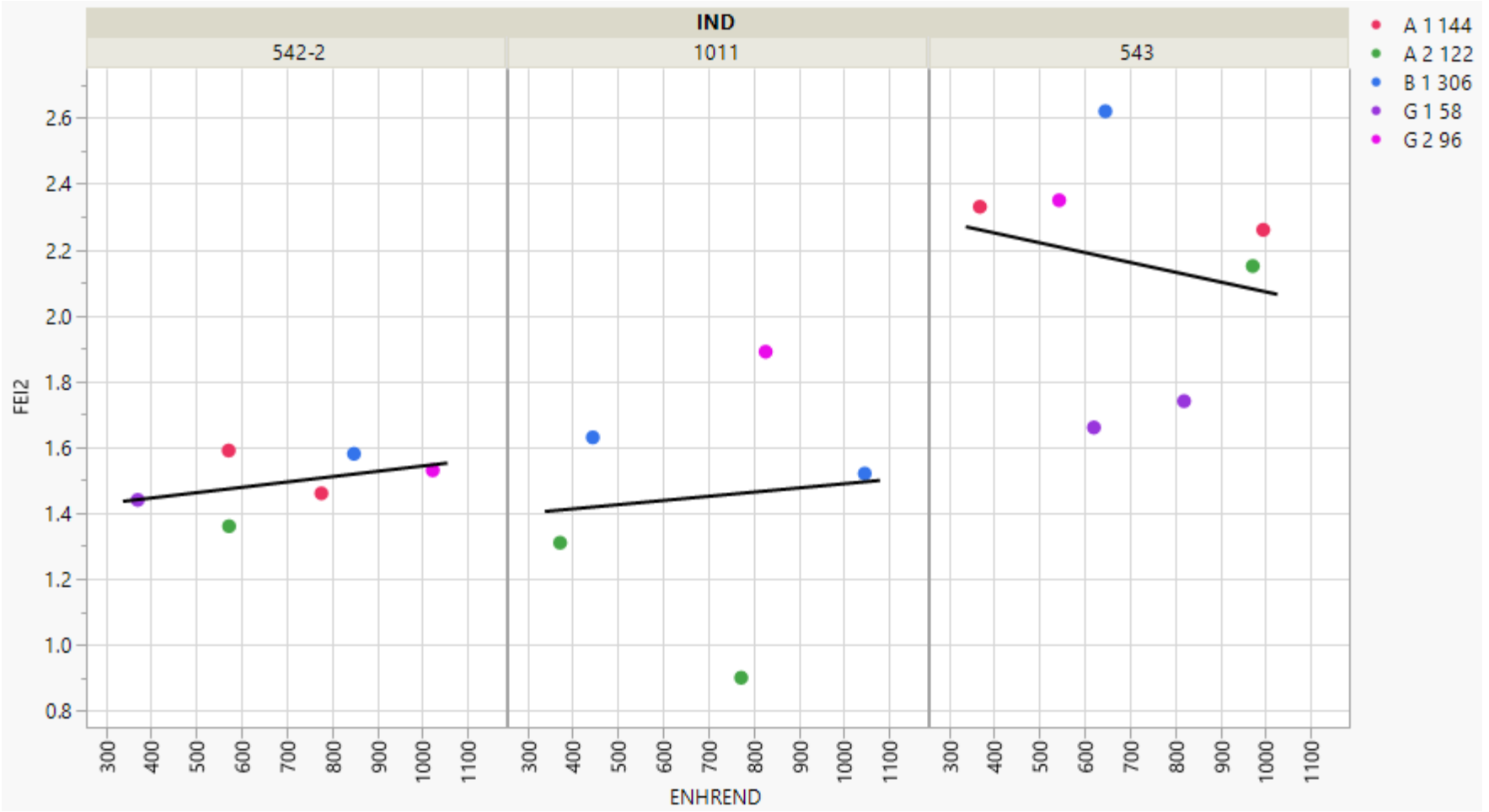
Note 1: An FEI1 of 2.0 was arbitrarily selected in the calculations as the upper pass/fail limit.

Agenda

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

Analyzing PM Data – FEI2

- Plot of FEI2_OR



Analyzing PM Data – FEI2

- Overall ANOVA Summary of FEI2 data:
  - Oil and engines within lab effects are statistically significant
  - Labs marginally differ
  - VIF PM Test Precision: 0.20 *(contrast w/ VID PM test precision of 0.14; VIE is 0.12)*

Summary of Fit

RSquare	0.88295
RSquare Adj	0.801015
Root Mean Square Error	0.197072
Mean of Response	1.74
Observations (or Sum Wgts)	18

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	7	2.9296278	0.418518	10.7762
Error	10	0.3883722	0.038837	Prob > F
C. Total	17	3.3180000		0.0006*

Parameter Estimates

Term	Estimate	Prob>|t|
Intercept	1.9324298	<.0001*
LTMSLAB[A]	-0.104097	0.1337
LTMSLAB[B]	0.2021927	0.0286*
LTMSLAB[A]:ENGNO[122]	-0.122791	0.1372
LTMSLAB[G]:ENGNO[58]	-0.322516	0.0040*
IND[542-2]	-0.205381	0.0133*
IND[1011]	-0.314703	0.0030*
ENHREND	-0.000293	0.2083

Effect Tests

Source	DF	Prob > F
LTMSLAB	2	0.0791
ENGNO[LTMSLAB]	2	0.0060*
IND	2	<.0001*
ENHREND	1	0.2083

FEI2 Engine Hours Adjustment:

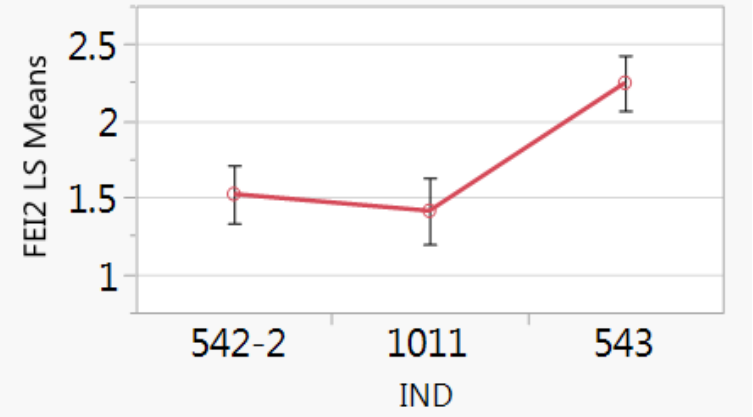
FEI2 = FEI2_OR + 0.000293*(ENHREND – 700)

Analyzing PM Data – FEI2

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

Level	Least Sq Mean
542-2	1.52
1011	1.41
543	2.25

LS Means Plot

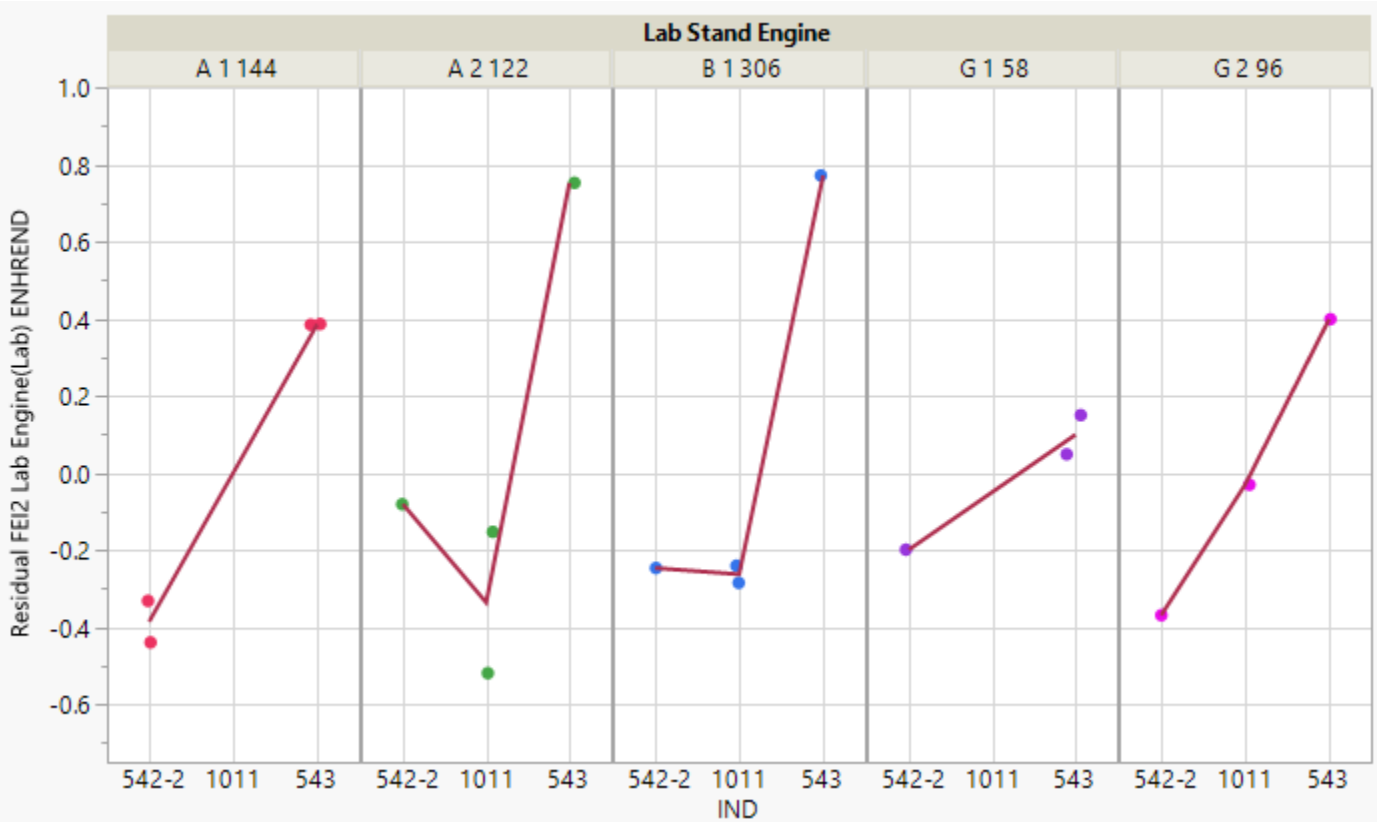


Level	- Level	Difference	p-Value
543	1011	0.83	0.00*
543	542-2	0.73	0.00*
542-2	1011	0.11	0.70

Ref Oil	VID FEI2 Target	VIE FEI2 Target
542	0.8	1.73

Analyzing PM 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 PM Data – FEI2

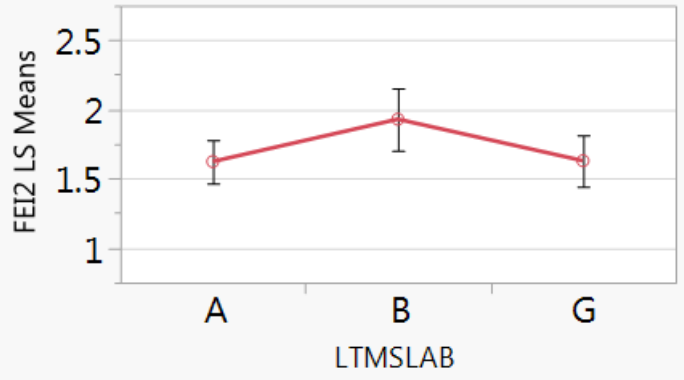
- Labs marginally differ
  - Lab B tends to be higher than both A and G

Effect Tests

Source	DF	Prob > F
LTMSLAB	2	0.0791
ENGNO[LTMSLAB]	2	0.0060*
IND	2	<.0001*
ENHREND	1	0.2083

Level	Least Sq Mean
A	1.62
B	1.93
G	1.63

LS Means Plot



Level	- Level	Difference	p-Value
B	A	0.31	0.08
B	G	0.30	0.11
G	A	0.01	1.00

Analyzing PM Data – FEI2

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

Parameter Estimates

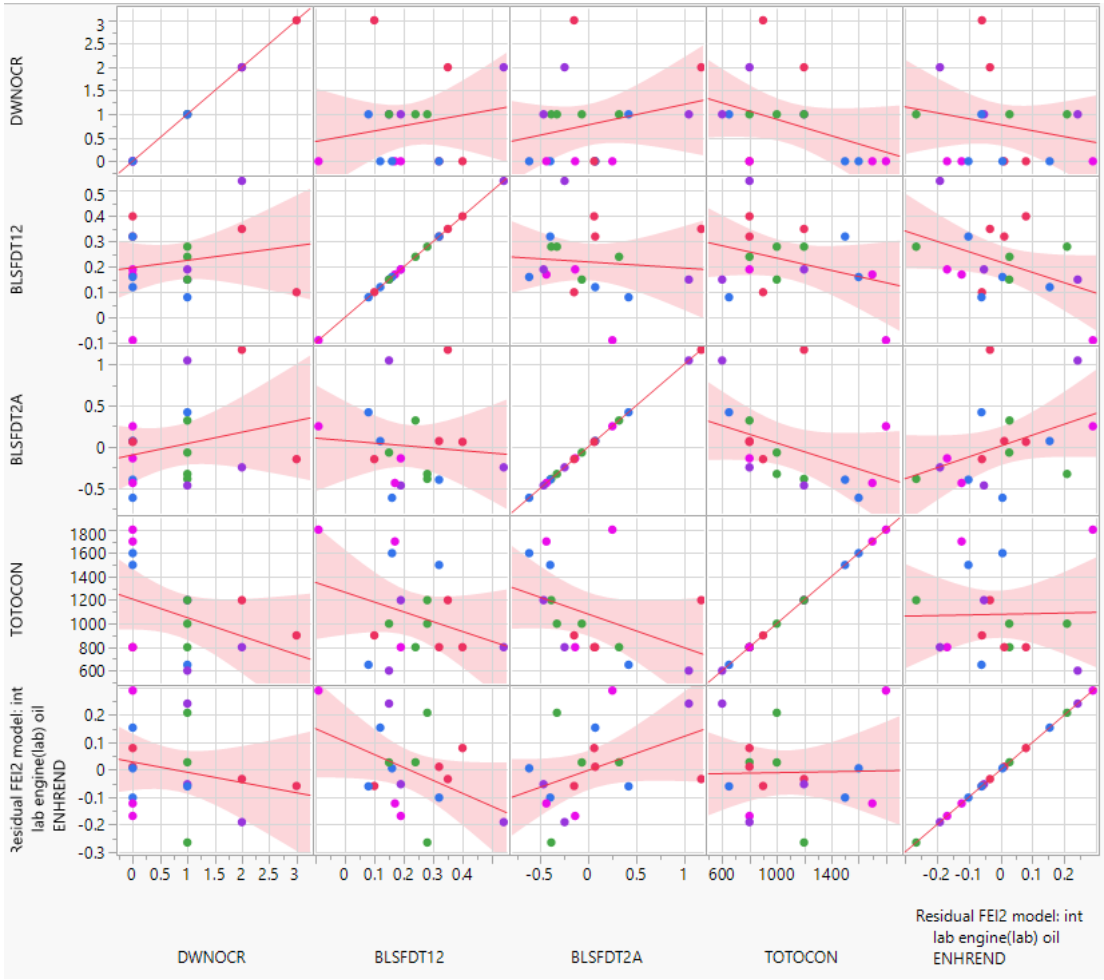
Term	Estimate	Prob>|t|
Intercept	1.9324298	<.0001*
LTMSLAB[A]	-0.104097	0.1337
LTMSLAB[B]	0.2021927	0.0286*
LTMSLAB[A]:ENGNO[122]	-0.122791	0.1372
LTMSLAB[G]:ENGNO[58]	-0.322516	0.0040*
IND[542-2]	-0.205381	0.0133*
IND[1011]	-0.314703	0.0030*
ENHREND	-0.000293	0.2083

Effect Tests

Source	DF	Prob > F
LTMSLAB	2	0.0791
ENGNO[LTMSLAB]	2	0.0060*
IND	2	<.0001*
ENHREND	1	0.2083

Analyzing PM 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 = 0.19 • VIE Precision Matrix s=0.12 • VID Precision Matrix s=0.16 • VID LTMS s=0.14	• s = 0.19 • r = 0.53	• s = 0.30 • R = 0.83

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 0.97 – 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 PM 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)	Method Standard Deviation	0.13
540 (GF5A)	1.32		
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)	Method Standard Deviation	0.14
540 (GF5A)	1.04		
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)	Regression RMSE	0.29
1010-1	1.90		
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)	Regression RMSE	0.25
1010-1	1.82		
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)	Regression RMSE	0.22
542-2	2.23		
1011	1.45	Full span of results (st devs)	3.55
543	1.88		
Sequence VIF FEI2			
Oil	Target (LTMS)	Regression RMSE	0.30
542-2	1.52		
1011	1.41	Full span of results (st devs)	2.80
543	2.25		

Comments

- 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

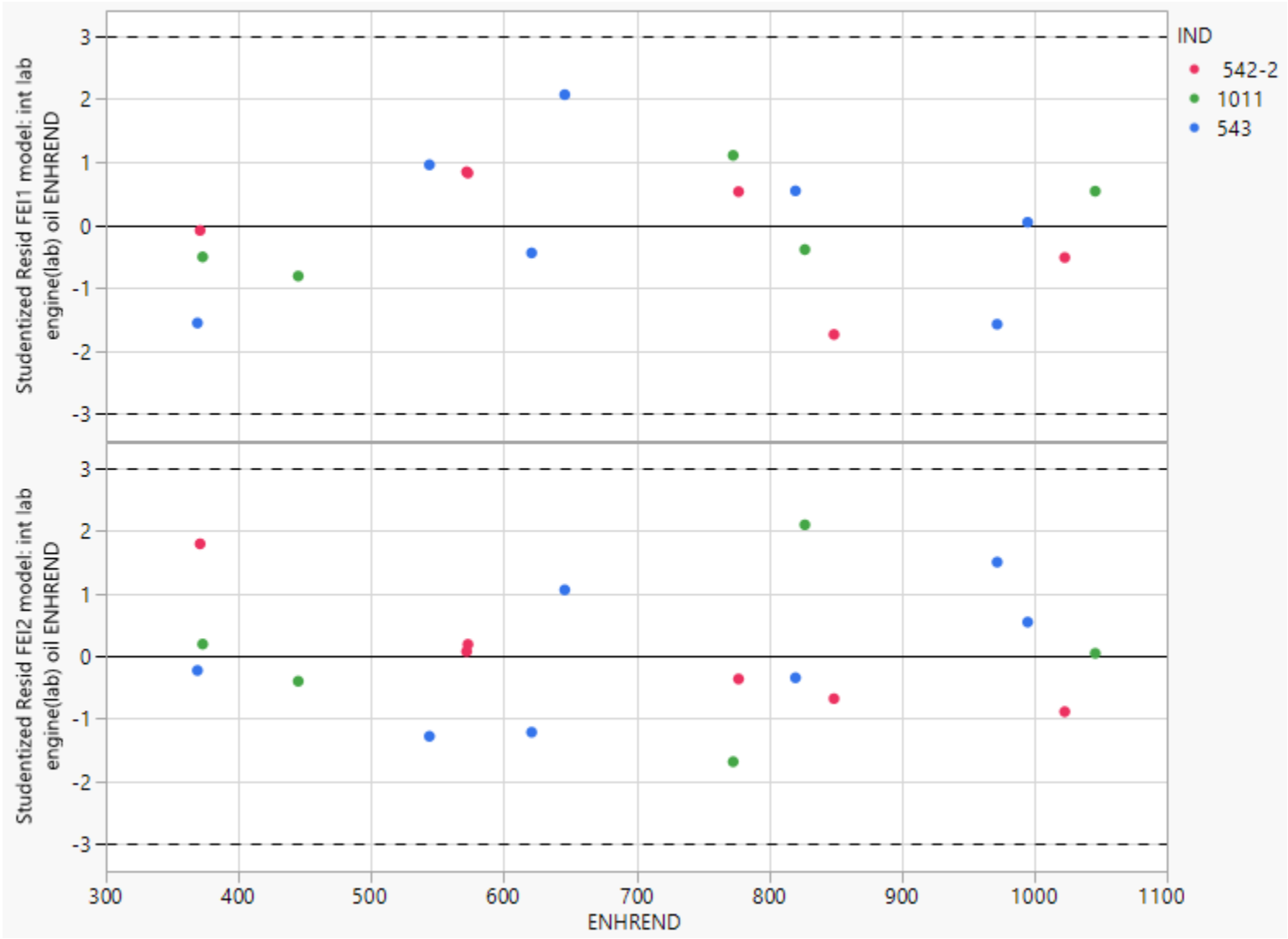
FUEL ECONOMY IMPROVEMENT at 100 Hours
Unit of Measure: Percent

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

Residual Diagnostics Model

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

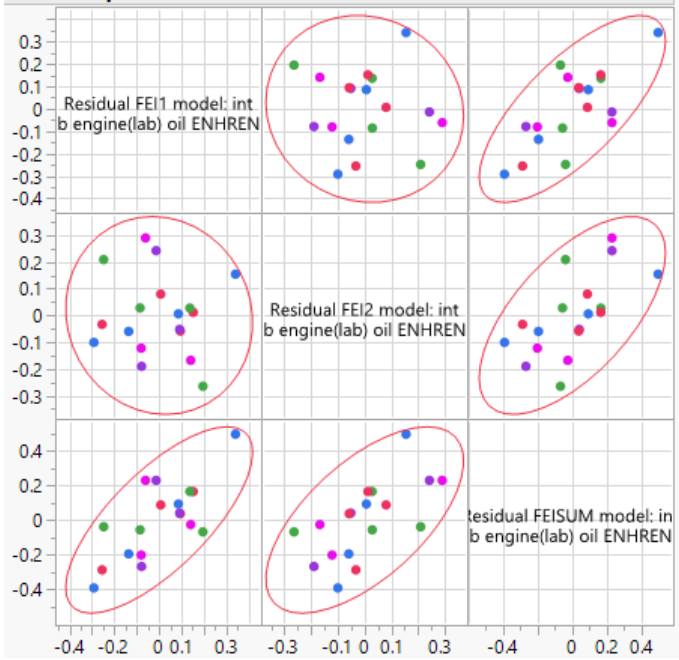


Correlation among parameters
Model: Oil, Lab, Engine(Lab), ENHREND

Correlations

	Residual FEI1 model: int lab engine(lab) oil ENHREND	Residual FEI2 model: int lab engine(lab) oil ENHREND	Residual FEISUM model: int lab engine(lab) oil ENHREND
Residual FEI1 model: int lab engine(lab) oil ENHREND	1.0000	-0.0706	0.7278
Residual FEI2 model: int lab engine(lab) oil ENHREND	-0.0706	1.0000	0.6327
Residual FEISUM model: int lab engine(lab) oil ENHREND	0.7278	0.6327	1.0000

Scatterplot Matrix



Appendix 2: VIF Engine Life Review

Industry Statistician Team

Date: December 2016

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

Executive Summary

1. There are a couple of key factors leading to high uncertainty in this analysis.
   - Missing 1011 2nd run data could have a major impact on engine life effect estimates, especially given the difference observed in FEI1 for run #2.
   - There are several data points with high studentized residuals for both FEI1 and FEI2 that have a significant impact on the Oil*ENHREND interaction term affect if excluded.
2. Limiting the engine life to 4 tests does not mean that the engine life affect is the same in this range. Some oils may still perform better or worse depending on the engine run number.
3. If one accepts that the engines effect may be different by oil, the mean confidence interval approach suggests 5 or 6 tests is reasonable.
4. There is no strong evidence that the engine life effect is different by oil, so the "Innocent until proven guilty" approach could argue for a full 8 test engine life.

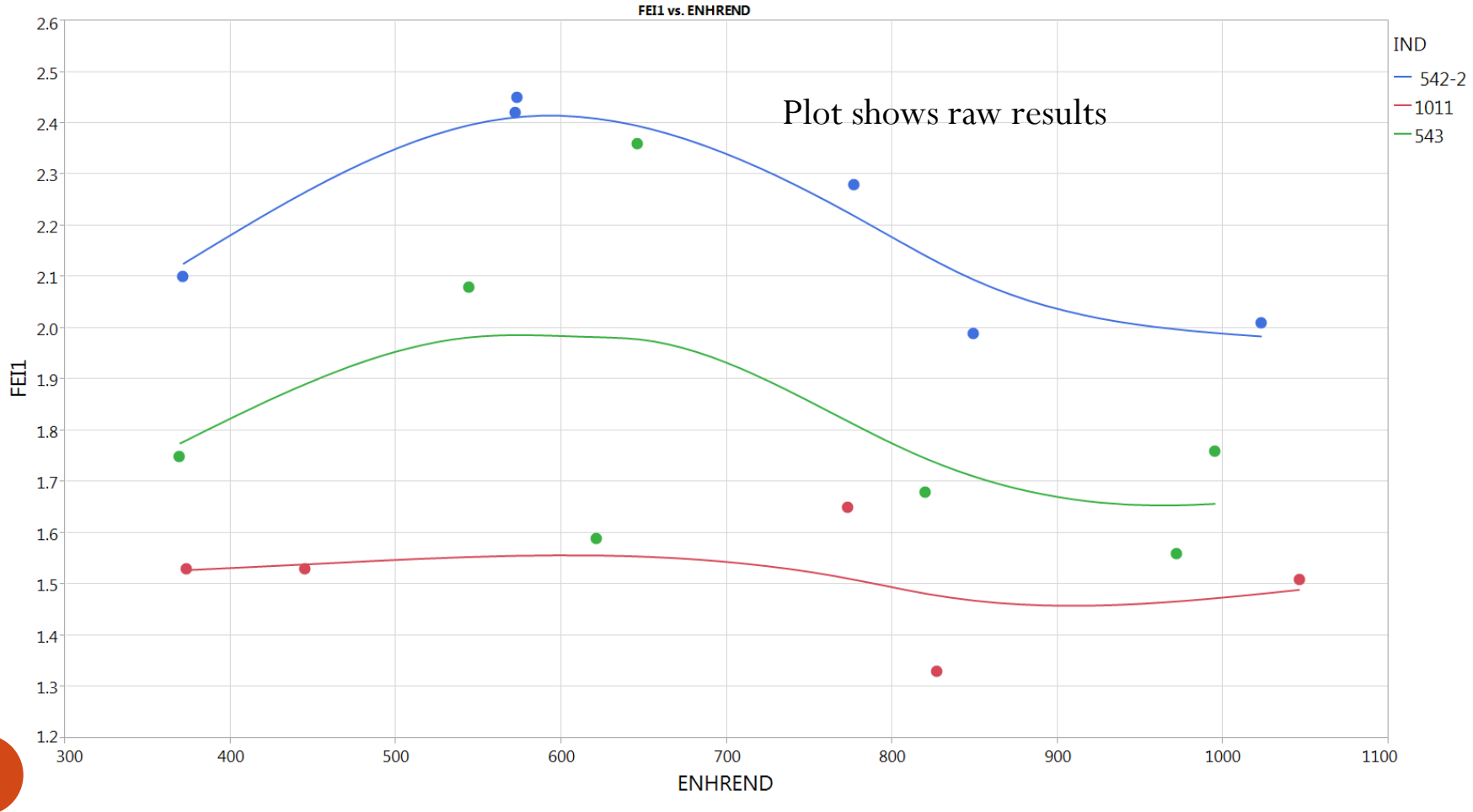
If none of the options above are desirable, then additional data should be pursued to clear up the uncertainties.

VIF Engine Life

Based on FEI1 Oil Discrimination

Assess Engine Life Based on Oil Discrimination

- Analysis of the n=18 data set showed a non linear trend in FEI1 as the engine ages for 542-2 and 543. No 2nd run data on oil 1011.



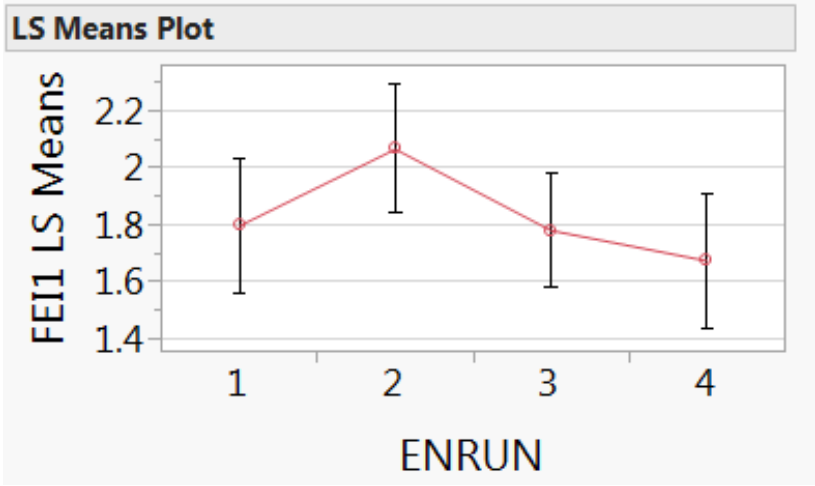
Assess Engine Life Based on Oil Discrimination

- Analysis of a statistical model with Oil, LabEngine, ENRUN terms revealed that FEI1 for engine run #2 is statistically milder than other runs, with engine run #4 being borderline statistically severe.

Expanded Estimates

Nominal factors expanded to all levels

Term	Estimate	Prob>|t|
Intercept	1.8281641	<.0001*
IND[542-2]	0.3368439	0.0011*
IND[1011]	-0.304507	0.0104*
IND[543]	-0.032337	0.6794
LabEngine[A122]	0.0454625	0.6331
LabEngine[A144]	0.0720826	0.4651
LabEngine[B306]	0.0954625	0.3279
LabEngine[G58]	-0.180633	0.1399
LabEngine[G96]	-0.032374	0.7571
ENRUN[1]	-0.032631	0.7289
ENRUN[2]	0.2365007	0.0235*
ENRUN[3]	-0.048632	0.5540
ENRUN[4]	-0.155238	0.1084



Level	- Level	Difference	p-Value
2	4	0.3917388	0.0681
2	3	0.2851323	0.2247
2	1	0.2691318	0.3409
1	4	0.1226070	0.8454
3	4	0.1066065	0.8618
1	3	0.0160005	0.9993

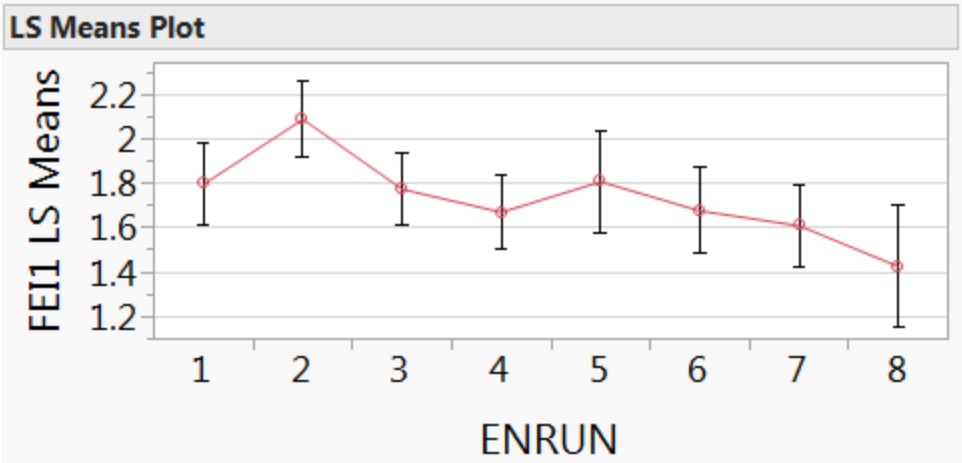
Assess Engine Life Based on Oil Discrimination

- LS Means plot for ENRUN for all 8 tests.

Expanded Estimates

Nominal factors expanded to all levels

Term	Estimate	Prob>|t|
Intercept	1.733166	<.0001*
IND[542-2]	0.2900324	<.0001*
IND[1011]	-0.240728	0.0002*
IND[543]	-0.049304	0.3026
LabEngine[A122]	0.0230723	0.7096
LabEngine[A144]	0.032993	0.5902
LabEngine[B306]	0.0724994	0.3770
LabEngine[G58]	-0.174507	0.0095*
LabEngine[G96]	0.0459423	0.5285
ENRUN[1]	0.0660017	0.4414
ENRUN[2]	0.3604035	0.0004*
ENRUN[3]	0.0429733	0.5788
ENRUN[4]	-0.061312	0.4388
ENRUN[5]	0.0765682	0.4495
ENRUN[6]	-0.055025	0.5288
ENRUN[7]	-0.122549	0.1627
ENRUN[8]	-0.307061	0.0179*

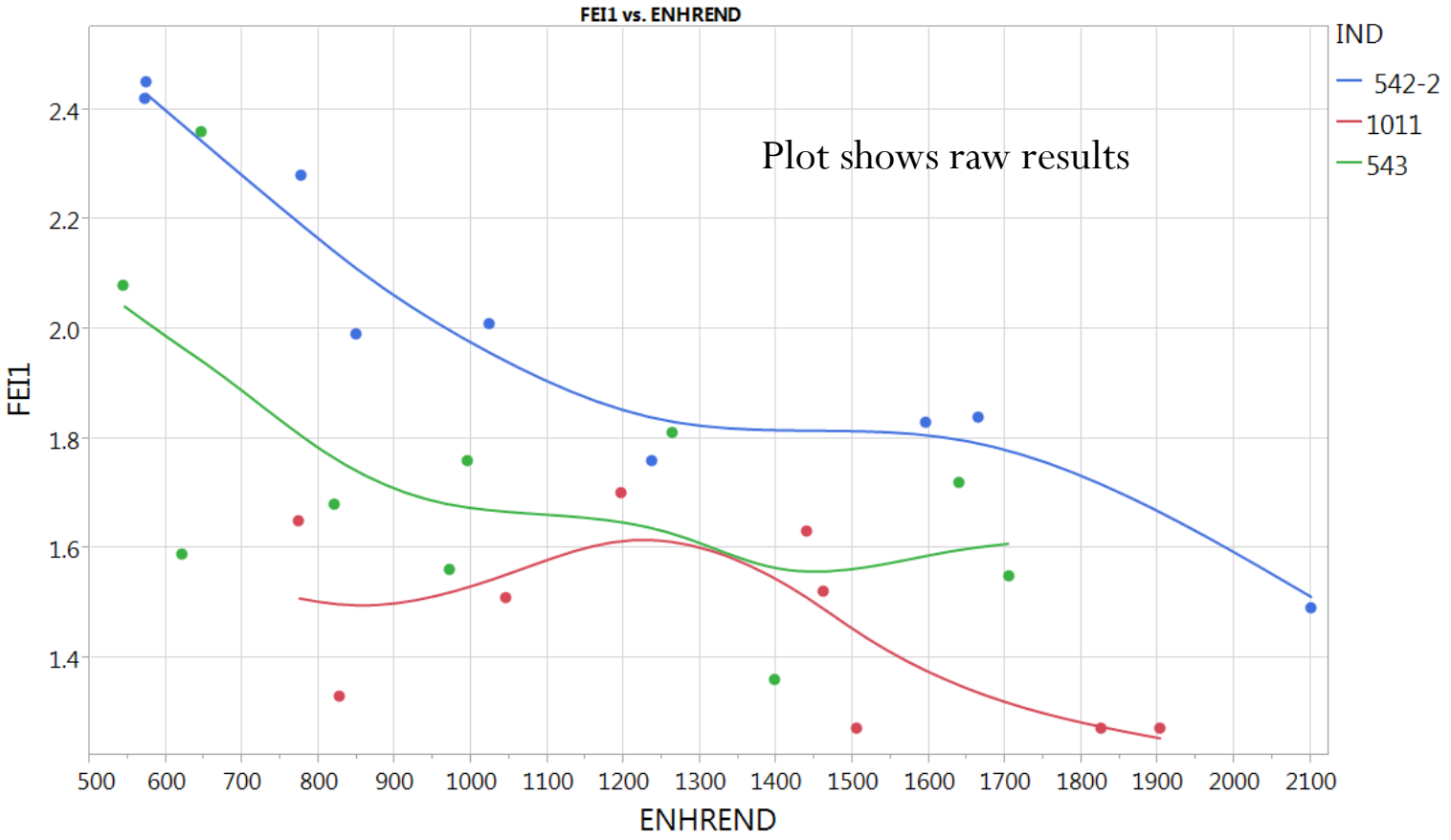


Assess Engine Life Based on Oil Discrimination

- Raw plot of FEI1 with n=32 data points

Assess Engine Life Based on Oil Discrimination

- Raw plot of FEI1 with n=28 data points (1st run points removed)
- 542-2 and 543 have similar trend
- No data for 1011 for ENHREND between 500 and 750 hours (ENRUN #2).

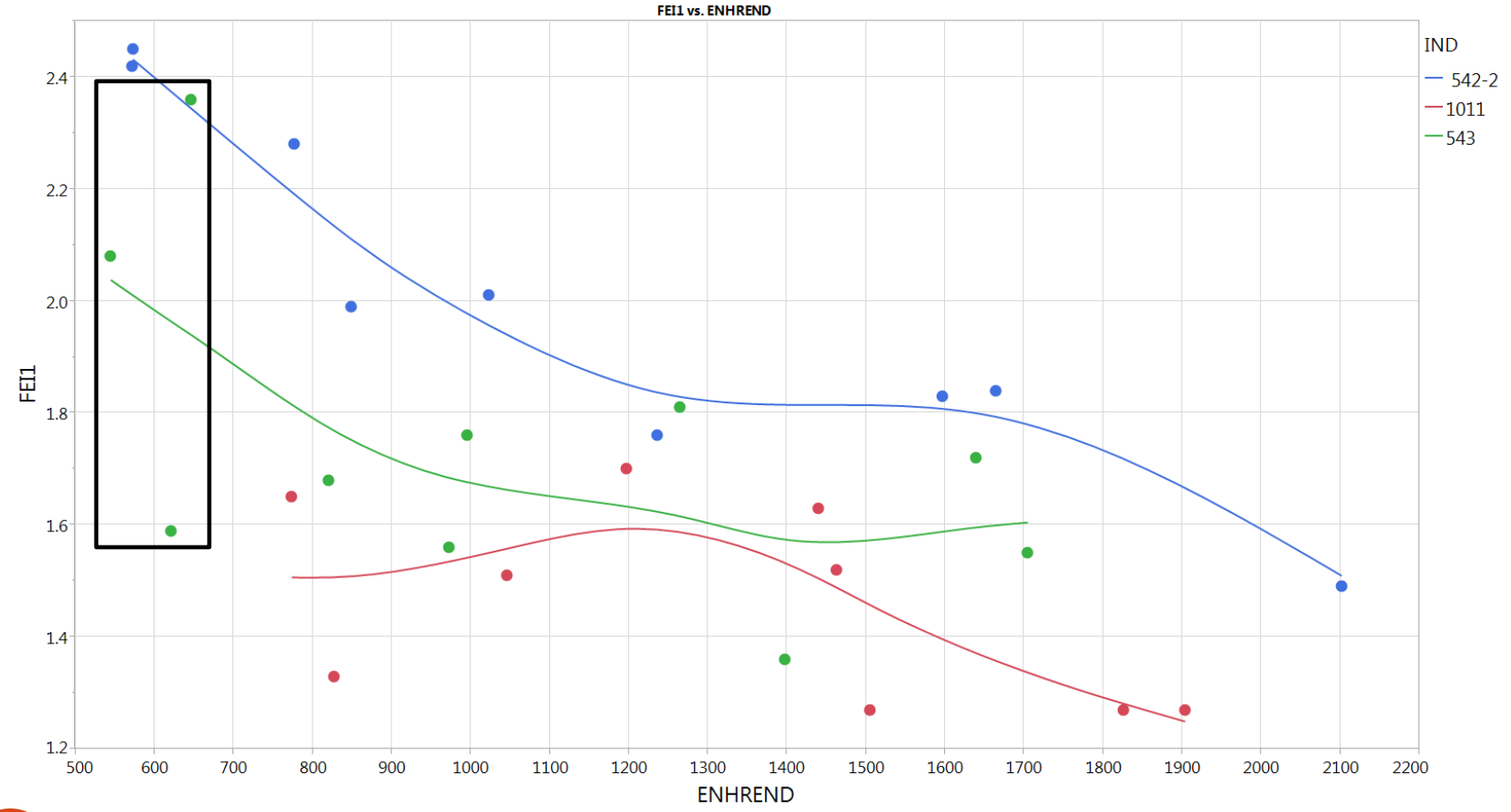


Concerns Affecting the Analysis

With small sample sizes, resulting analysis can be very sensitive to outlier results. Changes to any of the following points/sets of points on the following slides have a substantial impact on the conclusions.

Concerns Affecting the Analysis

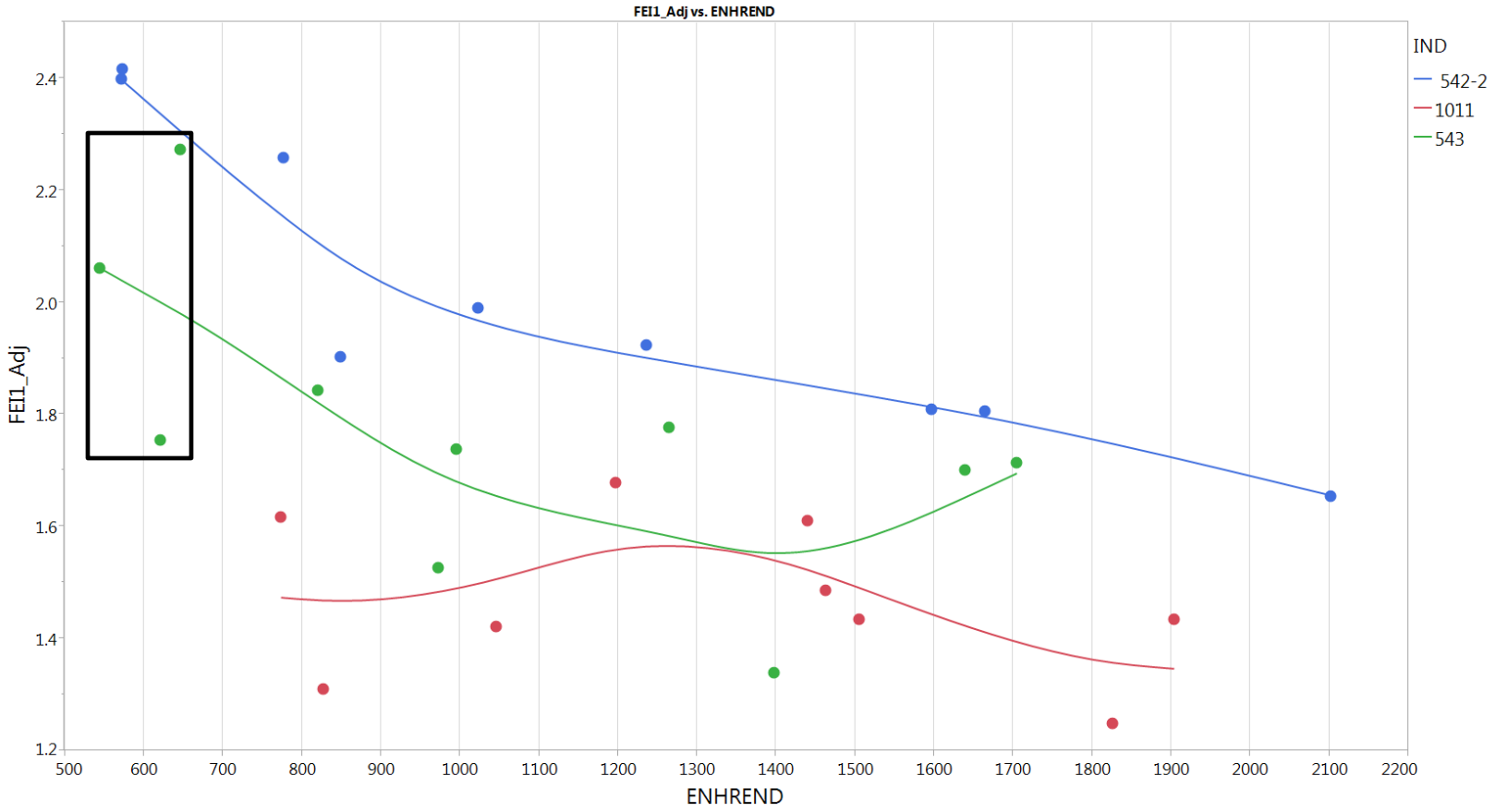
1. High variability in the 543 results for engine run #2. Results (unadjusted) span a range of 0.77%



Concerns Affecting the Analysis

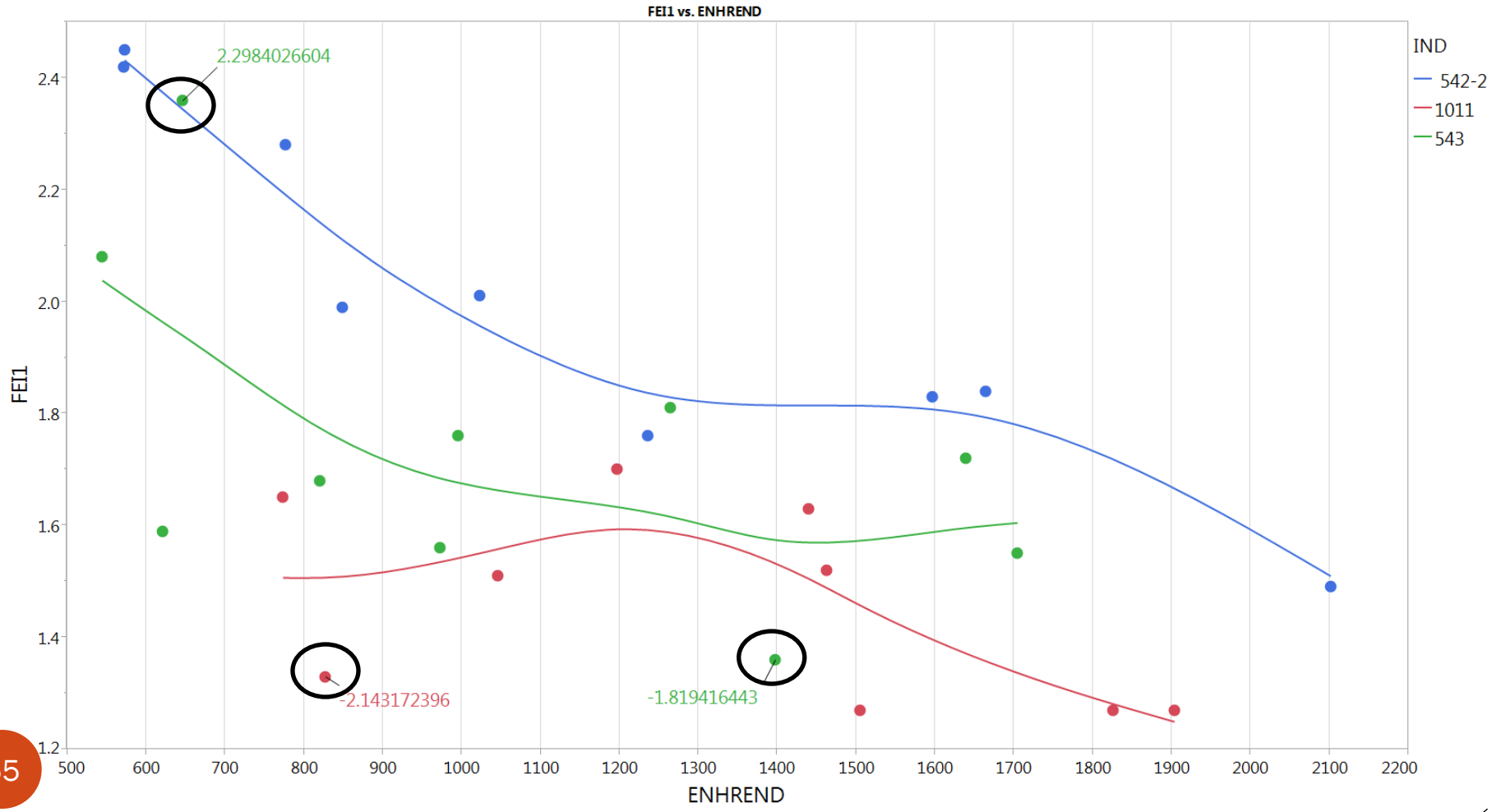
1. Using a model with Oil, Lab, Eng[Lab], and Ln(ENGHREND) shows a residual difference of 0.53% for the max-min of these points.

*Plot adjusted for engine differences only using LabEngine term in same model in place of Lab & Eng[Lab] terms



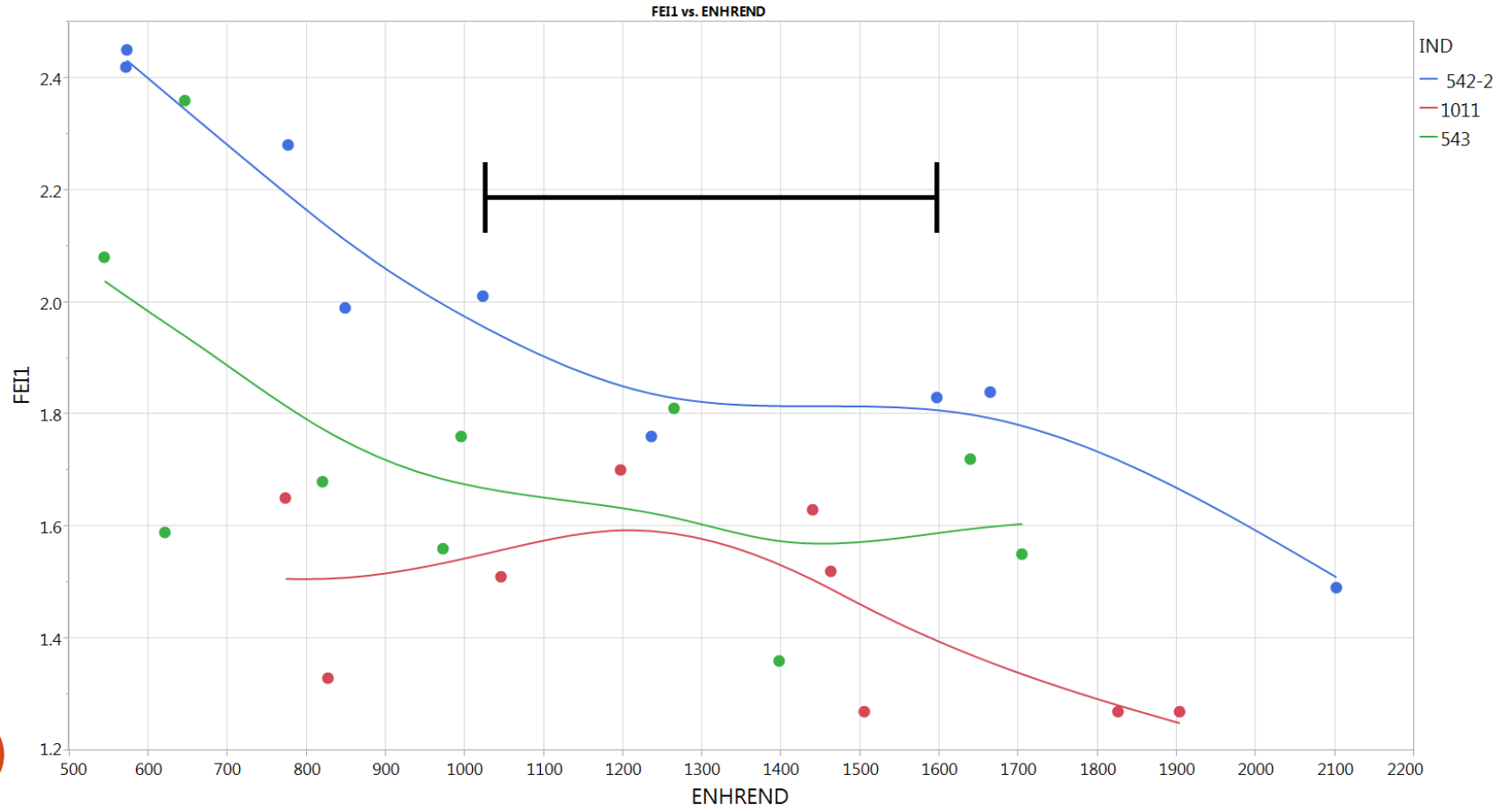
Concerns Affecting the Analysis

2. The circled points have high studentized residuals.



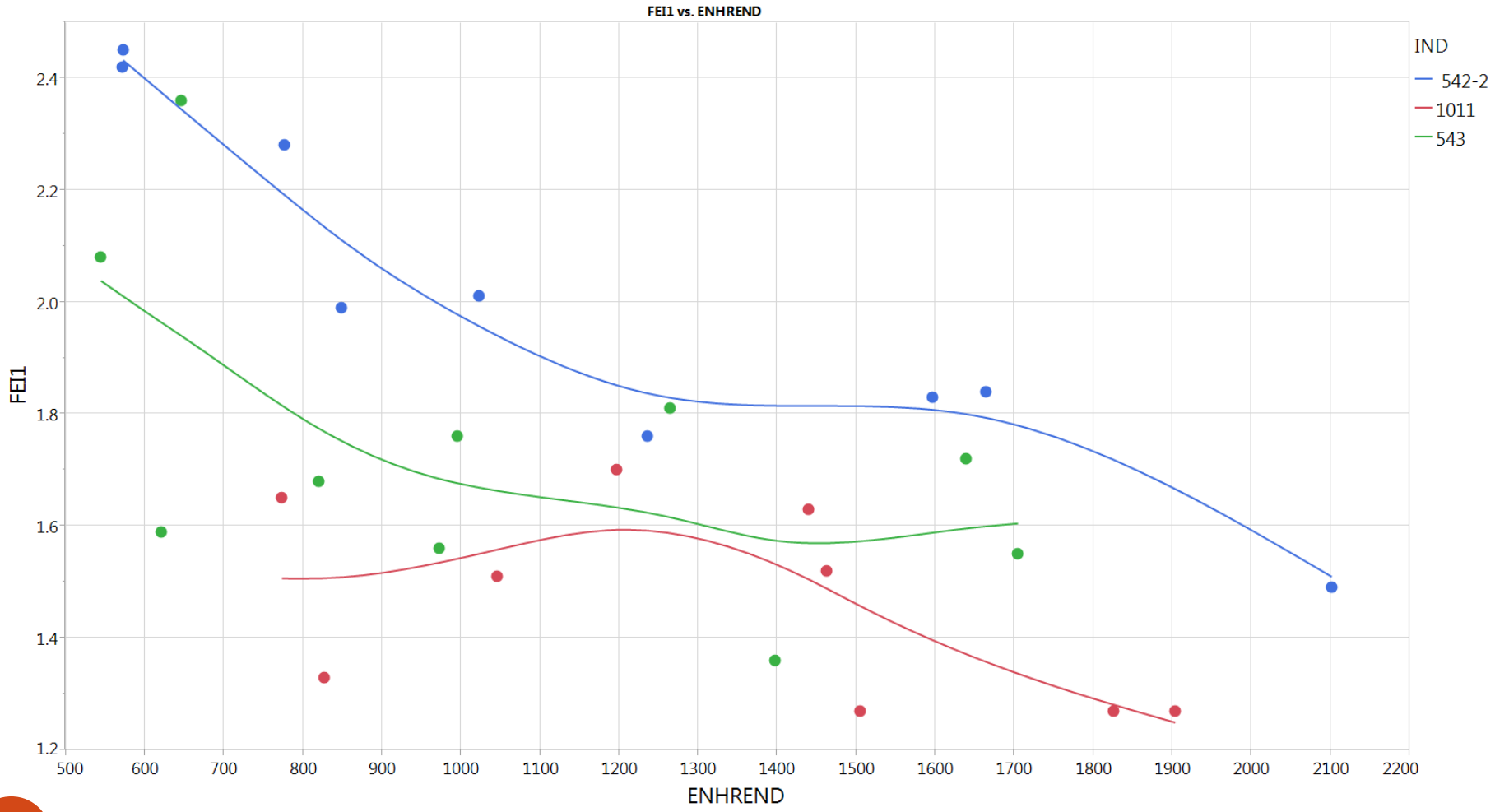
Concerns Affecting the Analysis

3. There are only 3 combined data points for 542-2 and 543 for the range 1023 < ENHREND < 1596
   - Residual difference between the two 543 results is 0.40%



Concerns Affecting the Analysis

4. No 2nd run data for 1011



Using Linear Engine Hours Correction

Assess Engine Life Based on Oil Discrimination

- Overall ANOVA Summary of FEI1 data:
  - Analysis indicates that no strong evidence exists that the engine hour effect is inconsistent across oils using all 28 data points.

Summary of Fit

RSquare	0.792998
RSquare Adj	0.689497
Root Mean Square Error	0.191025
Mean of Response	1.738929
Observations (or Sum Wgts)	28

Analysis of Variance

Parameter Estimates

Term	Estimate	Prob>|t|	VIF
Intercept	2.1105711	<.0001*	.
IND[542-2]	0.2694355	<.0001*	1.4917753
IND[1011]	-0.258725	0.0002*	1.6333332
LTMSLAB[A]	0.0024078	0.9660	2.1183154
LTMSLAB[B]	0.0784005	0.3470	2.1870603
LTMSLAB[A]:ENGNO[122]	0.0260869	0.6383	1.0577362
LTMSLAB[G]:ENGNO[58]	-0.102089	0.1064	1.172464
ENHREND	-0.000299	0.0056*	1.3671563
(ENHREND-1177.5)*IND[542-2]	-0.000167	0.1677	1.4734904
(ENHREND-1177.5)*IND[1011]	0.0002151	0.1279	1.5015411

Effect Tests

Source	Nparm	DF	Prob > F
IND	2	2	0.0001*
LTMSLAB	2	2	0.3962
ENGNO[LTMSLAB]	2	2	0.2450
ENHREND	1	1	0.0056*
ENHREND*IND	2	2	0.2382

Assess Engine Life Based on Oil Discrimination

- Overall ANOVA Summary of FEI1 data:
  - Linear engine hour estimate of -.000342
  - RMSE approximately 0.20
  - 542-2 > 543, 1011

Summary of Fit	
RSquare	0.757227
RSquare Adj	0.672256
Root Mean Square Error	0.196257
Mean of Response	1.738929
Observations (or Sum Wgts)	28

Analysis of Variance

Parameter Estimates

Term	Estimate	Prob>|t|	VIF
Intercept	2.1576091	<.0001*	.
IND[542-2]	0.255296	0.0001*	1.4223859
IND[1011]	-0.231568	0.0005*	1.5076273
LabEngine[A122]	0.0299943	0.6869	1.53062
LabEngine[A144]	0.0174383	0.8065	1.5195574
LabEngine[B306]	0.0855857	0.4015	2.0337874
LabEngine[G58]	-0.154995	0.0520	1.7316222
ENHREND	-0.000342	0.0016*	1.2748697

Effect Tests

Source	Nparm	DF	Prob > F
IND	2	2	0.0002*
LabEngine	4	4	0.3956
ENHREND	1	1	0.0016*

Level		Least Sq Mean
542-2	A	2.0099395
543	B	1.7309155
1011	B	1.5230756

Levels not connected by same letter are significantly different.

Level	- Level	Difference	Std Err Dif	p-Value
542-2	1011	0.4868640	0.0950829	0.0001*
542-2	543	0.2790240	0.0918579	0.0171*
543	1011	0.2078400	0.0946428	0.0963

Assess Engine Life Based on Oil Discrimination

- FEI1 oil discrimination over the engine life
  - One approach to determine VIF engine life would be to track the p-value of the oil*ENHREND term using various subsets of the valid matrix data. The significance of this term represents the point at which the same engine hour correction should no longer be used for all oils.

Data used	Number of test results	Overall p-value of oil*ENHREND term	Range of p-values by oil of oil*ENHREND term
ENHREND < 1000	12	.9487	.8002 to .8587
ENHREND < 1100	14	.8390	.5773 to .8507
ENHREND < 1300	17	.4996	.3023 to .9484
ENHREND < 1450	19	.0620	.0310 to .8564
ENHREND < 1596	21	.0491	.0236 to .8412
ENHREND < 1800	25	.2032	.0965 to .5550
All Valid Tests	28	.2383	.1279 to .7084

Assess Engine Life Based on Oil Discrimination

- Here is the same table with the low 543 result, testkey #117626

Data used	Number of test results	Overall p-value of oil*ENHREND term	Range of p-values by oil of oil*ENHREND term
ENHREND < 1000	12	.9487	.8002 to .8587
ENHREND < 1100	14	.8390	.5773 to .8507
ENHREND < 1300	17	.4996	.3023 to .9484
ENHREND < 1450	18	.1686	.0695 to .7859
ENHREND < 1596	20	.1370	.0532 to .7003
ENHREND < 1800	24	.1489	.0685 to .7699
All Valid Tests	27	.2389	.1209 to .9844

Assess Engine Life Based on Oil Discrimination

- Here is the same table without the low 1011 result, testkey #112956

Data used	Number of test results	Overall p-value of oil*ENHREND term	Range of p-values by oil of oil*ENHREND term
ENHREND < 1000	11	Not Estimable	
ENHREND < 1100	13	.9822	.8744 to .9307
ENHREND < 1300	16	.7949	.5247 to .8874
ENHREND < 1450	18	.2772	.1246 to .8366
ENHREND < 1596	20	.2205	.0937 to .7688
ENHREND < 1800	24	.5469	.2853 to .9031
All Valid Tests	27	.5769	.3242 to .9966

Assess Engine Life Based on Oil Discrimination

- Here is the same table without the high 543 result, testkey #118267

Data used	Number of test results	Overall p-value of oil*ENHREND term	Range of p-values by oil of oil*ENHREND term
ENHREND < 1000	11	.3864	.2528 to 2566
ENHREND < 1100	13	.5821	.3466 to .7623
ENHREND < 1300	16	.3342	.1550 to .4991
ENHREND < 1450	18	.0478	.0174 to .4202
ENHREND < 1596	20	.0680	.0246 to .4988
ENHREND < 1800	24	.1024	.0377 to .8950
All Valid Tests	27	.1166	.0438 to .5866

Assess Engine Life Based on Oil Discrimination

- FEI1 oil discrimination over the engine life
  - FEI1 ~ Oil, Lab, ENG[Lab], ENHREND, Oil*ENHREND
  - Reminder: Oil*ENHREND, Lab, and Eng[Lab] terms not significant to model

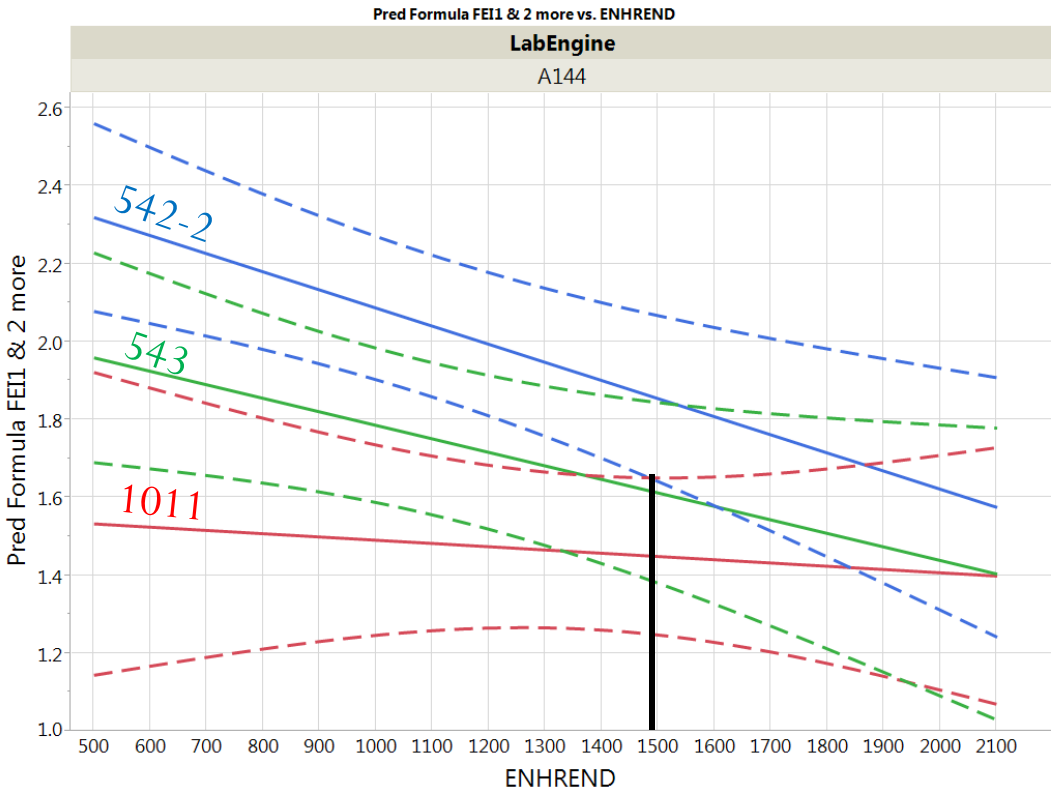
Lab-Engine	Predicted Hours at which 542-2 no longer discriminates from any other oil
A 144	1500
A 122	1450
G 58	1500
G 96	1400
B 306	1175*

* - sample size = 3 tests

Refer to Appendix A for plots of other stands

Example: Using A 144

Notice how the 95% confidence interval for 542-2 begins to overlap the 95% confidence interval for 1011 at around ENHREND = 1500.



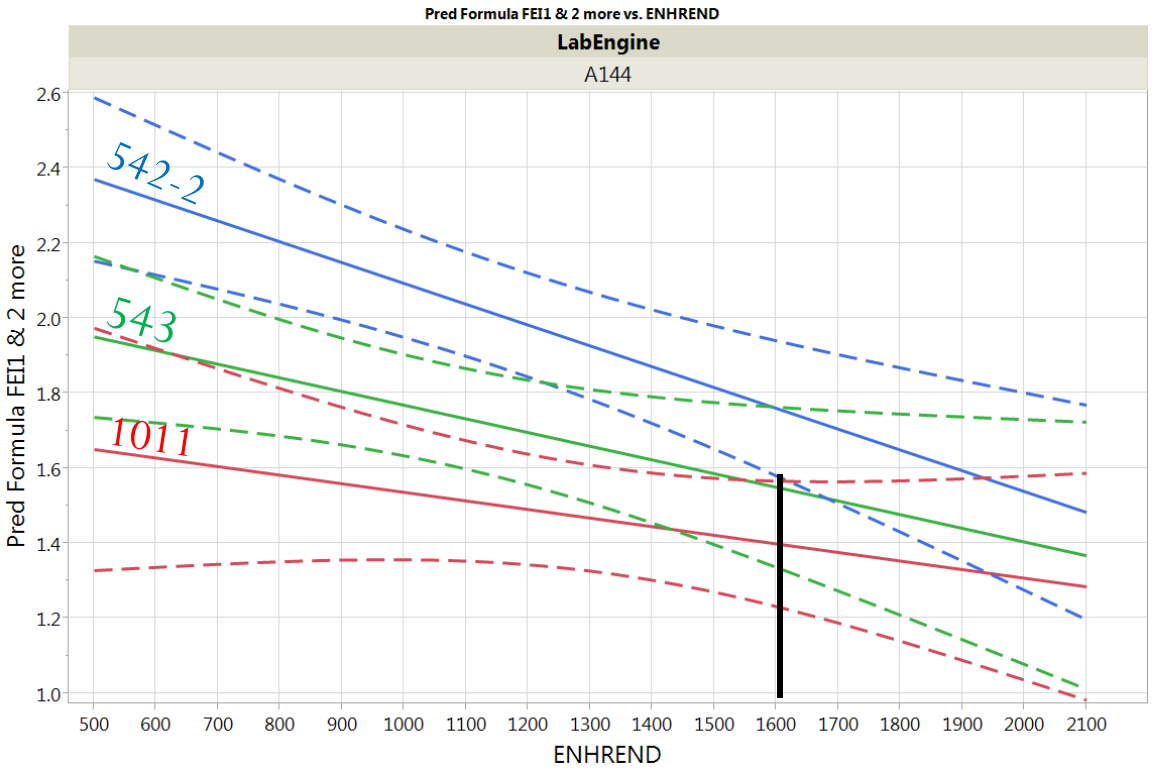
Assess Engine Life Based on Oil Discrimination

- FEI1 oil discrimination over the engine life, removing insignificant model terms.
  - FEI1 ~ Oil, ENHREND, and Oil*ENHREND

Predicted Hours at which 542-2 no longer discriminates from any other oil
1600

Example:

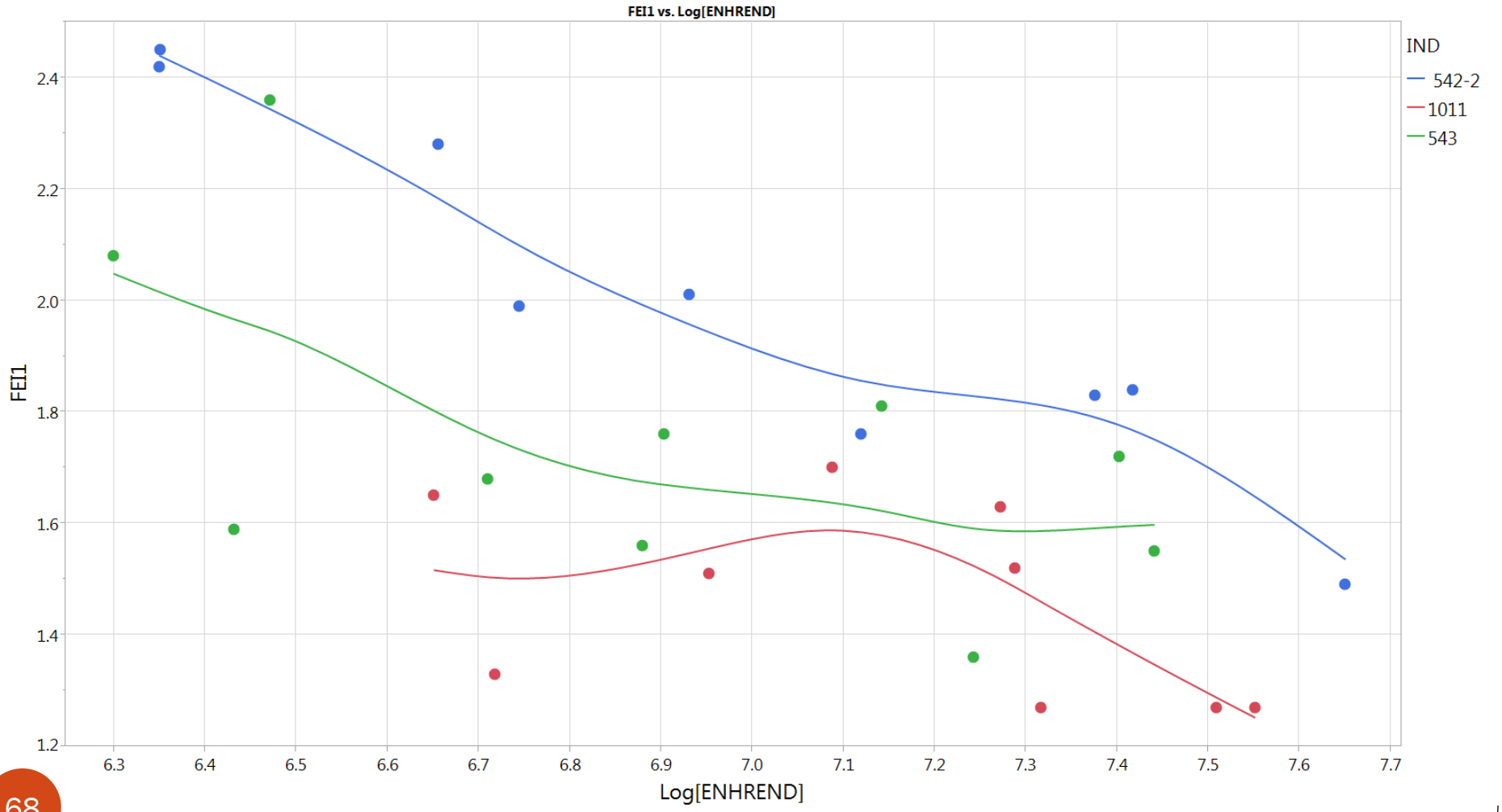
This example shows how the number of model degrees of freedom used directly affects the oil mean confidence intervals.



Using Ln(EngineHours) Correction

Assess Engine Life Based on Oil Discrimination

- Plot of Raw FEI1 by Ln of engine hours



Assess Engine Life Based on Oil Discrimination

- Overall ANOVA Summary of FEI1 data:
  - Analysis indicates that no strong evidence exists that the engine hour effect is inconsistent across oils using all 28 data points.

Summary of Fit

RSquare	0.818747
RSquare Adj	0.72812
Root Mean Square Error	0.17875
Mean of Response	1.738929
Observations (or Sum Wgts)	28

Analysis of Variance

Parameter Estimates

Term	Estimate	Prob>|t|	VIF
Intercept	4.1006382	<.0001*	.
IND[542-2]	0.2616914	<.0001*	1.5194489
IND[1011]	-0.256281	0.0002*	1.7426644
LabEngine[A122]	0.0462551	0.5053	1.5891367
LabEngine[A144]	-0.006828	0.9190	1.6262617
LabEngine[B306]	0.0986616	0.2909	2.0215933
LabEngine[G58]	-0.17509	0.0214*	1.7915682
Log[ENHREND]	-0.337508	0.0037*	1.4324099
(Log[ENHREND]-6.99486)*IND[542-2]	-0.212576	0.1067	1.6643497
(Log[ENHREND]-6.99486)*IND[1011]	0.26336	0.1016	1.7969863

Effect Tests

Source	Nparm	DF	Prob > F
IND	2	2	0.0001*
LabEngine	4	4	0.2098
Log[ENHREND]	1	1	0.0037*
Log[ENHREND]*IND	2	2	0.1830

Assess Engine Life Based on Oil Discrimination

- Overall ANOVA Summary of FEI1 data:
  - RMSE approximately 0.19
  - 542-2 > 543, 1011

Summary of Fit	
RSquare	0.781105
RSquare Adj	0.704492
Root Mean Square Error	0.186356
Mean of Response	1.738929
Observations (or Sum Wgts)	28

Analysis of Variance

Parameter Estimates

Term	Estimate	Prob>|t|	VIF
Intercept	4.5809237	<.0001*	.
IND[542-2]	0.2460968	0.0001*	1.430158
IND[1011]	-0.221658	0.0005*	1.5315996
LabEngine[A122]	0.0336826	0.6337	1.5298675
LabEngine[A144]	0.0217746	0.7477	1.522296
LabEngine[B306]	0.0882937	0.3597	2.0069947
LabEngine[G58]	-0.163389	0.0299*	1.6678285
Log[ENHREND]	-0.403997	0.0006*	1.2432375

Effect Tests

Source	Nparm	DF	Prob > F
IND	2	2	0.0002*
LabEngine	4	4	0.2763
Log[ENHREND]	1	1	0.0006*

Level		Least Sq Mean
542-2	A	2.0011172
543	B	1.7305816
1011	B	1.5333625

Levels not connected by same letter are significantly different.

Level	- Level	Difference	Std Err Dif	p-Value
542-2	1011	0.4677547	0.0910098	0.0001*
542-2	543	0.2705356	0.0869631	0.0146*
543	1011	0.1972191	0.0901103	0.0977

Assess Engine Life Based on Oil Discrimination

- FEI1 oil discrimination over the log of engine life
  - One approach to determine VIF engine life would be to track the p-value of the oil*ln(ENHREND) term using various subsets of the valid matrix data. The significance of this term represents the point at which the same engine hour correction should no longer be used for all oils.

Data used	Number of test results	Overall p-value of oil*Ln(ENHREND) term	Range of p-values by oil of oil*Ln(ENHREND) term
ENHREND < 1000	12	.9628	.8196 to .8530
ENHREND < 1100	14	.9371	.7486 to .8728
ENHREND < 1300	17	.5340	.3024 to .9545
ENHREND < 1450	19	.0778	.0365 to .7910
ENHREND < 1596	21	.0723	.0334 to .7962
ENHREND < 1800	25	.1676	.0765 to .4689
All Valid Tests	28	.1830	.1016 to .7038

Assess Engine Life Based on Oil Discrimination

- Here is the same table with the low 543 result, testkey #117626

Data used	Number of test results	Overall p-value of oil*Ln(ENHREND) term	Range of p-values by oil of oil*Ln(ENHREND) term
ENHREND < 1000	12	.9628	.8196 to .8530
ENHREND < 1100	14	.9371	.7486 to .8728
ENHREND < 1300	17	.5340	.3024 to .9545
ENHREND < 1450	18	.1920	.0800 to .6891
ENHREND < 1596	20	.1594	.0631 to .6284
ENHREND < 1800	24	.1255	.0576 to .6624
All Valid Tests	27	.1719	.0755 to .9925

Assess Engine Life Based on Oil Discrimination

- Here is the same table without the low 1011 result, testkey #112956

Data used	Number of test results	Overall p-value of oil*Ln(ENHREND) term	Range of p-values by oil of oil*Ln(ENHREND) term
ENHREND < 1000	11	Not Estimable	
ENHREND < 1100	13	.9458	.7586 to .9259
ENHREND < 1300	16	.8343	.5726 to .8918
ENHREND < 1450	18	.3300	.1514 to .7883
ENHREND < 1596	20	.3213	.1447 to .7544
ENHREND < 1800	24	.5003	.2503 to .8714
All Valid Tests	27	.4976	.2446 to .8765

Assess Engine Life Based on Oil Discrimination

- Here is the same table without the high 543 result, testkey #118267

Data used	Number of test results	Overall p-value of oil*Ln(ENHREND) term	Range of p-values by oil of oil*Ln(ENHREND) term
ENHREND < 1000	11	.3850	.2518 to .2578
ENHREND < 1100	13	.6771	.4251 to .7399
ENHREND < 1300	16	.3513	.1656 to .4036
ENHREND < 1450	18	.0532	.0193 to .4020
ENHREND < 1596	20	.0919	.0342 to .5037
ENHREND < 1800	24	.0789	.0289 to .9589
All Valid Tests	27	.0763	.0262 to .6117

Assess Engine Life Based on Oil Discrimination

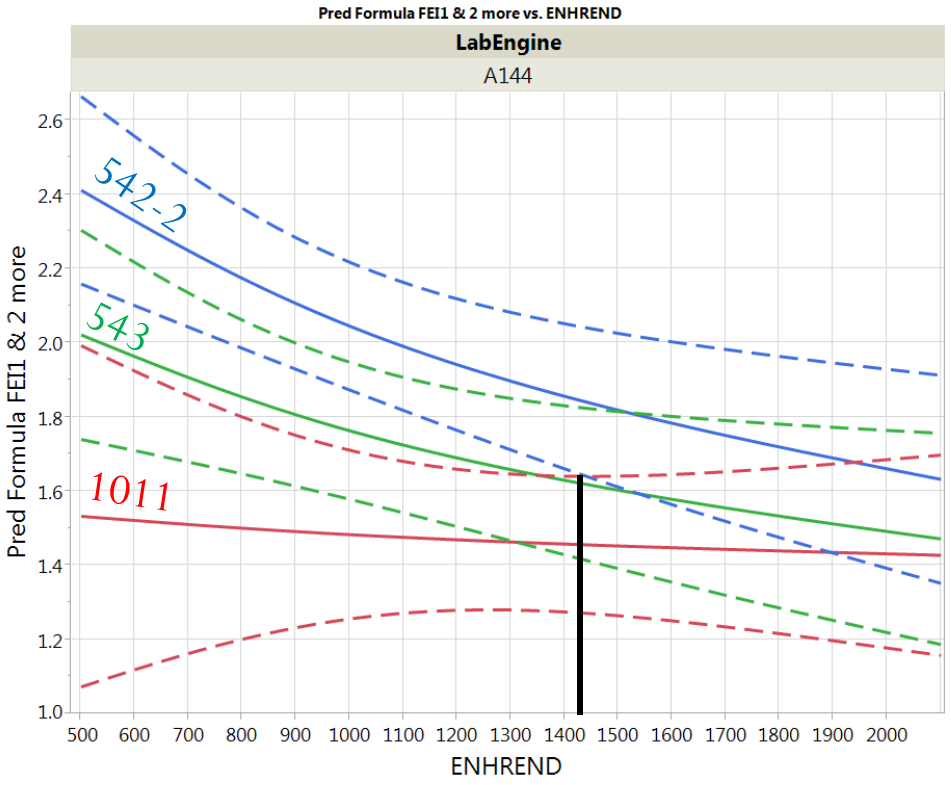
- FEI1 oil discrimination over the engine life
  - FEI1 ~ Oil, LabEngine, Ln(ENHREND), Oil*Ln(ENHREND)
  - Reminder: Oil*Ln(ENHREND) AND LabEngine terms not significant to overall model, but p-value = .02 for LabEngine[G58].

Lab-Engine	Predicted Hours at which 542-2 no longer discriminates from any other oil
A 144	1425
A 122	1400
G 58	1475
G 96	1350
B 306	1125*

* - sample size = 3 tests

Example: Using A 144

Notice how the 95% confidence interval for 542-2 begins to overlap the 95% confidence interval for 1011 at around ENHREND = 1425.



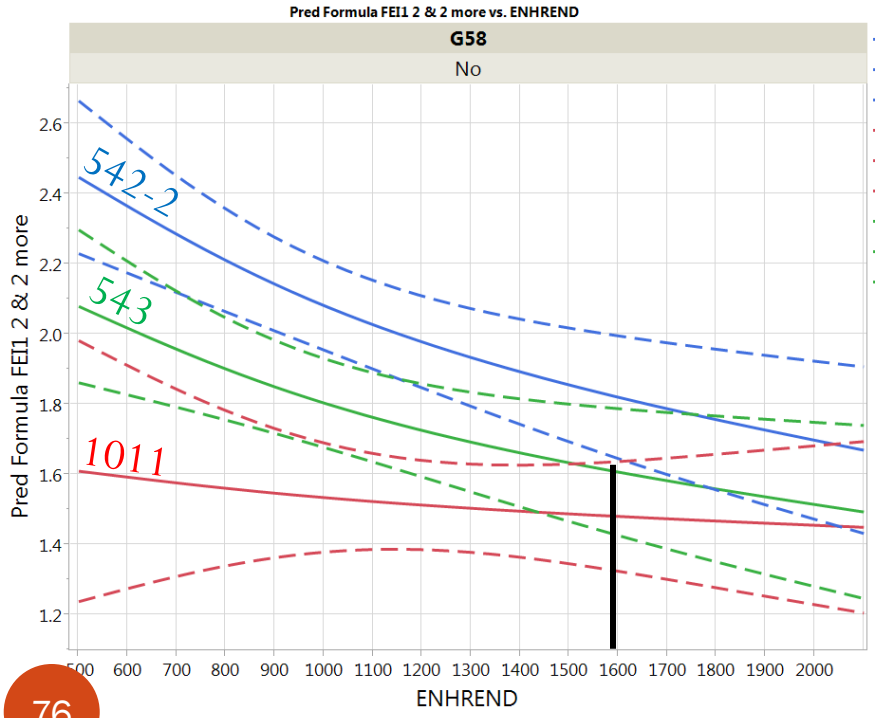
Assess Engine Life Based on Oil Discrimination

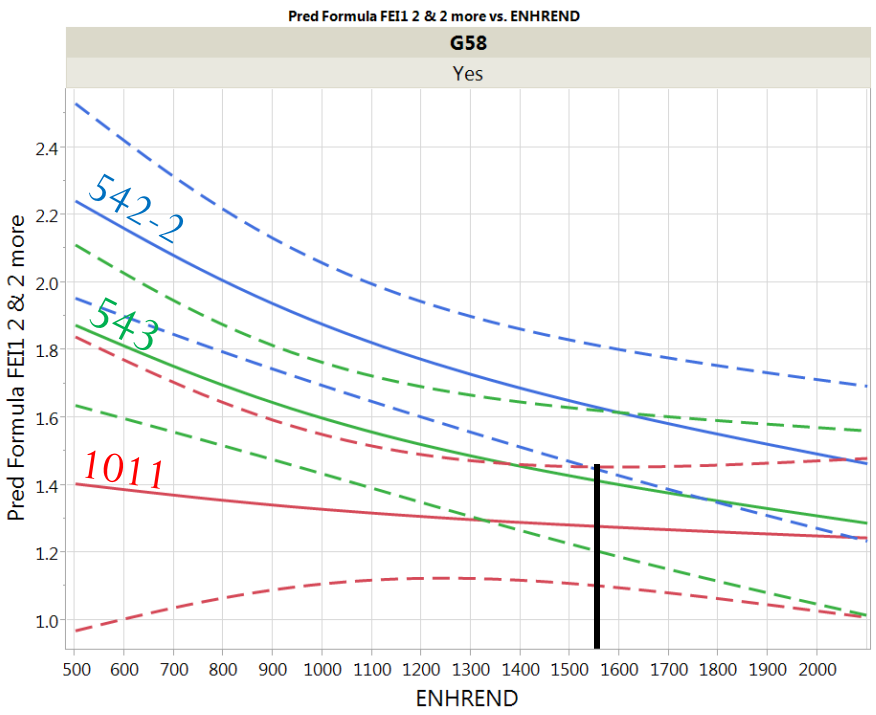
- FEI1 oil discrimination over the engine life
  - FEI1 ~ Oil, G58 (Categorical Y/N variable), Ln(ENHREND), and Oil*Ln(ENHREND)

G58	Predicted Hours at which 542-2 no longer discriminates from any other oil
Yes	1550
No	1600

Example:

This example shows how the number of model degrees of freedom used directly affects the oil mean confidence intervals.





VIF Engine Life

Based on # of standard deviations of oil separation

Diminishing Oil Discrimination in VIF

FEI1	EngHr	542-2	1011	543	542-2-1011	# of Sd	543-1011	# of Sd
	350	2.41	1.57	2.03	0.84	4.21	0.46	2.32
	550	2.32	1.55	1.96	0.76	3.82	0.41	2.05
	750	2.22	1.54	1.89	0.69	3.43	0.36	1.78
	950	2.13	1.52	1.82	0.61	3.04	0.30	1.51
	1150	2.04	1.51	1.75	0.53	2.65	0.25	1.24
	1350	1.94	1.49	1.68	0.45	2.26	0.19	0.97
	1550	1.85	1.47	1.61	0.37	1.87	0.14	0.70
	1750	1.75	1.46	1.54	0.30	1.48	0.09	0.43
	1950	1.66	1.44	1.47	0.22	1.09	0.03	0.16
	2150	1.57	1.43	1.40	0.14	0.70	-0.02	-0.11
	2350	1.47	1.41	1.33	0.06	0.31	-0.08	-0.38
FEI2	EngHr	542-2	1011	543	543-542-2	# of Sd	543-1011	# of Sd
	350	1.52	1.49	2.37	0.86	4.76	0.88	4.90
	550	1.49	1.47	2.30	0.81	4.49	0.82	4.58
	750	1.46	1.46	2.22	0.76	4.22	0.77	4.26
	950	1.43	1.44	2.15	0.71	3.96	0.71	3.94
	1150	1.41	1.42	2.07	0.66	3.69	0.65	3.62
	1350	1.38	1.40	1.99	0.62	3.42	0.59	3.29
	1550	1.35	1.38	1.92	0.57	3.16	0.53	2.97
	1750	1.32	1.37	1.84	0.52	2.89	0.48	2.65
	1950	1.29	1.35	1.77	0.47	2.62	0.42	2.33
	2150	1.27	1.33	1.69	0.42	2.36	0.36	2.00
	2350	1.24	1.31	1.61	0.38	2.09	0.30	1.68

n=28	FEI1	FEI2
RMSE	0.20	0.18
LSMeans		
542-2	2.02	1.40
1011	1.54	1.44
543	1.75	2.08
Effect Size		
%	0.48	0.68
SD	2.40	3.78

Model: Oil, Lab, Engine(Lab), Enghr

Test discriminates FEI1 approximately 3 standard deviations up to around the 5th test.

Diminishing Oil Discrimination in VIF

FEI1	EngHr	542-2	1011	543	542-2-1011	# of Sd	543-1011	# of Sd
	350	2.64	1.58	2.19	1.06	5.57	0.61	3.20
	550	2.39	1.55	2.02	0.84	4.44	0.47	2.45
	750	2.22	1.53	1.90	0.70	3.66	0.37	1.94
	950	2.09	1.51	1.80	0.58	3.07	0.29	1.55
	1150	1.99	1.50	1.73	0.49	2.59	0.23	1.23
	1350	1.90	1.48	1.67	0.42	2.19	0.18	0.97
	1550	1.82	1.47	1.61	0.35	1.84	0.14	0.74
	1750	1.76	1.47	1.57	0.29	1.54	0.10	0.54
	1950	1.70	1.46	1.53	0.24	1.27	0.07	0.36
	2150	1.64	1.45	1.49	0.19	1.02	0.04	0.20
	2350	1.60	1.44	1.45	0.15	0.80	0.01	0.05
FEI2	EngHr	542-2	1011	543	543-542-2	# of Sd	543-1011	# of Sd
	350	1.58	1.47	2.49	0.91	5.04	1.02	5.65
	550	1.51	1.45	2.32	0.81	4.50	0.87	4.84
	750	1.46	1.43	2.21	0.74	4.13	0.77	4.29
	950	1.43	1.42	2.12	0.69	3.85	0.70	3.87
	1150	1.40	1.41	2.05	0.65	3.63	0.64	3.53
	1350	1.37	1.41	1.99	0.62	3.44	0.58	3.24
	1550	1.35	1.40	1.94	0.59	3.27	0.54	3.00
	1750	1.33	1.39	1.89	0.56	3.13	0.50	2.78
	1950	1.32	1.39	1.85	0.54	3.00	0.47	2.59
	2150	1.30	1.38	1.82	0.52	2.88	0.43	2.41
	2350	1.29	1.38	1.79	0.50	2.78	0.41	2.26

n=32	FEI1	FEI2
RMSE	0.19	0.18
LSMeans		
542-2	2.02	1.40
1011	1.55	1.44
543	1.75	2.08
Effect Size		
%	0.47	0.68
SD	2.47	3.78

Model: Oil, Lab, Engine(Lab), LnEnghr

Test discriminates FEI1 approximately 3 standard deviations up to around the 5th test.

VIF Engine Life

Differences in Estimated Slopes Over Engine Life

Comparing Slopes by Oil Over Various Subsets

- Table 1 shows the estimated linear engine life effect by oil using the model coefficients over various subsets of data. Data is scaled times 1000 to represent the estimated decrease in FEI1 over 1000 hours

- Table 2 shows the absolute difference in the oil slopes, using the data from Table 1.

The differences are minimized using the full 28 test data set.

Table 1: Estimated Change in FEI1 per 1000 hours

	542-2	1011	543
ENHREND < 1000	-1.88	-4.74	-1.18
ENHREND < 1100	-0.68	-0.41	-1.39
ENHREND < 1300	-0.40	0.20	-0.90
ENHREND < 1450	-0.40	0.39	-0.99
ENHREND < 1596	-0.49	0.13	-0.91
ENHREND < 1800	-0.52	0.09	-0.35
All Valid Tests	-0.47	-0.08	-0.25

Table 2: Estimated Abs(Differences) in slopes

	542-2 &1011	542-2 & 543	1011 & 543
ENHREND < 1000	2.86	0.71	3.57
ENHREND < 1100	0.27	0.71	0.98
ENHREND < 1300	0.60	0.50	1.10
ENHREND < 1450	0.79	0.59	1.38
ENHREND < 1596	0.62	0.43	1.05
ENHREND < 1800	0.61	0.17	0.44
All Valid Tests	0.38	0.22	0.17

Conclusions for FEI1

- There is a lot of uncertainty for engine run #2 for 543 (high variability) and 1011 (no data).
- There are two points with high contribution to the significance of the Oil*Ln(ENHREND) term in the 1300 to 1450 hour range.

Engine Life Options:

1. One option would be to limit engine life to 4 or 5 tests to be consistent with the VIE, but this does not guarantee that the engine life affect is the same for all oils in this range. Additional 543 and 1011 engine run #2 data would still be needed to make that conclusion.
2. Another option would be to use the mean confidence interval approach. Using the full model (Oil, Lab, Eng[Lab], ENHREND, and Oil*ENHREND), this would be 5 tests. Using only significant terms in the model, this would be 6 tests.
3. Finally, one could take the "Innocent until proven guilty approach" that says the engine life affect should be the same unless we are certain that its not. Given that we are not certain it is different, one could argue for a full 8 test engine life.

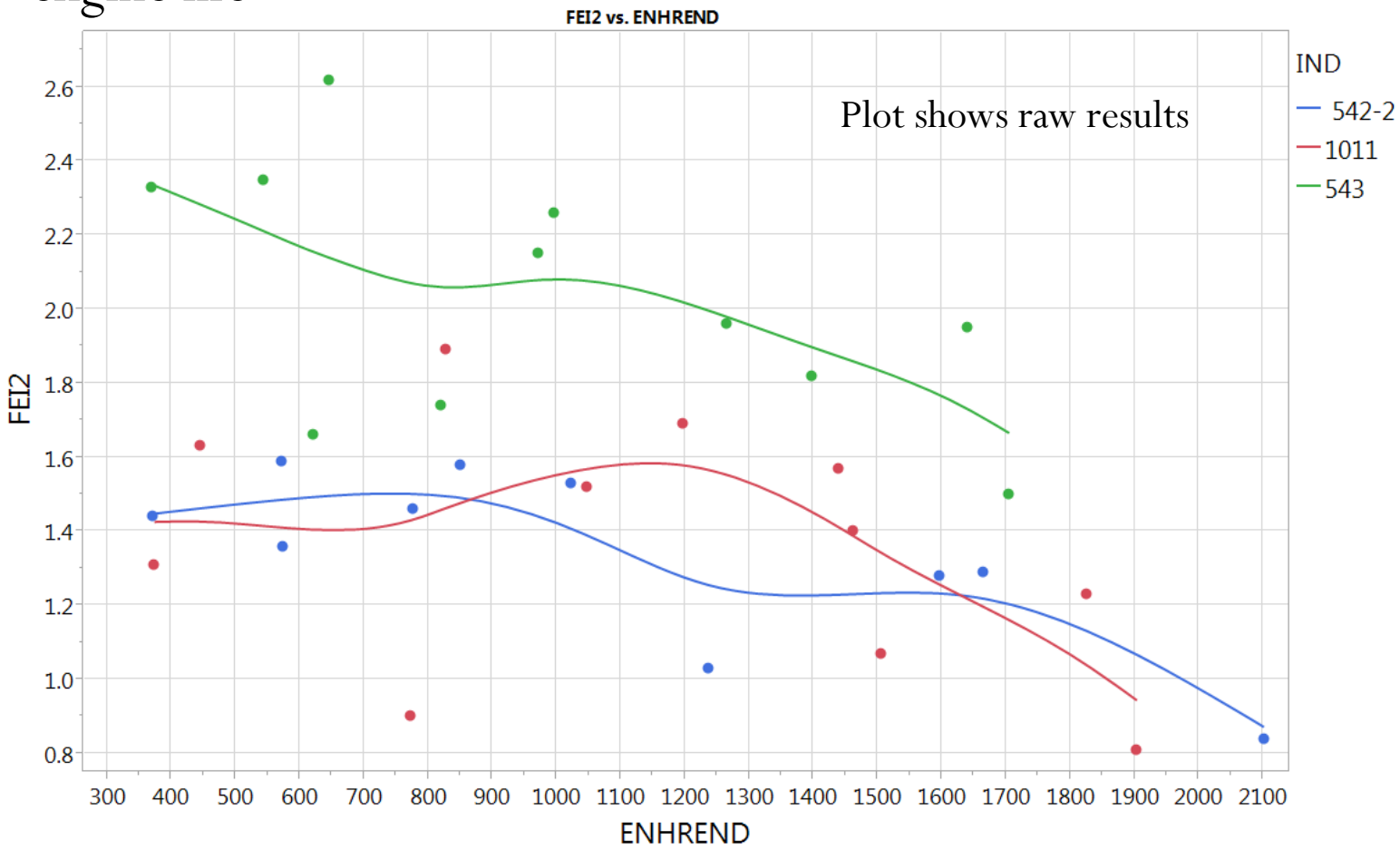
VIF Engine Life (n=28)

Based on FEI2 Oil Discrimination

Using Linear Engine Hours Correction

Assess Engine Life Based on Oil Discrimination

- FEI2 oil discrimination over the engine life
  - 543 discrimination from 542-2 and 1011 is consistent throughout the engine life



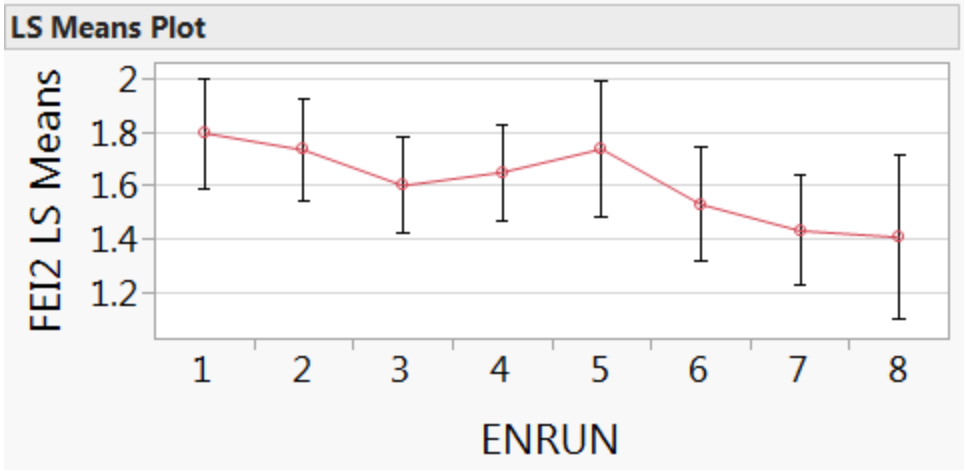
Assess Engine Life Based on Oil Discrimination

- Analysis of a statistical model with Oil, LabEngine, ENRUN terms show no unexpected deviations for any individual engine run.

Expanded Estimates

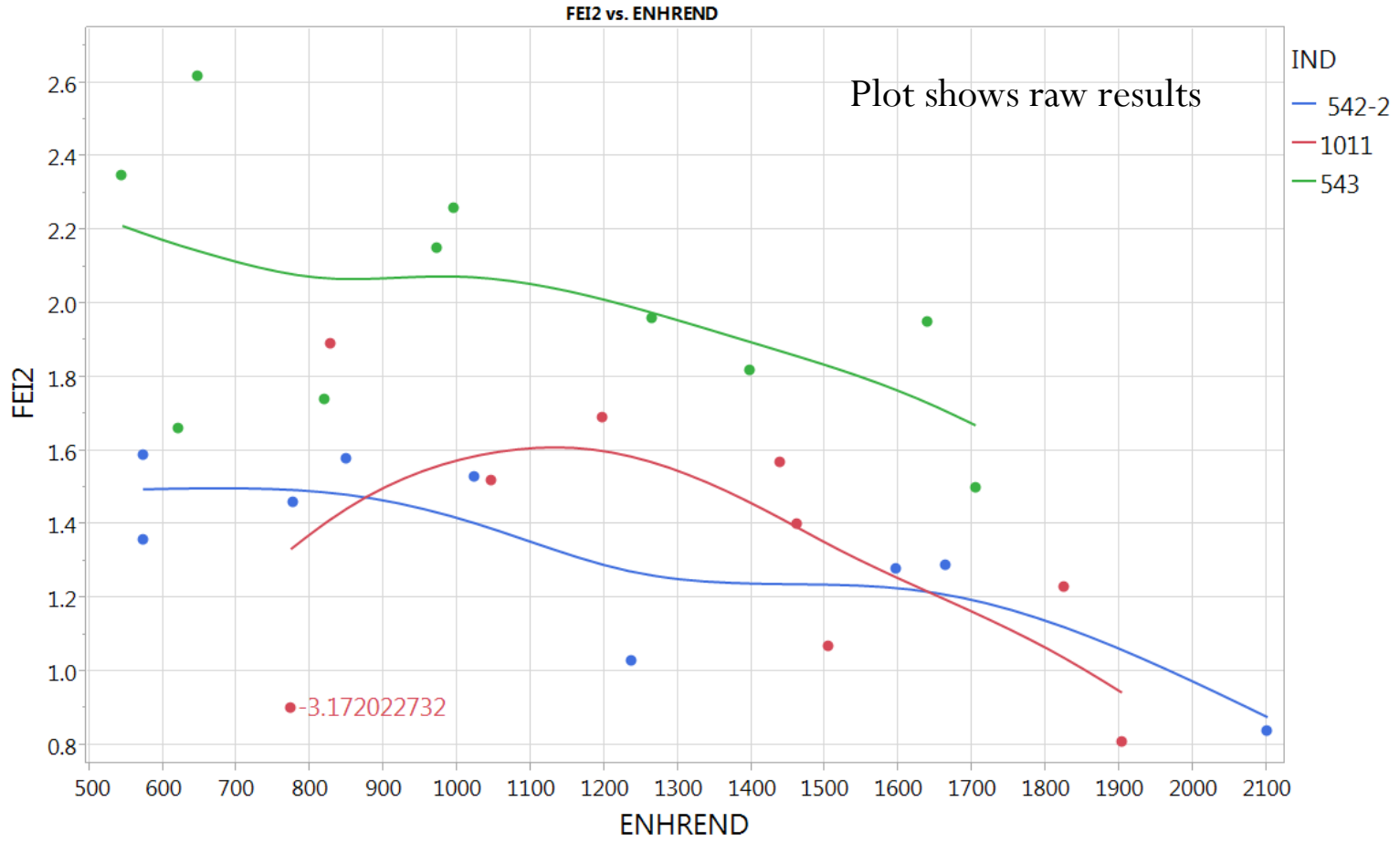
Nominal factors expanded to all levels

Term	Estimate	Prob>|t|
Intercept	1.6101654	<.0001*
IND[542-2]	-0.188065	0.0025*
IND[1011]	-0.24249	0.0003*
IND[543]	0.430555	<.0001*
LabEngine[A122]	-0.123208	0.0807
LabEngine[A144]	0.0670234	0.3210
LabEngine[B306]	0.2034689	0.0317*
LabEngine[G58]	-0.379227	<.0001*
LabEngine[G96]	0.2319421	0.0082*
ENRUN[1]	0.1859426	0.0572
ENRUN[2]	0.1227277	0.1887
ENRUN[3]	-0.010054	0.9049
ENRUN[4]	0.0393366	0.6472
ENRUN[5]	0.1264465	0.2574
ENRUN[6]	-0.080831	0.3987
ENRUN[7]	-0.179782	0.0661
ENRUN[8]	-0.203786	0.1306



Assess Engine Life Based on Oil Discrimination

- FEI2 oil discrimination over the engine life
  - Large studentized residual for testkey #112954 (Model with Linear engine hour correction, no interaction term)



Assess Engine Life Based on Oil Discrimination

- Overall ANOVA Summary of FEI2 data:
  - Analysis indicates that the engine hours effect in FEI2 is consistent across the oils tested

Summary of Fit

RSquare	0.893596
RSquare Adj	0.840394
Root Mean Square Error	0.180469
Mean of Response	1.573214
Observations (or Sum Wgts)	28

Analysis of Variance

Parameter Estimates

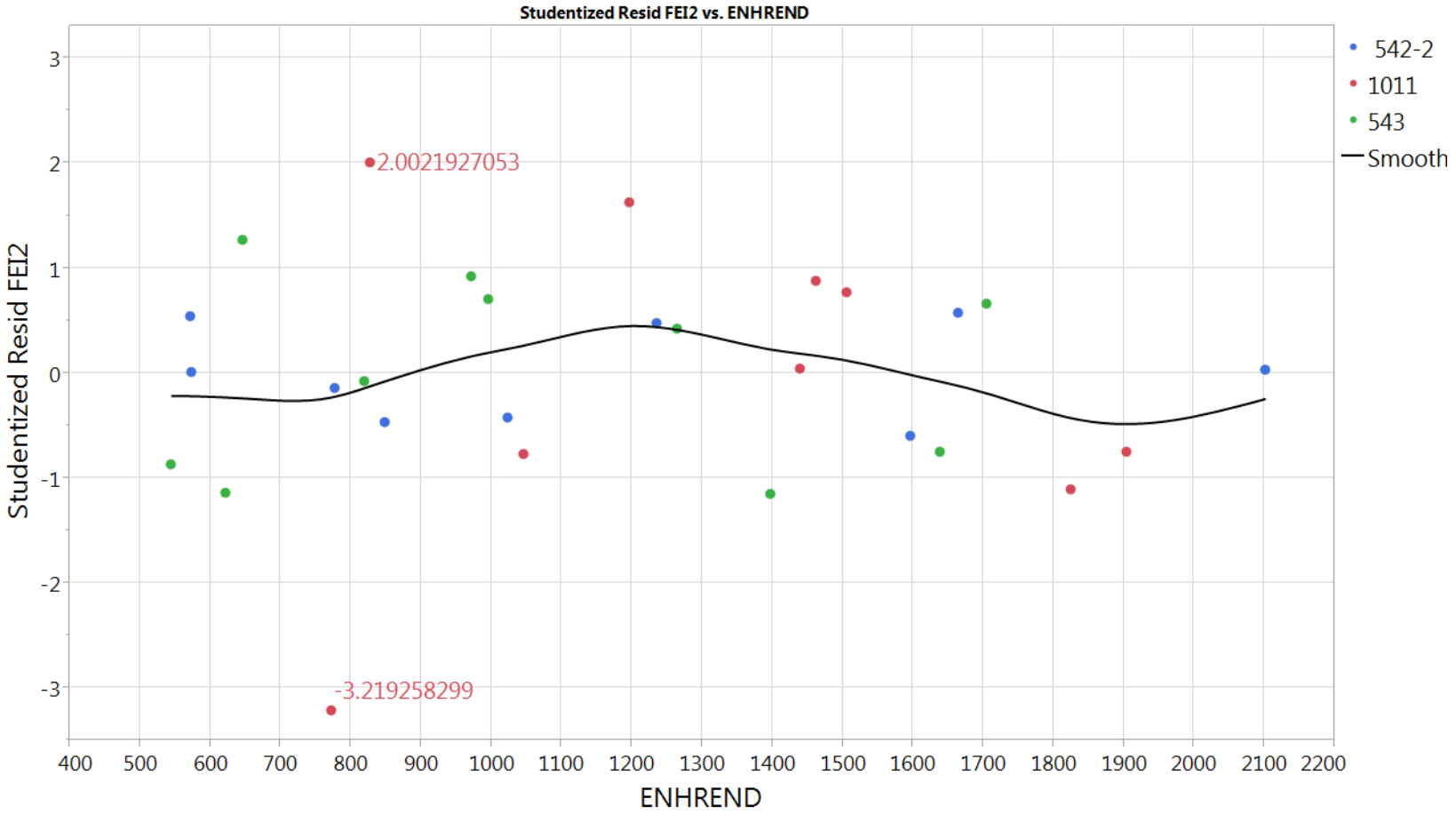
Term	Estimate	Prob>|t|	VIF
Intercept	1.8662722	<.0001*	.
IND[542-2]	-0.22198	0.0004*	1.4917753
IND[1011]	-0.208176	0.0010*	1.6333332
LTMSLAB[A]	-0.054386	0.3146	2.1183154
LTMSLAB[B]	0.1921775	0.0221*	2.1870603
LTMSLAB[A]:ENGNO[122]	-0.075591	0.1598	1.0577362
LTMSLAB[G]:ENGNO[58]	-0.304506	<.0001*	1.172464
ENHREND	-0.000202	0.0366*	1.3671563
(ENHREND-1177.5)*IND[542-2]	6.4956e-5	0.5605	1.4734904
(ENHREND-1177.5)*IND[1011]	0.0001144	0.3807	1.5015411

Effect Tests

Source	Nparm	DF	Prob > F
IND	2	2	<.0001*
LTMSLAB	2	2	0.0467*
ENGNO[LTMSLAB]	2	2	0.0001*
ENHREND	1	1	0.0366*
ENHREND*IND	2	2	0.3515

Assess Engine Life Based on Oil Discrimination

- Overall ANOVA Summary of FEI2 data:
  - Analysis indicates that the engine hours effect in FEI2 is consistent across the oils tested



Assess Engine Life Based on Oil Discrimination

- FEI2 oil discrimination over the engine life
  - One approach to determine VIF engine life would be to track the p-value of the oil*ENHREND term using various subsets of the valid matrix data. The significance of this term represents the point at which the same engine hour correction should no longer be used for all oils.

Data used	Number of test results	Overall p-value of oil*ENHREND term	Range of p-values by oil of oil*ENHREND term
ENHREND < 1000	12	.0568	.0424 to .0959
ENHREND < 1100	14	.1813	.1283 to .7264
ENHREND < 1300	17	.6453	.4156 to .9413
ENHREND < 1450	19	.5949	.4040 to .9060
ENHREND < 1596	21	.2988	.1789 to .9367
ENHREND < 1800	25	.1260	.0548 to .7965
All Valid Tests	28	.3515	.1538 to .5605

Assess Engine Life Based on Oil Discrimination

- FEI2 oil discrimination over the engine life
  - Here is the same table without testkey #112954

Data used	Number of test results	Overall p-value of oil*ENHREND term	Range of p-values by oil of oil*ENHREND term
ENHREND < 1000	11	Not Estimable	
ENHREND < 1100	13	.1435	.0971 to .5106
ENHREND < 1300	16	.4209	.2064 to .6406
ENHREND < 1450	18	.2100	.1012 to .5952
ENHREND < 1596	20	.2725	.1397 to .8027
ENHREND < 1800	24	.3288	.2489 to .8529
All Valid Tests	27	.0972	.0337 to .4400

Assess Engine Life Based on Oil Discrimination

- FEI2 oil discrimination over the engine life
  - Here is the same table without testkey #112956

Data used	Number of test results	Overall p-value of oil*ENHREND term	Range of p-values by oil of oil*ENHREND term
ENHREND < 1000	11	Not Estimable	
ENHREND < 1100	13	.3078	.2303 to .9015
ENHREND < 1300	16	.0175	.0071 to .4962
ENHREND < 1450	18	.0038	.0022 to .4440
ENHREND < 1596	20	.0036	.0023 to .5337
ENHREND < 1800	24	.0021	.0011 to .1105
All Valid Tests	27	.1166	.0490 to .9702

Assess Engine Life Based on Oil Discrimination

- FEI2 oil discrimination over the engine life
  - FEI2 ~ Oil, Lab, Eng[Lab], ENHREND, and Oil*ENHREND

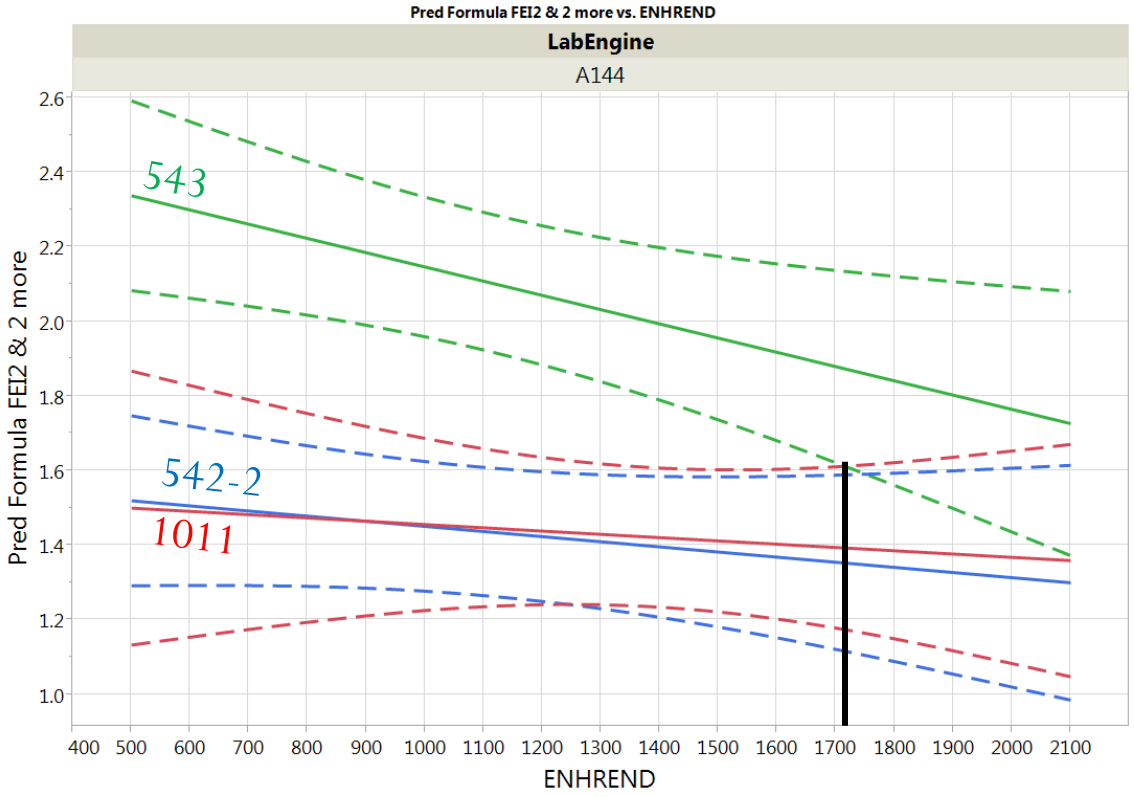
Lab-Engine	Predicted Hours at which 542-2 no longer discriminates from any other oil
A 144	1700
A 122	1675
G 58	1700
G 96	1650
B 306	1475*

* - sample size = 3 tests

Refer to Appendix A for plots of other stands

Example: Using A 144

Notice how the 95% confidence interval for 542-2 begins to overlap the 95% confidence interval for 1011 at around ENHREND = 1700.



VIF Engine Life

Based on # of standard deviations of oil separation

Diminishing Oil Discrimination in VIF

FEI1	EngHr	542-2	1011	543	542-2-1011	# of Sd	543-1011	# of Sd
	350	2.41	1.57	2.03	0.84	4.21	0.46	2.32
	550	2.32	1.55	1.96	0.76	3.82	0.41	2.05
	750	2.22	1.54	1.89	0.69	3.43	0.36	1.78
	950	2.13	1.52	1.82	0.61	3.04	0.30	1.51
	1150	2.04	1.51	1.75	0.53	2.65	0.25	1.24
	1350	1.94	1.49	1.68	0.45	2.26	0.19	0.97
	1550	1.85	1.47	1.61	0.37	1.87	0.14	0.70
	1750	1.75	1.46	1.54	0.30	1.48	0.09	0.43
	1950	1.66	1.44	1.47	0.22	1.09	0.03	0.16
	2150	1.57	1.43	1.40	0.14	0.70	-0.02	-0.11
	2350	1.47	1.41	1.33	0.06	0.31	-0.08	-0.38
FEI2	EngHr	542-2	1011	543	543-542-2	# of Sd	543-1011	# of Sd
	350	1.52	1.49	2.37	0.86	4.76	0.88	4.90
	550	1.49	1.47	2.30	0.81	4.49	0.82	4.58
	750	1.46	1.46	2.22	0.76	4.22	0.77	4.26
	950	1.43	1.44	2.15	0.71	3.96	0.71	3.94
	1150	1.41	1.42	2.07	0.66	3.69	0.65	3.62
	1350	1.38	1.40	1.99	0.62	3.42	0.59	3.29
	1550	1.35	1.38	1.92	0.57	3.16	0.53	2.97
	1750	1.32	1.37	1.84	0.52	2.89	0.48	2.65
	1950	1.29	1.35	1.77	0.47	2.62	0.42	2.33
	2150	1.27	1.33	1.69	0.42	2.36	0.36	2.00
	2350	1.24	1.31	1.61	0.38	2.09	0.30	1.68

n=28	FEI1	FEI2
RMSE	0.20	0.18
LSMeans		
542-2	2.02	1.40
1011	1.54	1.44
543	1.75	2.08
Effect Size		
%	0.48	0.68
SD	2.40	3.78

Model: Oil, Lab, Engine(Lab), Enghr

Test discriminates FEI1 approximately 3 standard deviations up to around the 5th test.

Diminishing Oil Discrimination in VIF

FEI1	EngHr	542-2	1011	543	542-2-1011	# of Sd	543-1011	# of Sd
	350	2.64	1.58	2.19	1.06	5.57	0.61	3.20
	550	2.39	1.55	2.02	0.84	4.44	0.47	2.45
	750	2.22	1.53	1.90	0.70	3.66	0.37	1.94
	950	2.09	1.51	1.80	0.58	3.07	0.29	1.55
	1150	1.99	1.50	1.73	0.49	2.59	0.23	1.23
	1350	1.90	1.48	1.67	0.42	2.19	0.18	0.97
	1550	1.82	1.47	1.61	0.35	1.84	0.14	0.74
	1750	1.76	1.47	1.57	0.29	1.54	0.10	0.54
	1950	1.70	1.46	1.53	0.24	1.27	0.07	0.36
	2150	1.64	1.45	1.49	0.19	1.02	0.04	0.20
	2350	1.60	1.44	1.45	0.15	0.80	0.01	0.05
FEI2	EngHr	542-2	1011	543	543-542-2	# of Sd	543-1011	# of Sd
	350	1.58	1.47	2.49	0.91	5.04	1.02	5.65
	550	1.51	1.45	2.32	0.81	4.50	0.87	4.84
	750	1.46	1.43	2.21	0.74	4.13	0.77	4.29
	950	1.43	1.42	2.12	0.69	3.85	0.70	3.87
	1150	1.40	1.41	2.05	0.65	3.63	0.64	3.53
	1350	1.37	1.41	1.99	0.62	3.44	0.58	3.24
	1550	1.35	1.40	1.94	0.59	3.27	0.54	3.00
	1750	1.33	1.39	1.89	0.56	3.13	0.50	2.78
	1950	1.32	1.39	1.85	0.54	3.00	0.47	2.59
	2150	1.30	1.38	1.82	0.52	2.88	0.43	2.41
	2350	1.29	1.38	1.79	0.50	2.78	0.41	2.26

n=32	FEI1	FEI2
RMSE	0.19	0.18
LSMeans		
542-2	2.02	1.40
1011	1.55	1.44
543	1.75	2.08
Effect Size		
%	0.47	0.68
SD	2.47	3.78

Model: Oil, Lab, Engine(Lab), LnEnghr

Test discriminates FEI1 approximately 3 standard deviations up to around the 5th test.

Conclusions for FEI2

- There is a lot of uncertainty surrounding 1011 2nd run (no data) and 3rd run (0.70% residual difference for the two data points) on an engine.

- No evidence to limit engine life until around 1700 hours.

Benchmarking: Oil Discrimination in Various GF-5 PCMO 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

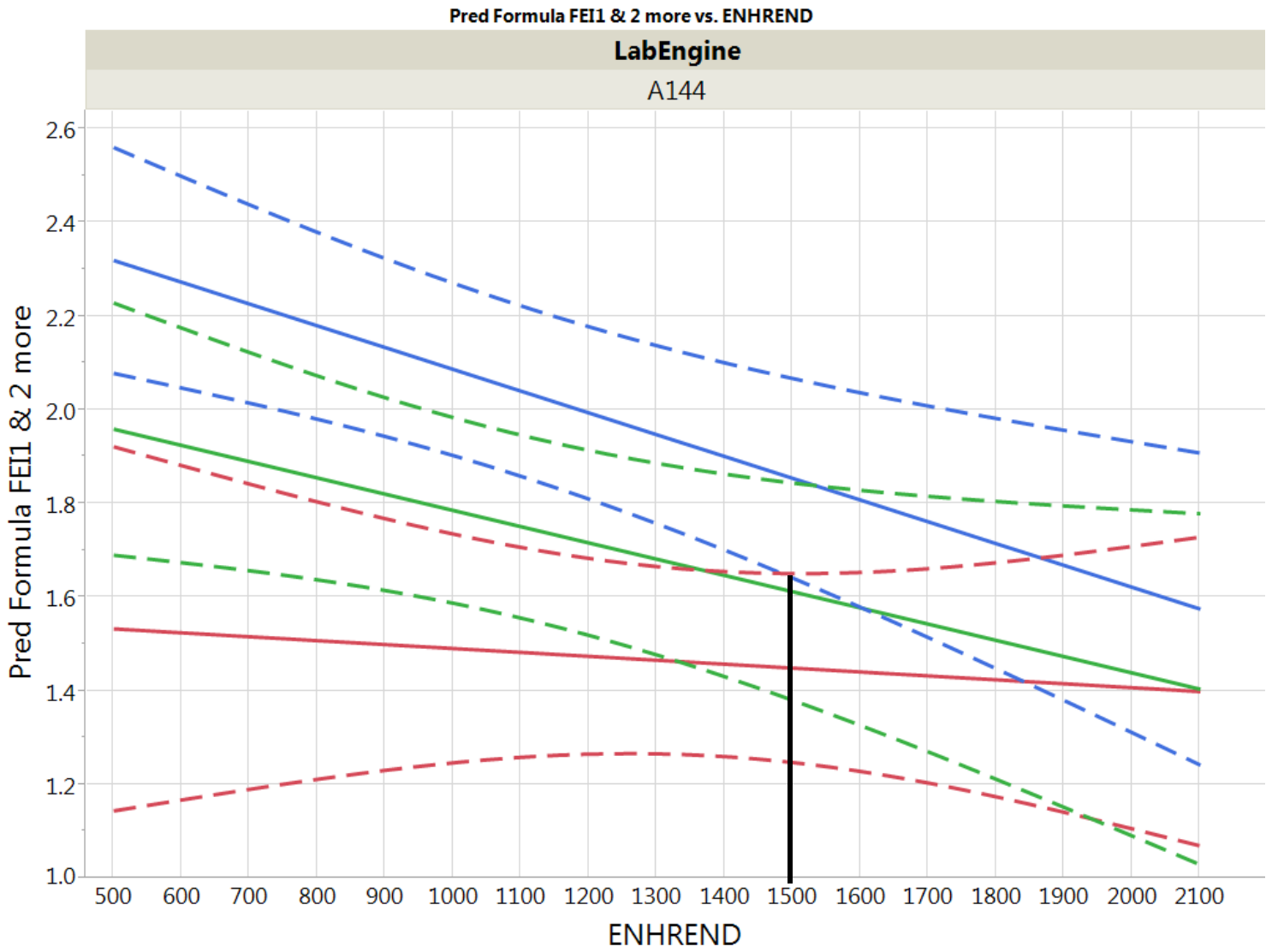
FUEL ECONOMY IMPROVEMENT at 100 Hours
Unit of Measure: Percent

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

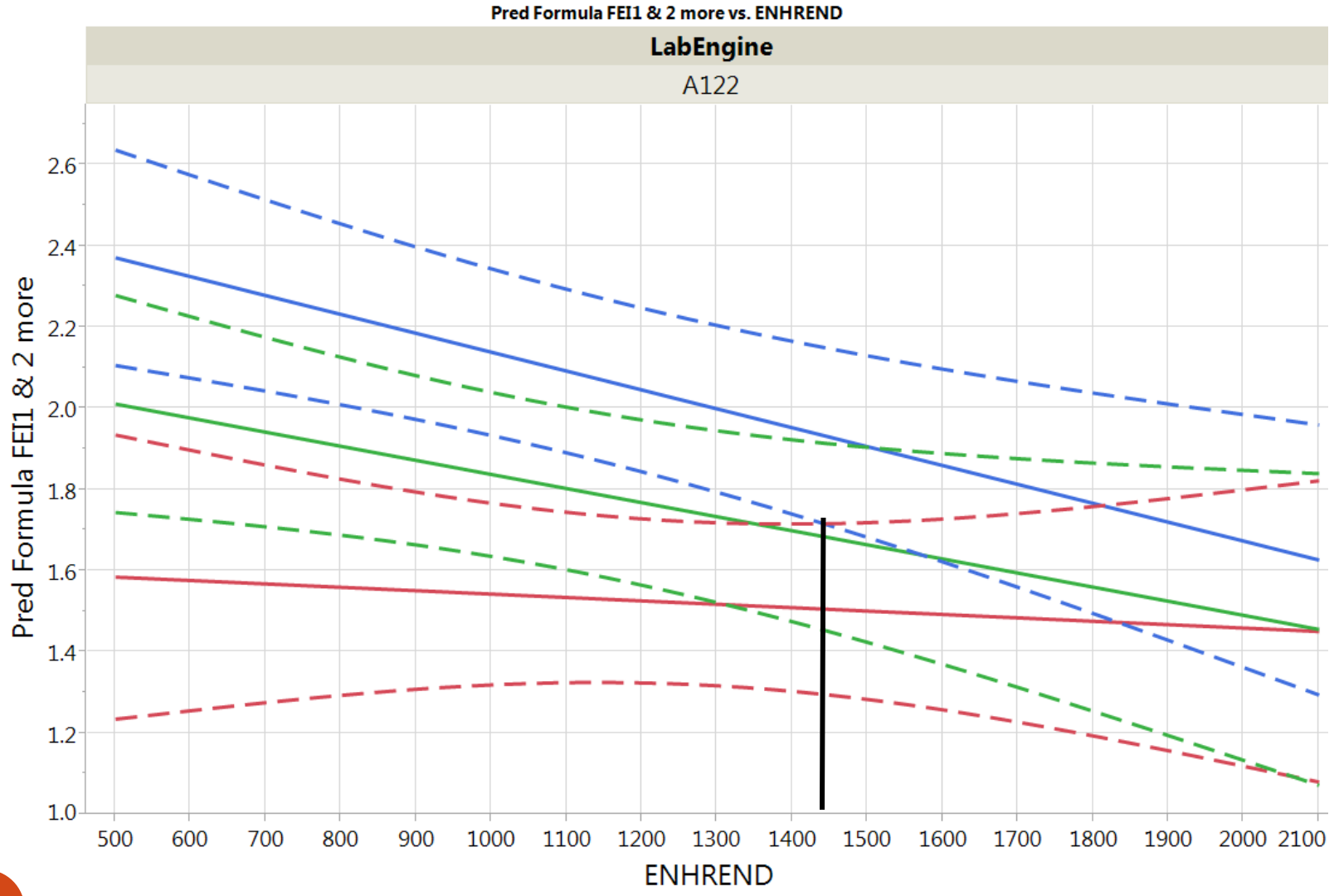
Appendix A

Additional Engine Plots Using Linear Engine Hour Correction w/ Interaction Term Included

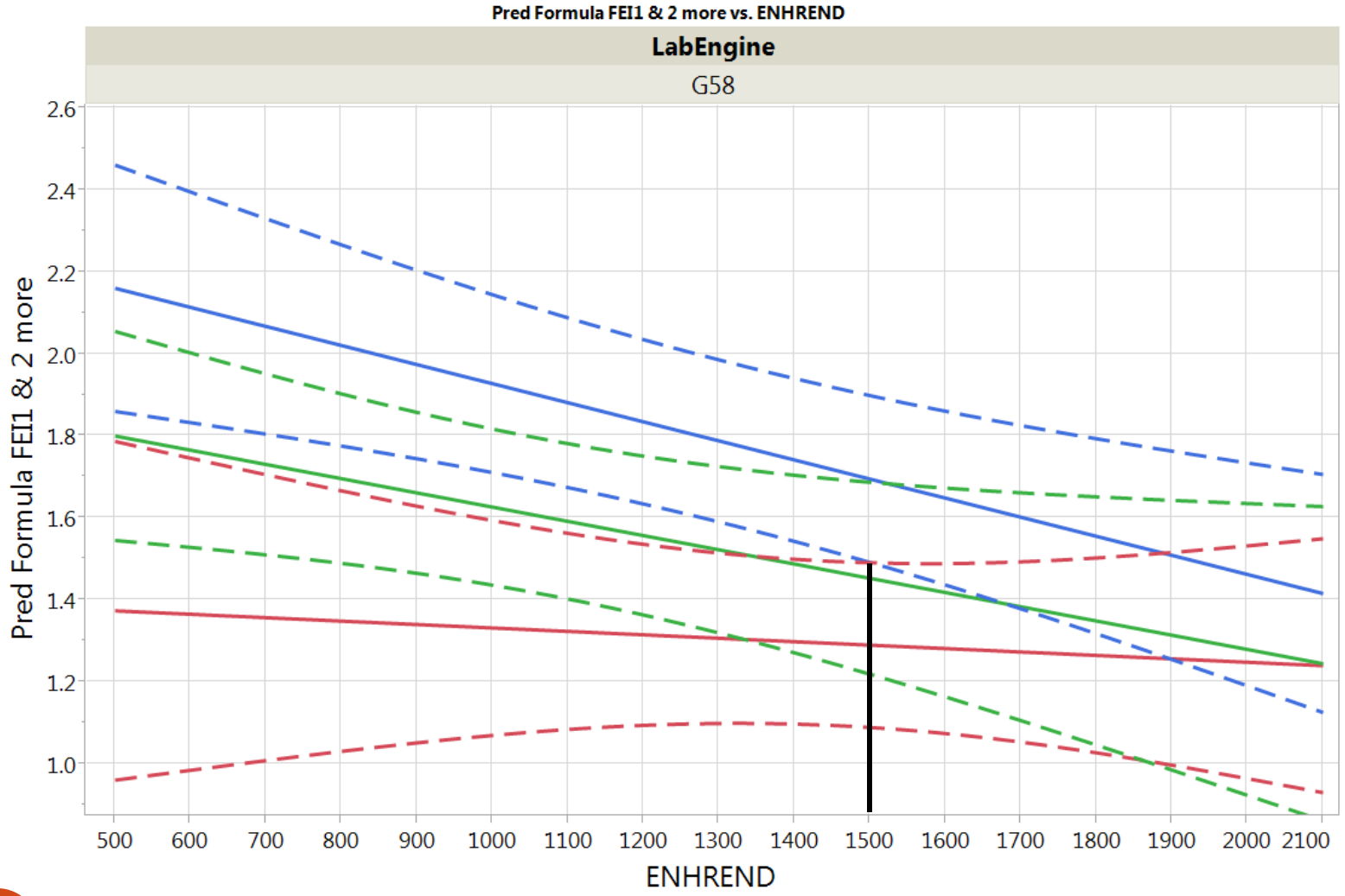
VIF Lab A Eng. 144 FEI1



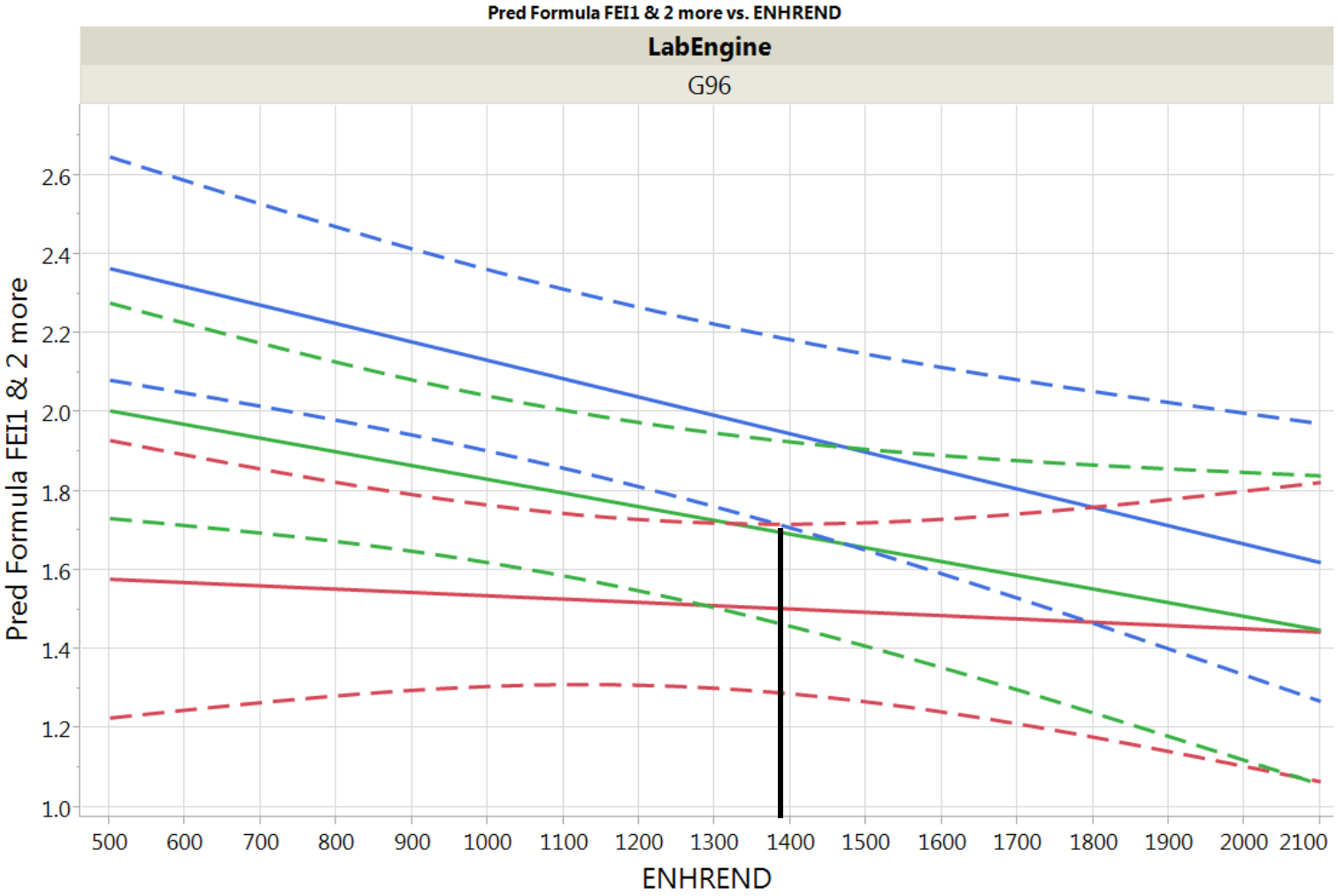
VIF Lab A Eng. 122 FEI1



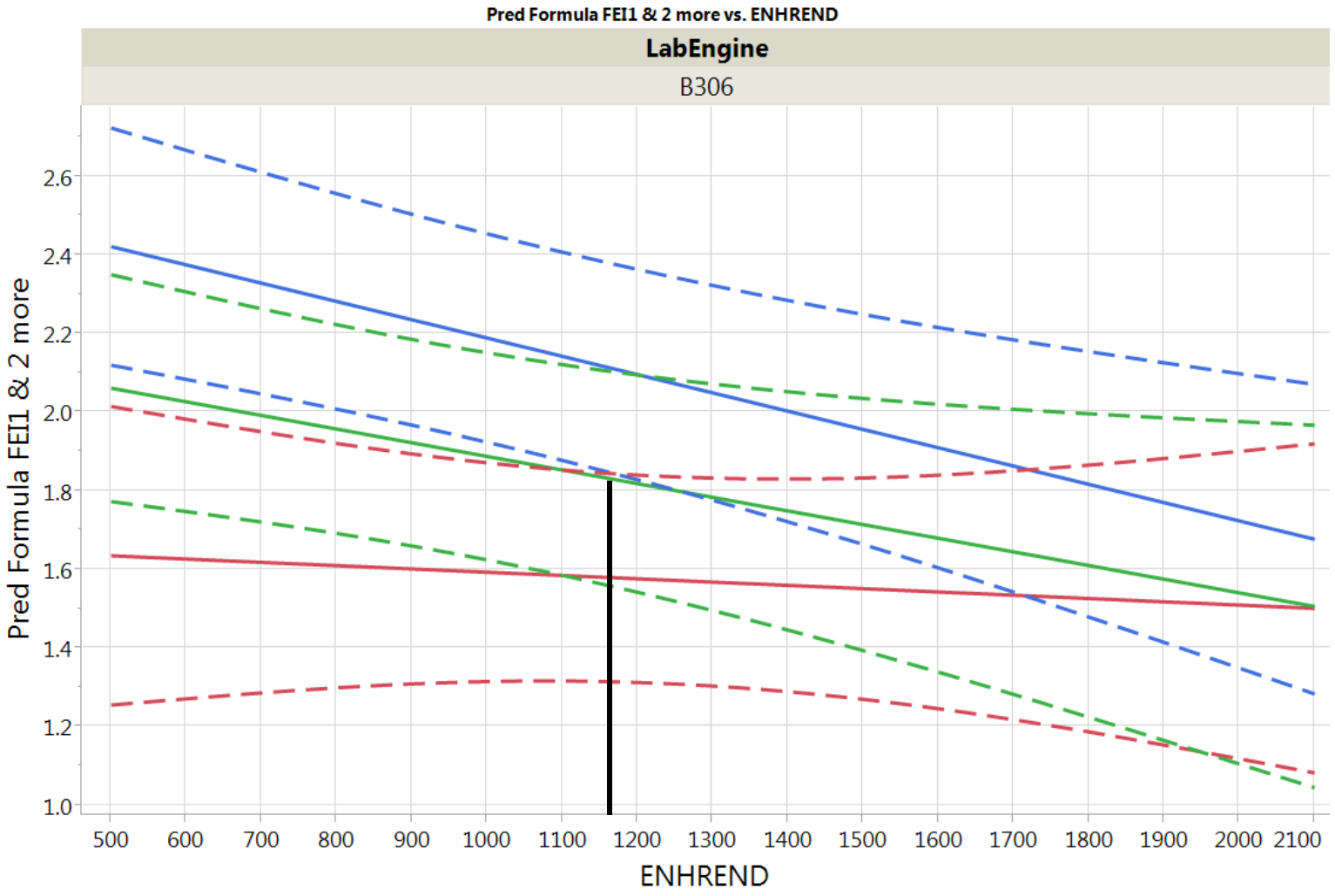
VIF Lab G Eng. 58 FEI1



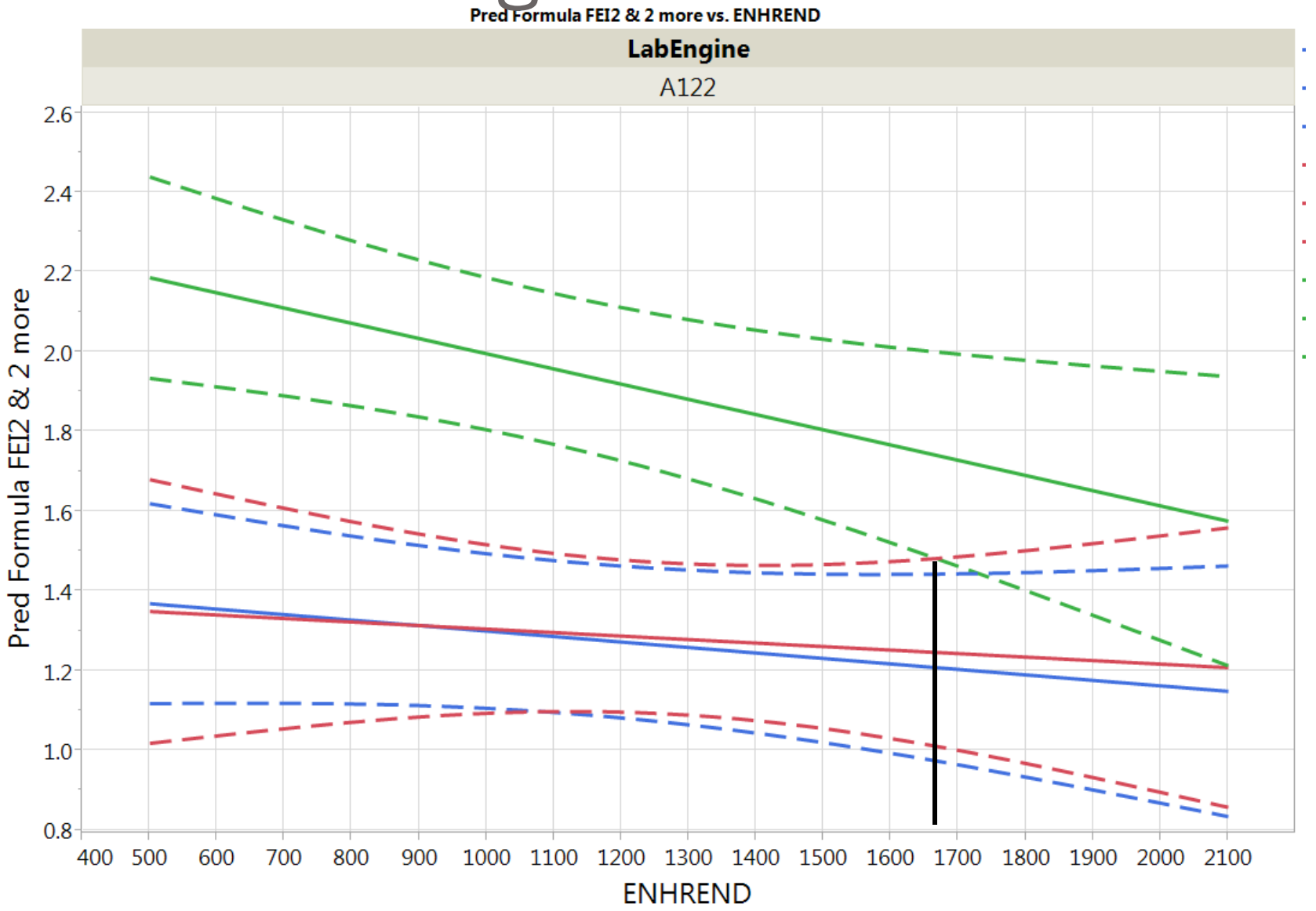
VIF Lab G Eng. 96 FEI1



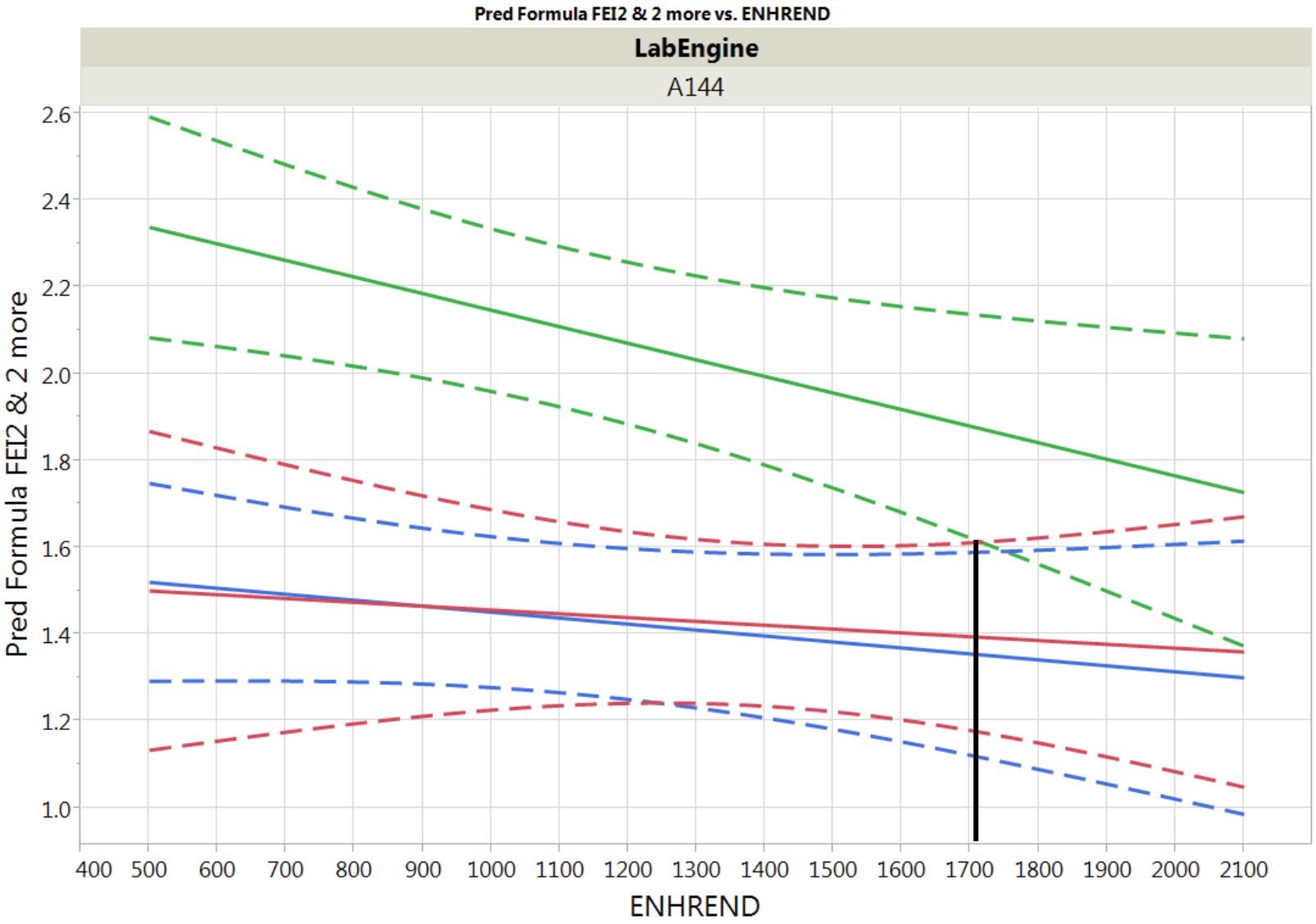
VIF Lab B Eng. 306 FEI1



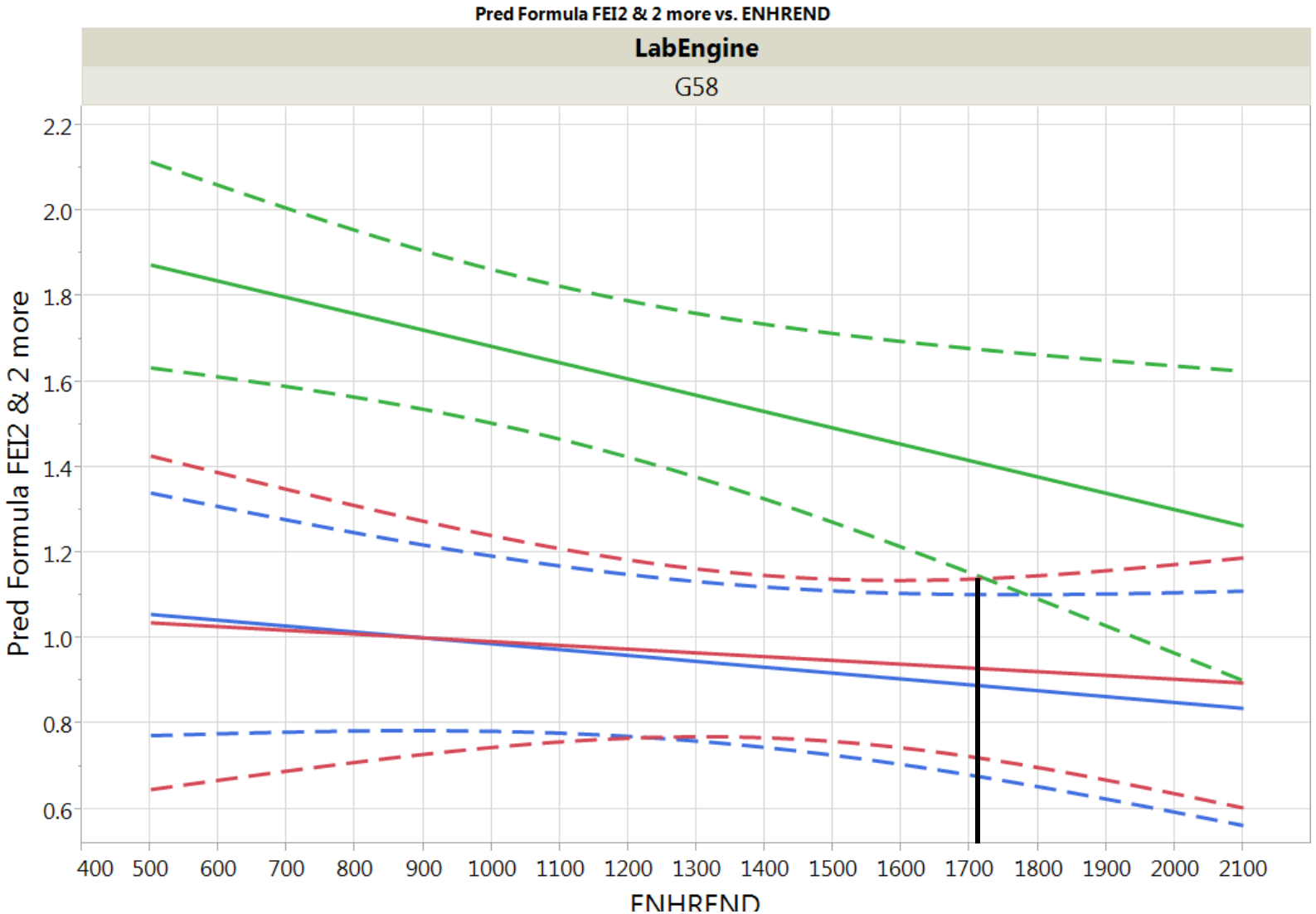
VIF Lab A Eng. 122 FEI2



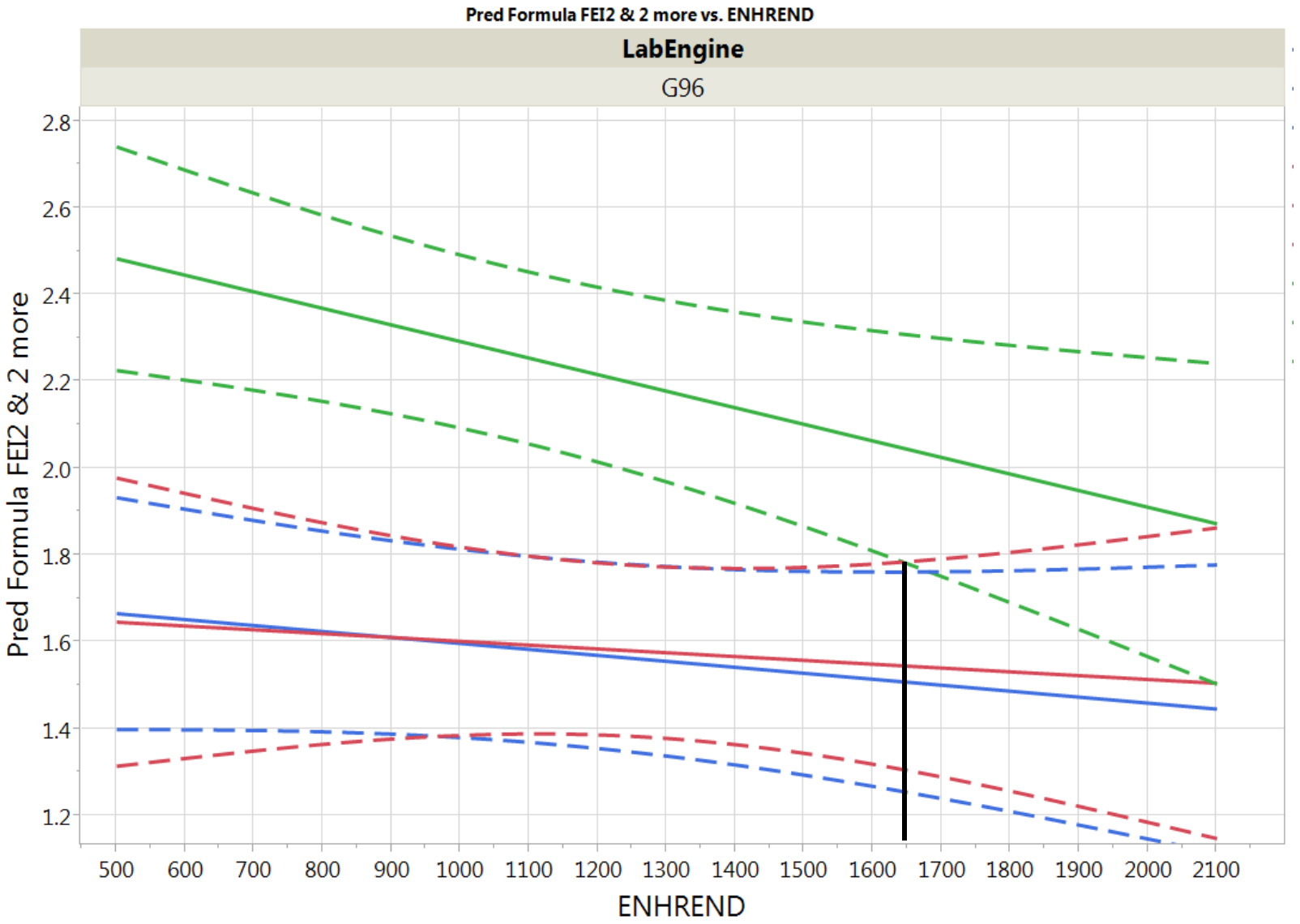
VIF Lab A Eng. 144 FEI2



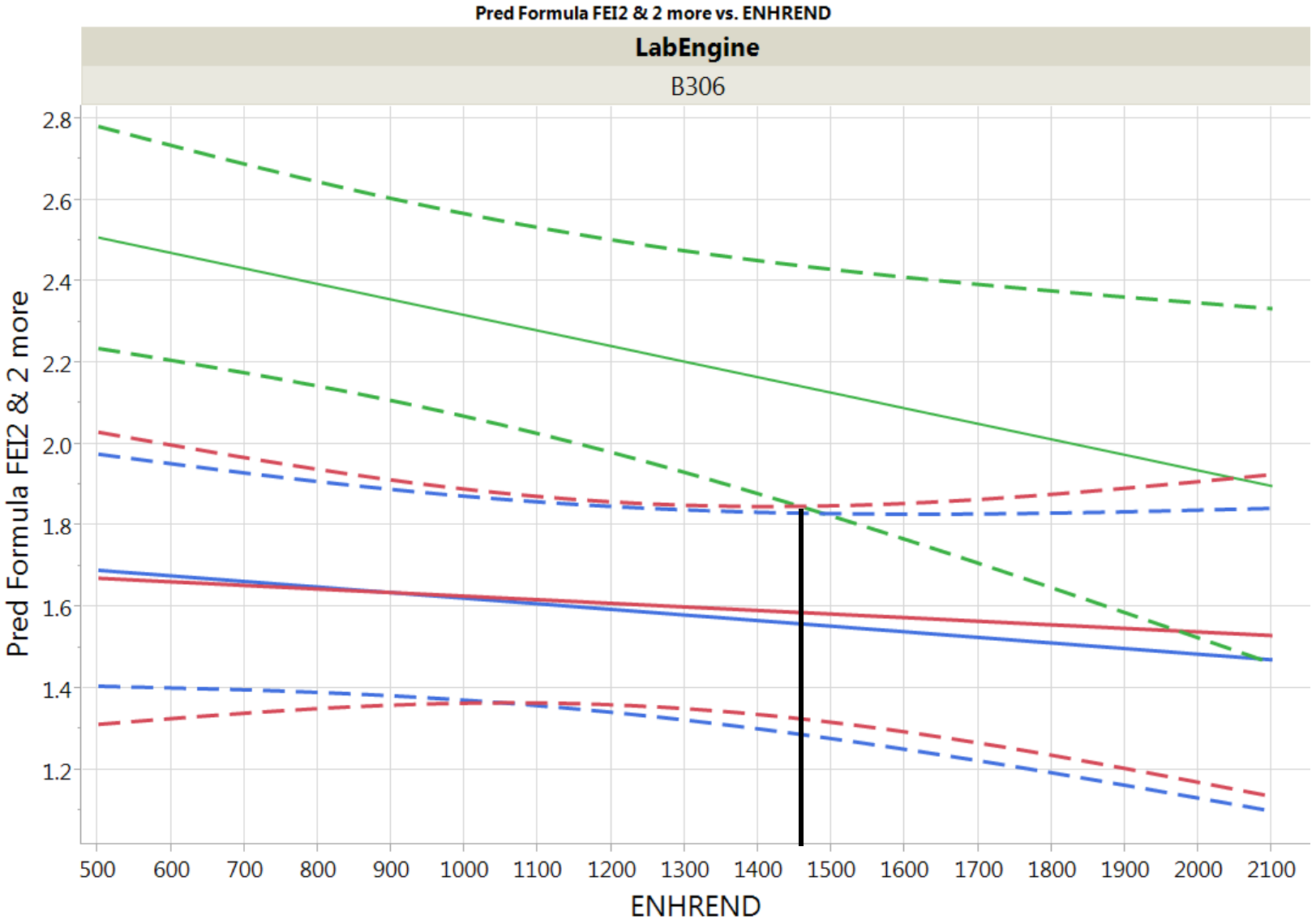
VIF Lab G Eng. 58 FEI2



VIF Lab G Eng. 96 FEI2



VIF Lab B Eng. 306 FEI2



VIF LTMS

Industry Statistician Team

Date: 02-07-2017

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 run engine life.

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.

Targets	FEI1 Target	FEI2 Target
542-2	2.23	1.52
1011	1.45	1.41
543	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

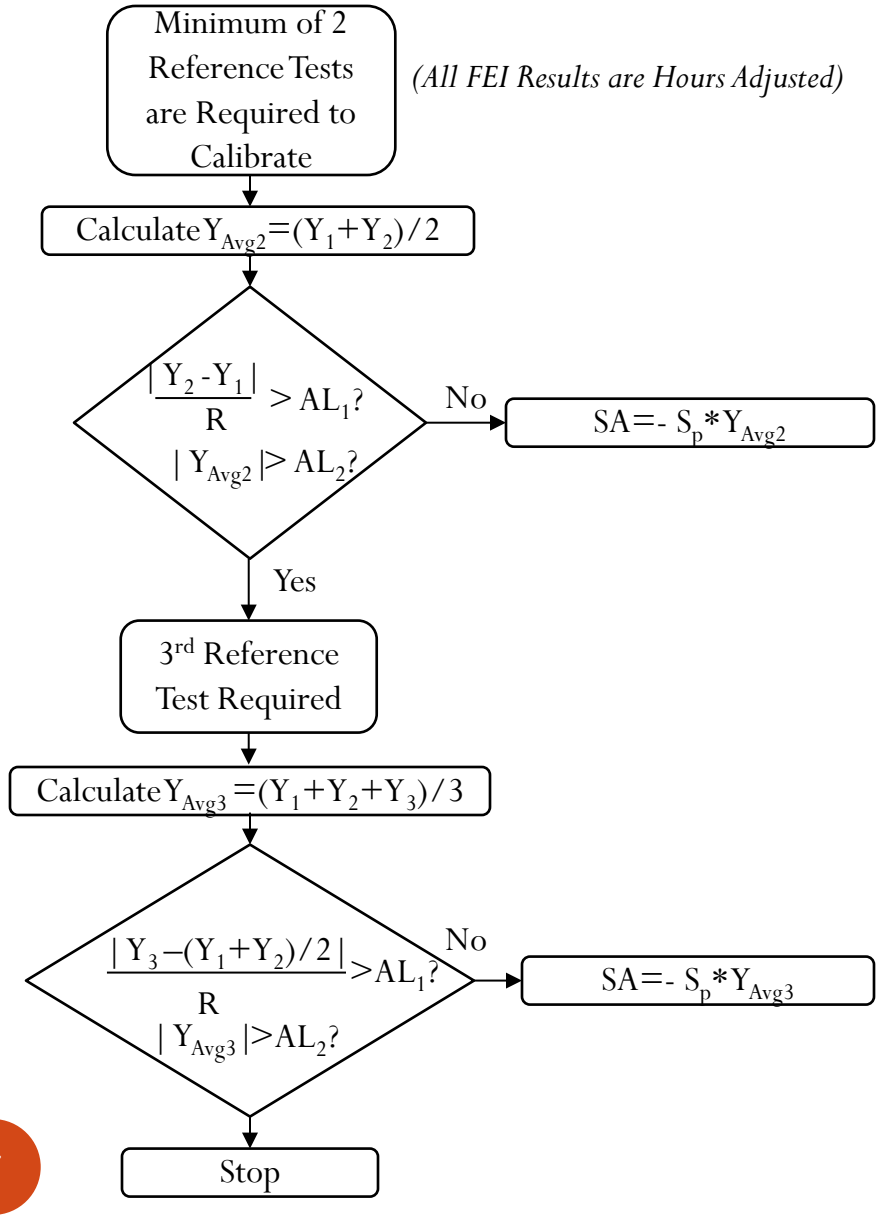
How are Yi's Calculated?

- 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

Targets	FEI1 Raw Stdev	FEI2 Raw Stdev
542-2	0.18	0.13
1011	0.14	0.39
543	0.27	0.34

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

VIF LTMS Flow Chart



Where:

$AL_1 = 2.8$

$AL_2 = 2.0$

S_p = Pooled 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