

# VH Statistical Review | MINUTES

Revision Date 7/11/2017 10:07:00 AM

<b>Relevant Test:</b>	Sequence VG and VH
<b>Note Taker:</b>	Chris Mileti
<b>Meeting Date:</b>	06-19-2017
<b>Comments:</b>	Full Sequence V Surveillance Panel conference call to discuss statistical analysis of VH Precision Matrix data.

## 1. REVIEW OF STATISTICAL GROUP PRESENTATION:

### a) Background:

- i) All of the slides discussed during this call were from the **VH PM Analysis – SG.pdf** presentation.
- ii) This presentation was distributed by A. Ritchie via email on 06-18-2017 at 1:38PM EST.
- iii) The presentation was reviewed by D. Boese during the conference call.

### b) Slide #3:

### Executive Summary

- There is correlation of Crankcase Pressure and Lambda with the parameters. It is not clear whether these operational parameters affects severity or whether there are lab/stand differences manifesting themselves.
- The Stands within a Lab are not statistically significantly different, therefore, a Lab-based LTMS is appropriate.
- AES:
  - Oil discrimination is statistically significant: 1011>1009, 940.
- RCS:
  - Oil discrimination is statistically significant: 1011, 1009 > 940.
- AEV and APV:
  - Recommend using 50% rating.
  - Using the 50% rating, oil discrimination is statistically significant: 1011>1009, 940.
  - A Lab × Oil interaction is apparent though could be an artifact of the small sample size.
  - Stand G /2 demonstrated minimal separation among the 3 Oils – again, may be an artifact of small sample size.

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- i) The VH test stands within each lab are not statistically different.  
(1) This means that a lab-based LTMS system is appropriate for the Sequence VH.
- ii) Oil discrimination is statistically significant.
- iii) The statisticians are recommending the use of the 50% piston skirt rating technique for the two varnish parameters (APV and AEV).

### c) Slide #7:

## Crankcase Pressure and Lambda

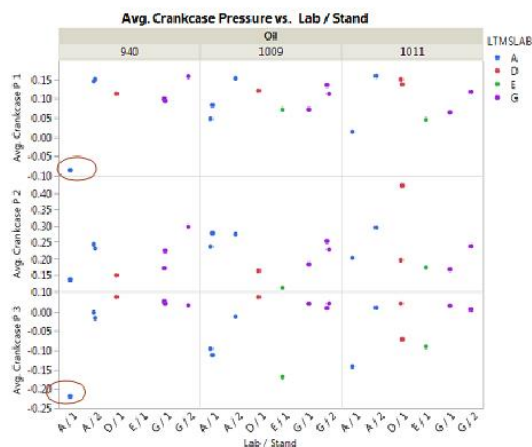
- During Operational Data Review, the TF noted a potential correlation between the VH parameters with Crankcase Pressure and Left and Right Lambda.
- The average of Crankcase Pressure and Left and Right Lambda for each of Phases 1, 2 and 3 were calculated for each test.

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- The engineering group asked the statisticians to review the following operational data parameters: *crankcase pressure, left-side lambda, right-side lambda*.
- The statisticians attempted to correlate these operational parameters to the rated parameters.

### d) Stand #8:

## Average Crankcase Pressure



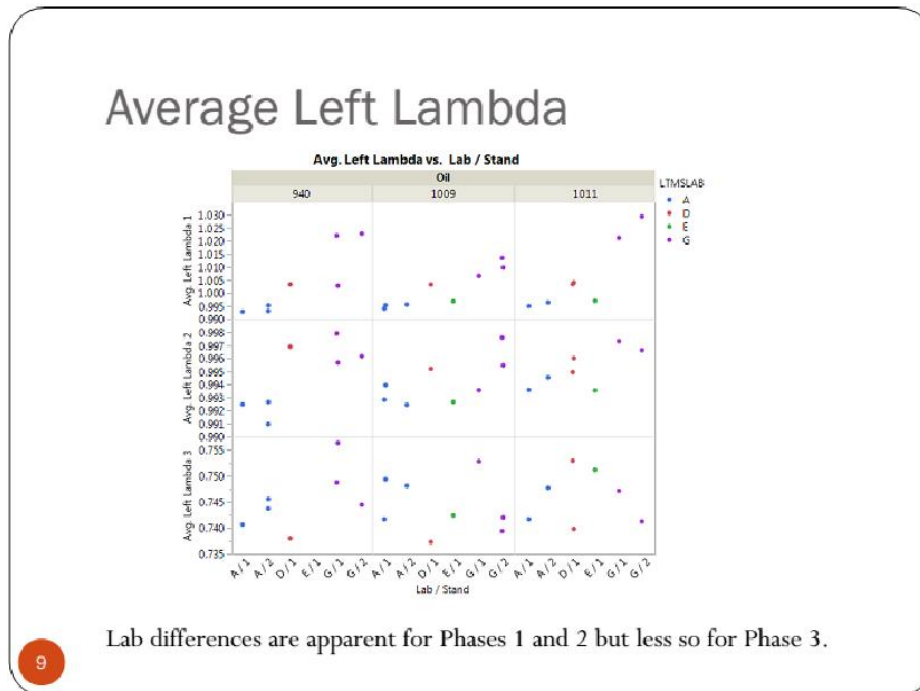
8

Two results for Oil 940 visually differ from the others within that Phase. They are both for the same test (Testkey 118698-VH).

- Two results are circled in the chart.
  - Both results are from Lab A.
  - Both results are from the same test.
  - The results are circled because they stand out in terms of crankcase pressure.
- The two circled results show a steady-state difference (and not a periodic difference) that was present in the Lab A test.

- iii) The difference in Stage/Phase 3 was of a lesser degree than the difference in Stage/Phase 1.

**e) Slide #9:**



- i) There are lab-to-lab differences in the left-side lambda measurements.
- ii) The left-side lambda measurement is generally low at Lab A for all stages/phases and oils.
- iii) The left-side lambda measurement is generally high at Lab G for all stages/phases and oils.
- iv) It was noted that the lambda differences were smaller during Stage/Phase 3 conditions.

**f) Stage #11:**

### Crankcase Pressure and Lambda Effects on Rated Test Parameters

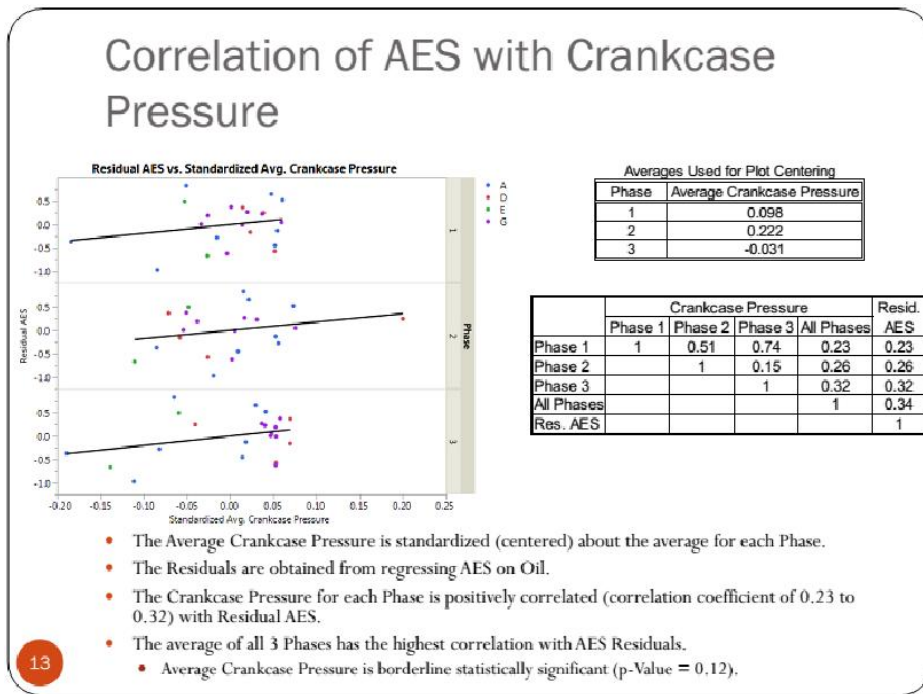
- The plots on the prior 3 slides illustrate lab differences with respect to operational parameters.
- Correlation of these operational parameters with the rated Varnish and Sludge are discussed in subsequent sections. In some cases, significant correlation exists.
- It is not clear whether these operational parameters affects severity or whether there are lab/stand differences manifesting themselves.

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- i) There is a correlation between these operational parameters and the varnish parameters.

ii) However, the statisticians stressed that a correlation does not prove causation.

**g) Slide #13:**



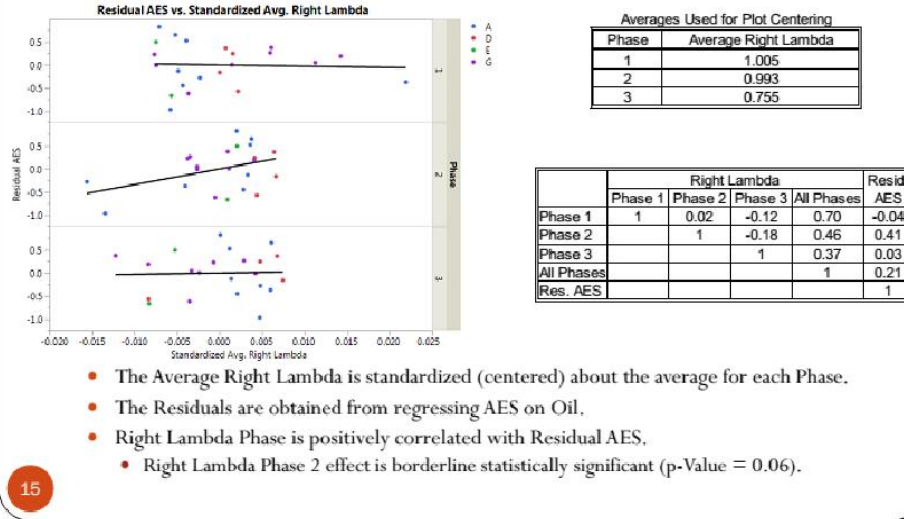
- i) The "oil effect" has been removed from this chart to facilitate the combination of results.
- ii) The P-value of 0.12 indicates that the correlation between AES and crankcase pressure is borderline statistically significant.
- iii) However, it is not currently known whether the crankcase pressure is directly driving the AES result or just correlated to the driving factor.

**iv) Ford's Comments:**

- (1) *Could the PCV valves be playing a role in this correlation?*
- (2) It would be useful to compare the crankcase pressure to other parameters such as PCV clogging and blowby flow rate.
- (3) The engineering team may need to consider flow testing the entire PCV system and not just the PCV valve itself.
- (4) Ford requested a follow-up conference call to discuss this.

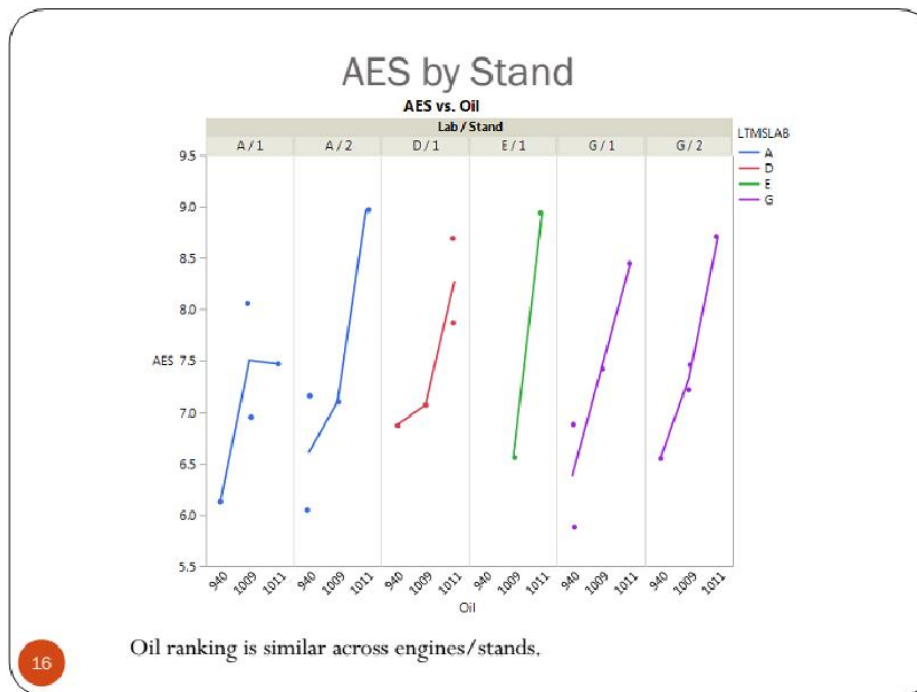
**h) Slide #15:**

## Correlation of AES with Right Lambda



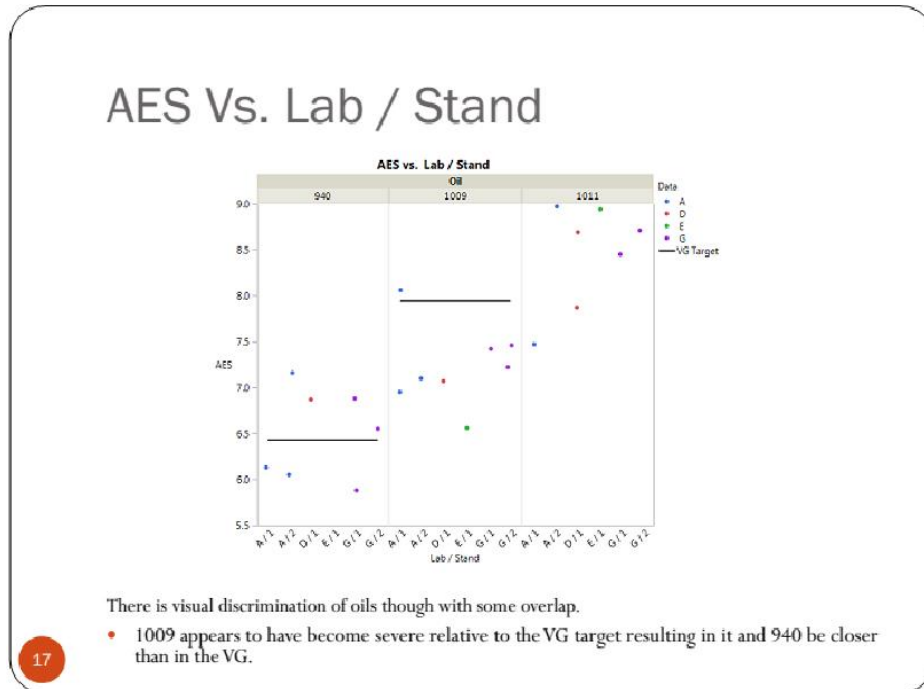
- The Stage/Phase 2 chart is showing a relatively high slope, but this slope is being heavily influenced by the two data points on the far left.
- The P-value of 0.06 indicates that the correlation between AES and the right-side lambda is borderline statistically significant.
  - However, the statisticians reemphasized the impact of the two data points on the far left.

### i) Slide #16:



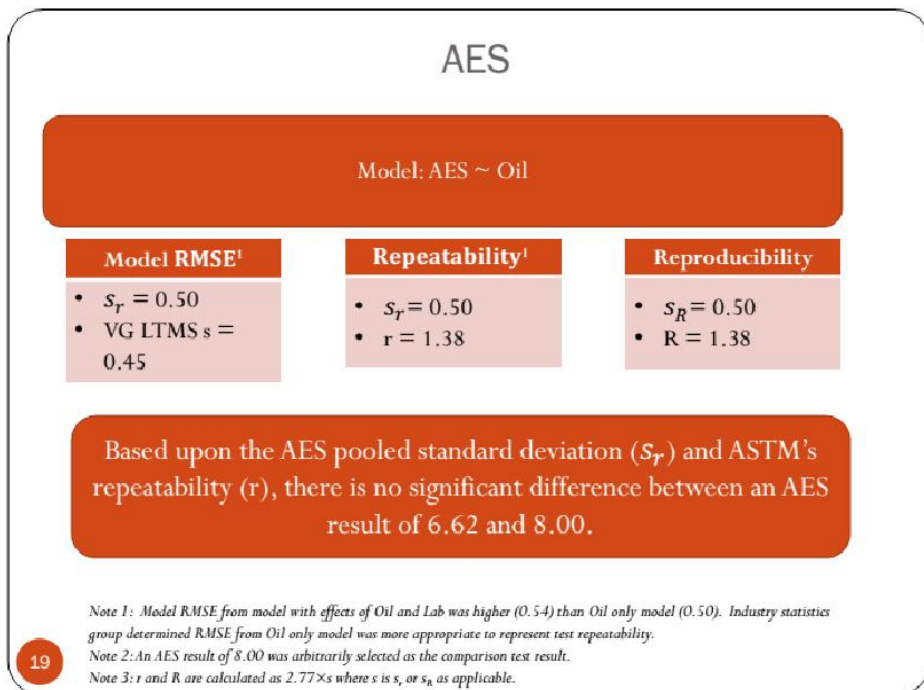
- Ideally, each plot should look the same and not have any horizontal segments.
  - In general, this appears to be the case.
- Stand A/1 does appear to show a small difference.
  - However, this is based on the single result from REO1011.

j) Slide #17:



- i) The Sequence VH REO940 AES results straddle those of the Sequence VG.
- ii) The Sequence VH REO1009 AES results are severe of the Sequence VG target.
- iii) There is discrimination between the three oils.

k) Slide #19:



- i) The  $S_r=0.50$  and  $S_R=0.50$  values for the Sequence VH are very similar to the  $s=0.45$  value for the Sequence VG.

l) Slide #20:

# Reference Oil Targets

Model: AES ~ Oil, Lab

Average Engine Sludge (AES), merits

Ref. Oil	Target	St. Dev
940	6.47	0.49
1009	7.21	0.44
1011	8.43	0.57

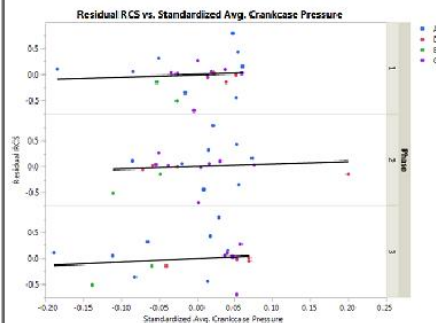
Note: Targets are the Model LS Means; Standard Deviations are calculated directly from the test results for each Oil without accounting for Lab or Stand differences.

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i) This slide contains the recommended standard deviations and targets for AES.

m) Slide #22:

# Correlation of RCS with Crankcase Pressure



Averages Used for Plot Centering

Phase	Average Crankcase Pressure
1	0.096
2	0.222
3	-0.031

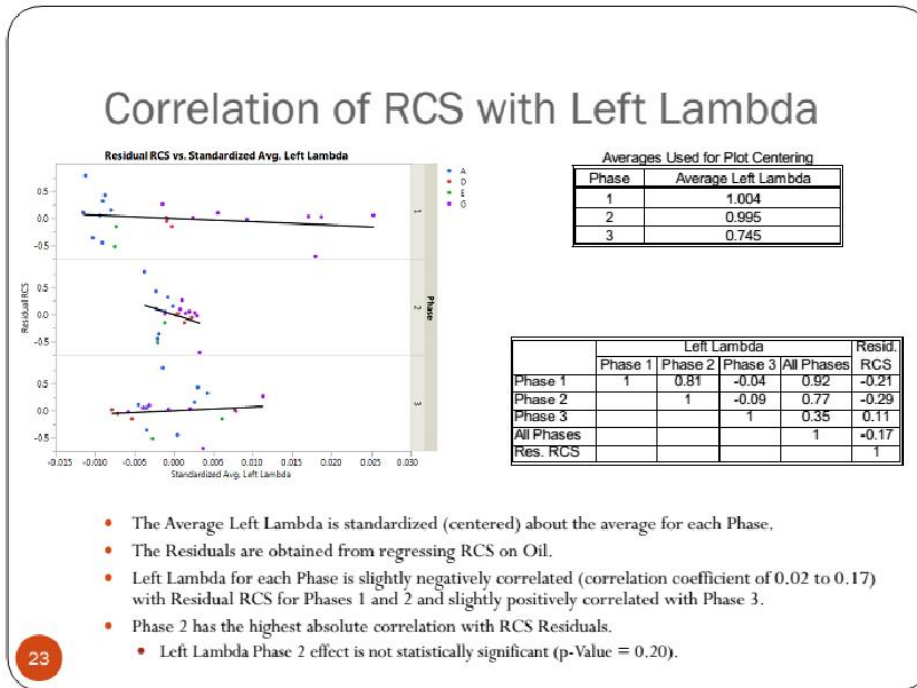
	Crankcase Pressure				Resid. RCS
	Phase 1	Phase 2	Phase 3	All Phases	
Phase 1	1	0.51	0.74	0.93	0.09
Phase 2		1	0.15	0.68	0.10
Phase 3			1	0.80	0.17
All Phases				1	0.15
Res. RCS					1

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- The Average Crankcase Pressure is standardized (centered) about the average for each Phase.
- The Residuals are obtained from regressing RCS on Oil.
- The Crankcase Pressure for each Phase is slightly positively correlated (correlation coefficient of 0.09 to 0.17) with Residual RCS.
- Crankcase Pressure Phase 3 has the highest correlation with RCS Residuals.
  - Crankcase Pressure Phase 3 is not statistically significant (p-Value = 0.46).

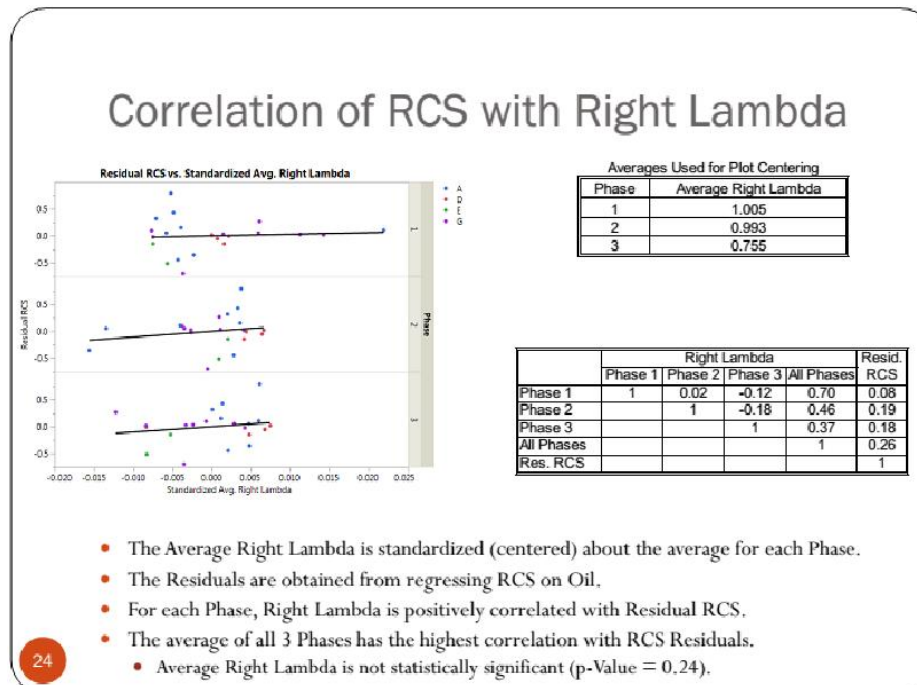
i) There is a slightly positive slope in the correlation between RCS and crankcase pressure.  
 ii) However, the slope is small and deemed to be not statistically significant.

n) Slide #23:



- i) There is a strong correlation between RCS and the left-side lambda with the Stage/Phase 2 data.
- ii) However, the slope is negative and not positive – so it does not make much sense from a technical standpoint.

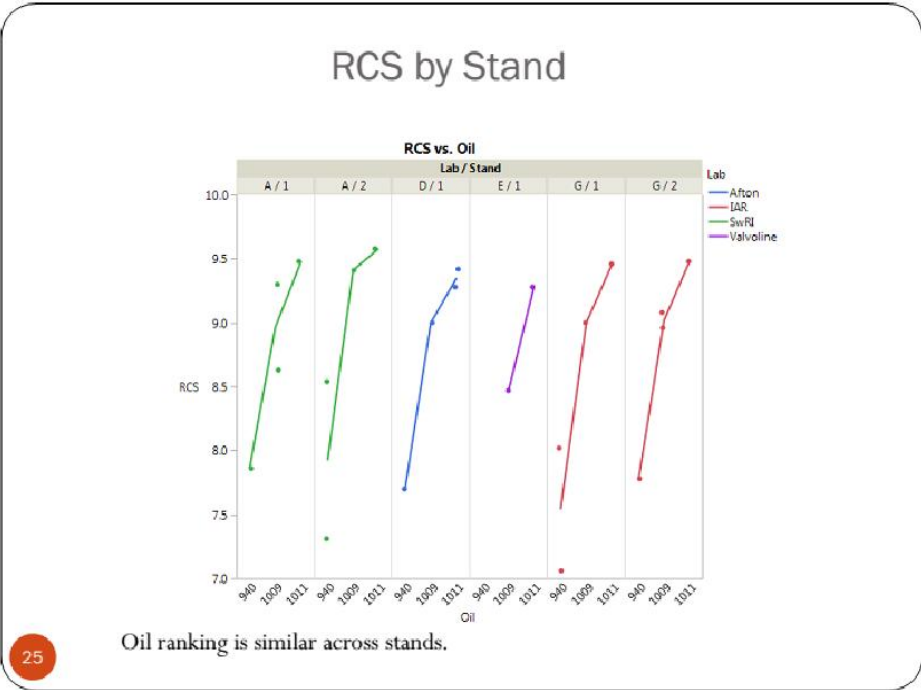
**o) Slide #24:**



- i) The correlation between RCS and the right-side lambda measurement is not statistically significant.

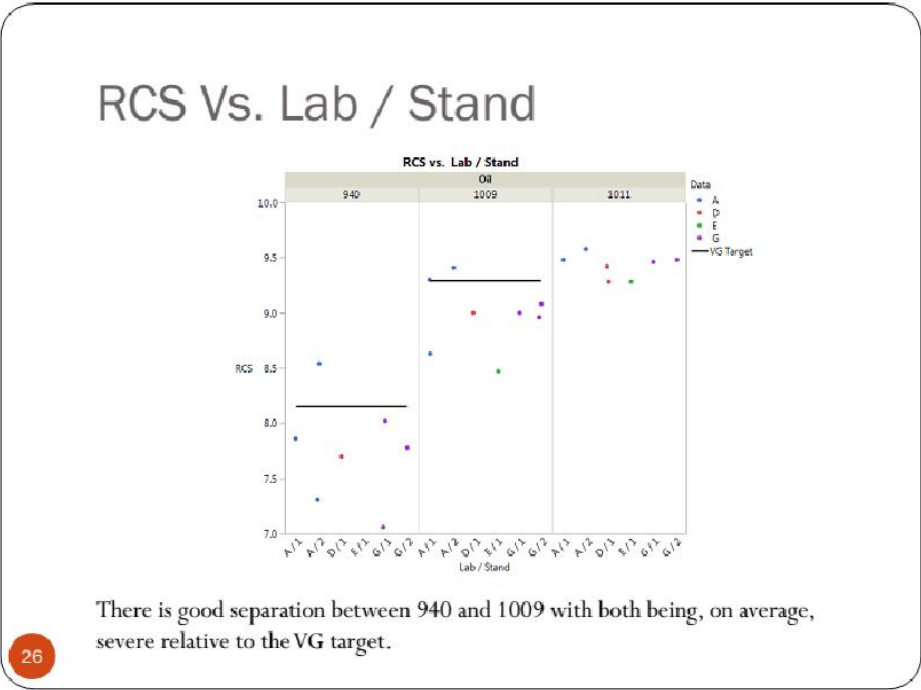
**p) Slide #25:**





- i) All of the lines are highly sloped and parallel to each other.
- ii) These are very favorable plots.

**q) Slide #26:**



- i) The Sequence VH RCS results for REO940 and REO1009 are both slightly severe of the Sequence VG targets.
- ii) There is good discrimination between the three oils.

**r) Slide #27:**

# RCS Regression Analysis

- $\ln(10 - \text{RCS})$  was regressed on:
  - Oil
  - Lab
  - Stand[Lab]
- The Oil term is statistically significant.
  - Each of the Oils are statistically significantly different from each other.
- The Lab term is borderline statistically significant.
  - The estimate of Lab E, which had just 2 valid tests completed, is higher (lower in untransformed units) than the other labs. Both of its RCS results were the lowest (or tied for the lowest) for that particular Oil.

Term	df	p-Value
Oil	2	<.0001
Lab	3	0.0521
Stand[Lab]	2	0.3017

Oil	Level	LS Mean	
		$\ln(10 - \text{RSC})$	RSC
940	1	0.9323	7.46
1009	2	0.0395	8.96
1011	3	-0.5286	9.41

Oils not connected by the same level are statistically significantly different.

Lab	LS Mean	
	$\ln(10 - \text{RSC})$	RSC
E	0.4407	8.45
D	0.1590	8.83
G	0.0710	8.93
A	-0.0798	9.08

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- i) There is a tight grouping with the REO1011 results.
  - (1) This is expected because all of the parts are near the highest level of cleanliness for a rated part.
- ii) There is a borderline statistical difference in labs.
  - (1) Lab E is severe relative to the other labs.
  - (2) However, there are only two results for Lab E.
  - (3) Additional results could potentially diminish this lab difference.

## s) Slide #28:

### RCS

Repeatability Model:  $\ln(10 - \text{RCS}) \sim \text{Oil, Lab}$

Model RMSE	Repeatability
• $s_r = 0.2194$	• $s_r = 0.2194$ • $r = 0.6081$

Reproducibility Model:  $\ln(10 - \text{RCS}) \sim \text{Oil}$

Reproducibility
• $s_R = 0.2532$ • $R = 0.7018$

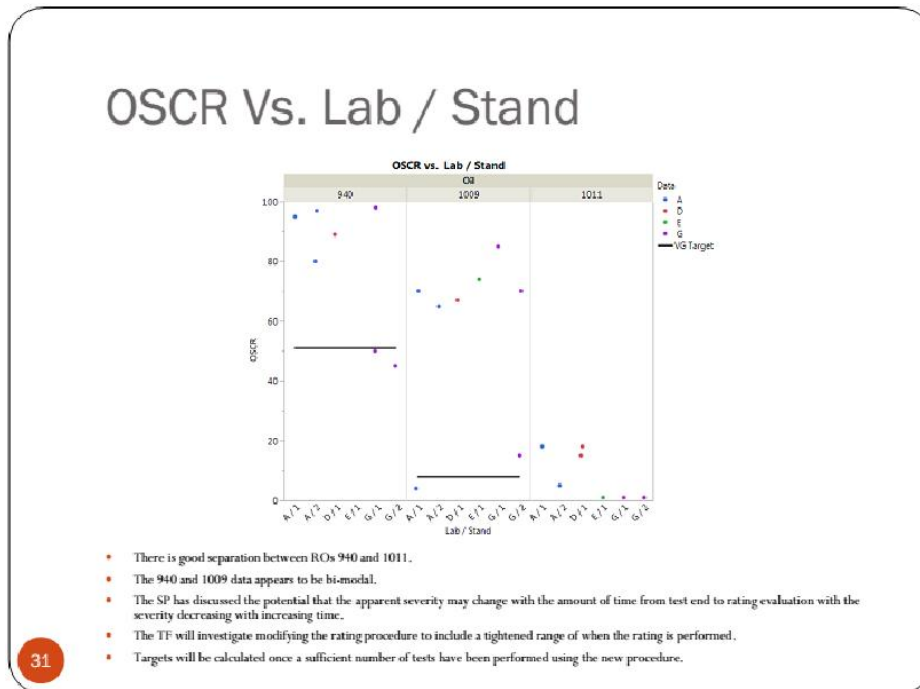
Based upon the RCS pooled standard deviation ( $s_r$ ) and ASTM's repeatability ( $r$ ), there is no significant difference between an RCS result of 6.88 and 8.30.

Note 1: An RCS result of 8.30 was arbitrarily selected as the comparison test result.  
 Note 2:  $r$  and  $R$  are calculated as  $z_{0.025} \times \sqrt{2} \times s$  where  $s$  is  $s_r$  or  $s_R$  as applicable.

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- i) The RCS results for the Sequence VH are very similar to those of the Sequence VG.

t) Slide #31:



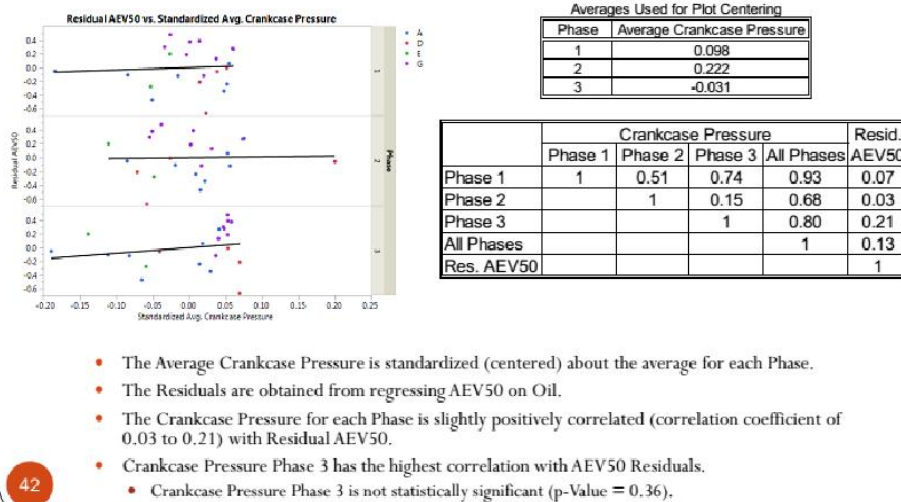
- i) The OSC results for REO940 have a bi-modal distribution.
- ii) The OSC results for REO1009 also have a bi-modal distribution with a much larger gap between the low and high values.
- iii) A task force has been formed to improve the OSC rating method used for the Sequence VH test.
- iv) The statisticians were instructed to not establish OSC targets using the Precision Matrix data.

u) **100% Varnish Ratings:**

- i) The statisticians did not review the slides in this presentation that covered the 100% APV and AEV parameters.
- ii) The decision was already made to use the 50% APV and AEV parameters for the Sequence VH test.

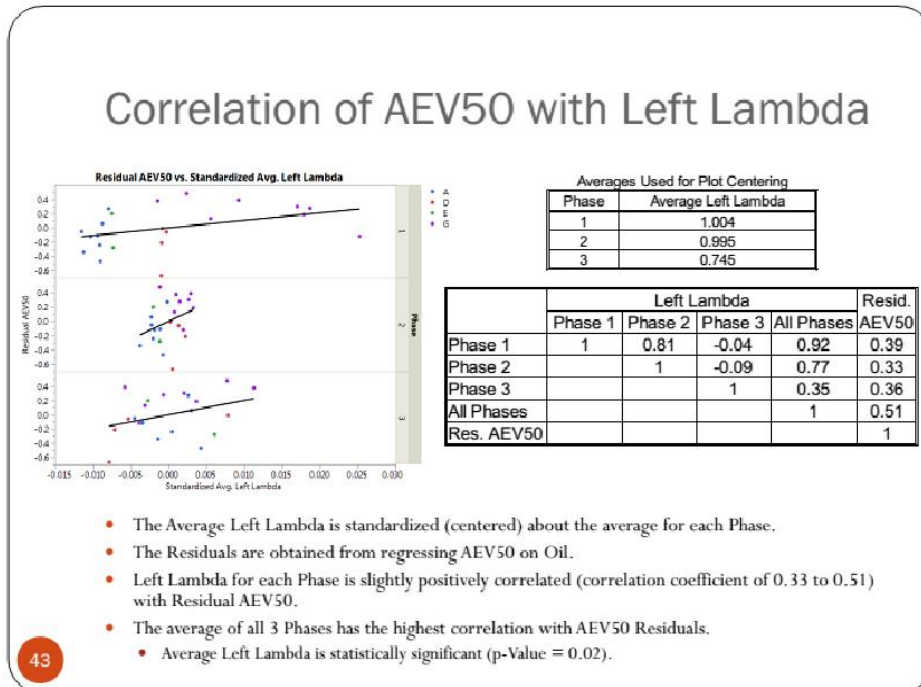
v) Slide #42:

## Correlation of AEV50 with Crankcase Pressure



- The lines for the Stage/Phase 1 and 2 correlations are fairly horizontal.
- The line for the Stage/Phase 3 correlation has a slope, but it is not statistically significant.

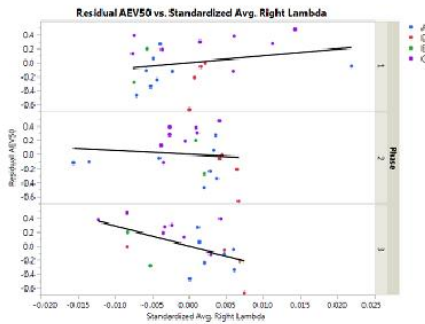
### w) Slide #43:



- There is a positive slope for the correlations for all three Stages/Phases.
- So the correlation between AEV50 and the left-side lambda measurement is statistically significant.

### x) Slide #44:

## Correlation of AEV50 with Right Lambda



Averages Used for Plot Centering	
Phase	Average Right Lambda
1	1.005
2	0.993
3	0.755

	Right Lambda				Resid. AEV50
	Phase 1	Phase 2	Phase 3	All Phases	
Phase 1	1	0.02	-0.12	0.70	0.26
Phase 2		1	-0.18	0.46	-0.11
Phase 3			1	0.37	-0.56
All Phases				1	-0.18
Res. AEV50					1

- The Average Right Lambda is standardized (centered) about the average for each Phase.
- The Residuals are obtained from regressing AEV50 on Oil.
- For Phase 1, Right Lambda is slightly positively correlated with Residual AEV50, however, for Phases 2 and 3, the correlation coefficients are negative.
- Right Lambda Phase 3 has the highest absolute correlation with AEV50 Residuals.
  - Right Lambda Phase 3 is statistically significant (p-Value = 0.007).

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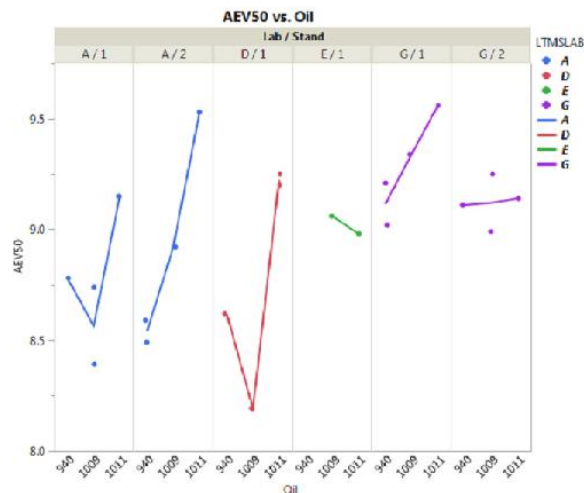
- The strongest correlation between AEV50 and the right-side lambda measurement is with the Stage/Phase 3 data.
- All of the Stage/Phase 3 data supports a negative correlation.
- The engineering team is of the opinion that this correlation does not make sense from a technical standpoint.

#### iv) Affon's comments:

- The statisticians may want to look at the difference between the left-side and right-side lambda measurements instead of each individual measurement.

#### y) Slide #45:

## AEV50 by Stand



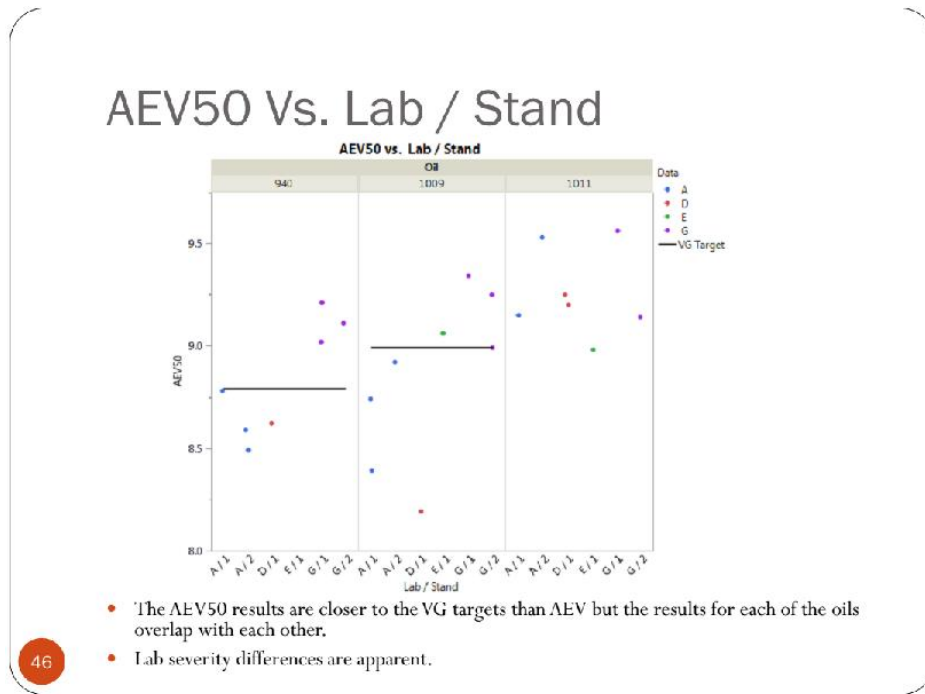
45

- Oil ranking appears to differ across stands, however, the sample size is low.
- Stand G / 2 shows minimal Oil discrimination.

- There are stand differences with the AEV50 parameter.
- Stands A1 and D1 have a V-shaped trend.

iii) The trend for stands A2 and G1 is a straight line.

**z) Slide #46:**

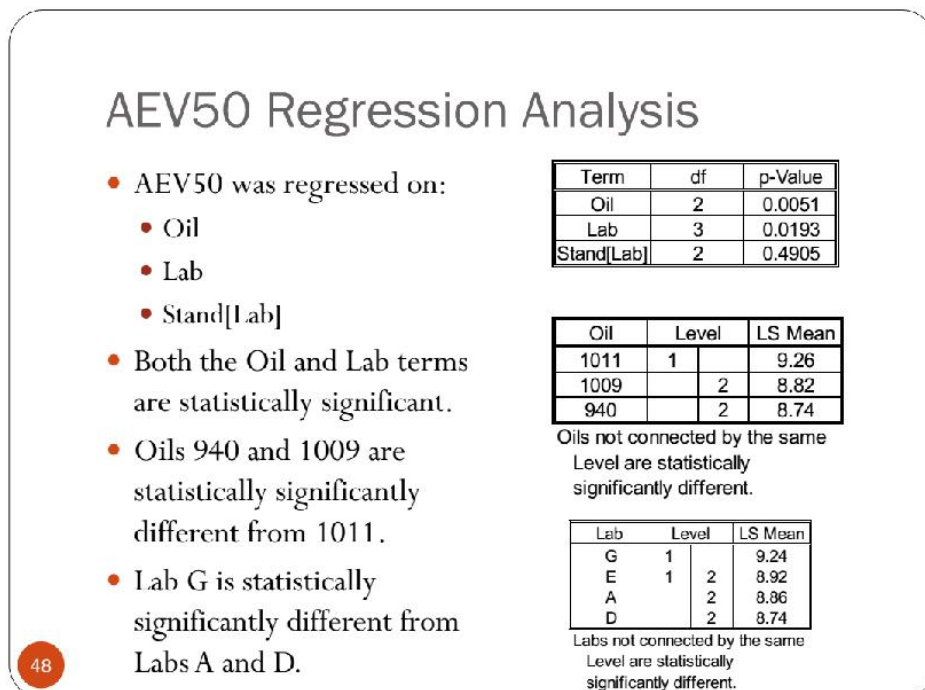


- i) The results for REO940 and REO1009 straddle the targets for the Sequence VG test.
- ii) There are lab differences with REO940 and REO1009.

**iii) Affon's comments:**

- (1) It would be interesting to repeat this analysis with just the left-side and right-side camshaft baffle varnish measurements.

**aa) Slide #48:**



- i) The AEV50 results for Lab G are milder than the results from the other labs.

**bb) Slide #49:**

### AEV or AEV50?

Choose AEV50 as it has:

- Lower p-Value for Oil term (0.005 vs. 0.033).
- Lower  $s_r$  (0.25 versus 0.28)
- Results for 940 and 1009 are better centered about the VG targets.

Note that the Lab effect is statistically significant for AEV50 but is only borderline statistically significant for AEV. The range between the highest and lowest Lab LS Mean for the two parameters is similar but AEV50 has a lower RMSE contributing to the difference in statistical significance.

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- i) The statisticians do not think that lab differences will be created by transitioning to the AEV50 parameter (in place of the original AEV parameter).

**cc) Slide #50:**

### AEV50

Repeatability Model: AEV50 ~ Oil, Lab		Reproducibility Model: AEV50 ~ Oil	
Model RMSE	Repeatability	Reproducibility	
<ul style="list-style-type: none"> <li>• <math>s_r = 0.25</math></li> <li>• VG LTMS <math>s = 0.16</math></li> </ul>	<ul style="list-style-type: none"> <li>• <math>s_r = 0.25</math></li> <li>• <math>r = 0.69</math></li> </ul>	<ul style="list-style-type: none"> <li>• <math>s_R = 0.31</math></li> <li>• <math>R = 0.86</math></li> </ul>	

Based upon the AEV50 pooled standard deviation ( $s_r$ ) and ASTM's repeatability ( $r$ ), there is no significant difference between an AEV50 result of 8.21 and 8.90.

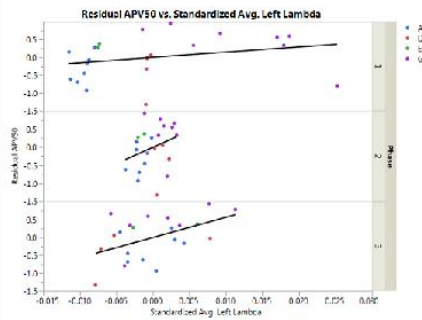
*Note 1: An AEV50 result of 8.90 was arbitrarily selected as the comparison test result.*  
*Note 2:  $r$  and  $R$  are calculated as  $2.77 \times s$  where  $s$  is  $s_r$  or  $s_R$  as applicable.*

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- i) The standard deviation for AEV50 is higher for the Sequence VH test than it was for the Sequence VG test.

**dd) Slide #63:**

## Correlation of APV50 with Left Lambda



Averages Used for Plot Centering

Phase	Average Left Lambda
1	1.004
2	0.995
3	0.745

	Left Lambda				Resid. APV50
	Phase 1	Phase 2	Phase 3	All Phases	
Phase 1	1	0.81	-0.04	0.92	0.27
Phase 2		1	-0.09	0.77	0.30
Phase 3			1	0.35	0.50
All Phases				1	0.46
Res. APV50					1

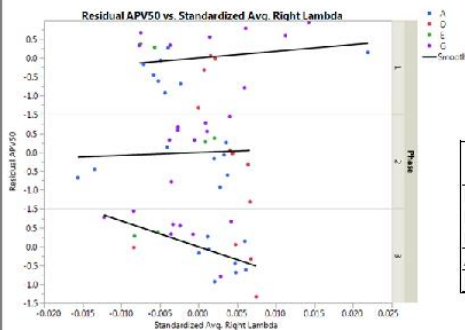
- The Average Left Lambda is standardized (centered) about the average for each Phase.
- The Residuals are obtained from regressing APV50 on Oil.
- Left Lambda for each Phase is positively correlated (correlation coefficient of 0.27 to 0.50) with Residual APV50.
- Left Lambda Phase 3 has the highest correlation with APV50 Residuals.
  - Average Left Lambda is statistically significant (p-Value = 0.07).

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- All three lines have clear positive slopes.
- The line for Stage/Phase 3 has the largest positive slope, so the correlation between APV50 and the left-side lambda measurement is statistically significant during this stage.

### ee) Slide #64:

## Correlation of AEV50 with Right Lambda



Averages Used for Plot Centering

Phase	Average Right Lambda
1	1.005
2	0.993
3	0.755

	Right Lambda				Resid. APV50
	Phase 1	Phase 2	Phase 3	All Phases	
Phase 1	1	0.02	-0.12	0.70	0.23
Phase 2		1	-0.18	0.46	0.07
Phase 3			1	0.37	-0.66
All Phases				1	-0.15
Res. APV50					1

- The Average Right Lambda is standardized (centered) about the average for each Phase.
- The Residuals are obtained from regressing APV50 on Oil.
- For Phases 1 and 2, Right Lambda is slightly positively correlated with Residual APV50, however, for Phase 3, the correlation is negative.
- Right Lambda Phase 3 has the highest absolute correlation with APV50 Residuals.
  - Right Lambda Phase 3 is statistically significant (p-Value = 0.0009).

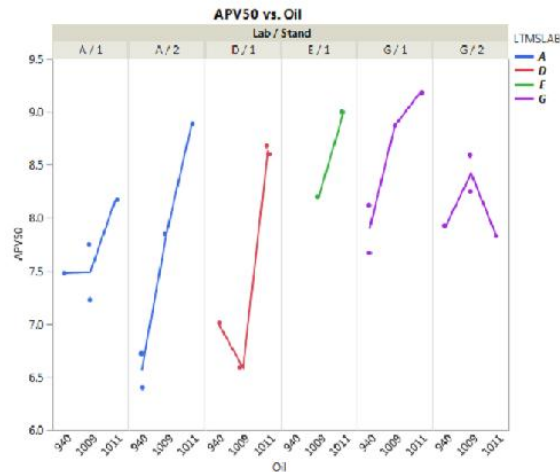
64

- The line for Stage/Phase 3 has a negative slope.
- The group agreed that the negative slope does not make sense from a technical standpoint.

### ff) Slide #65:



## APV50 by Stand



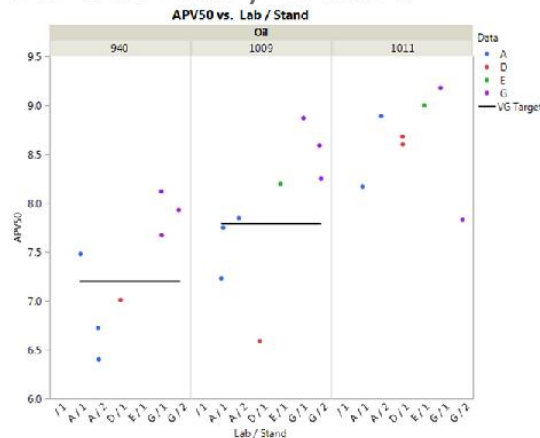
65

- Oil ranking is similar across stands except for Stand G/2, however, the sample size is low.

- This chart supports the theory that the APV50 parameter is probably driving the differences in the AEV50 parameter.
- The APV50 results for Lab G are milder than those of the other labs.

### gg) Slide #66:

## APV50 Vs. Lab / Stand

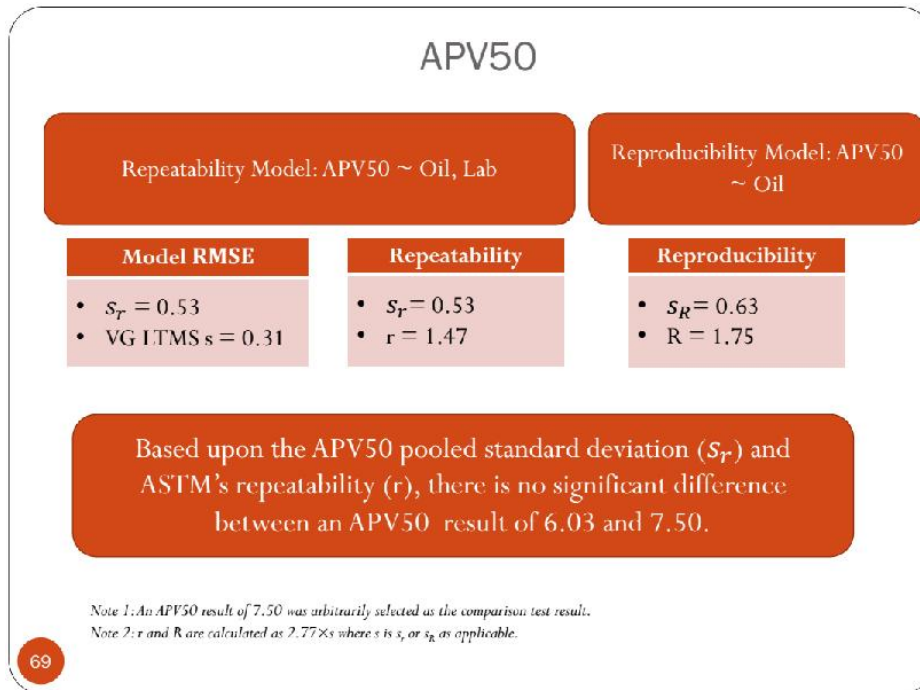


66

- APV50 is closer to the VG target than APV.
- There is considerable overlap of the oils with each other.

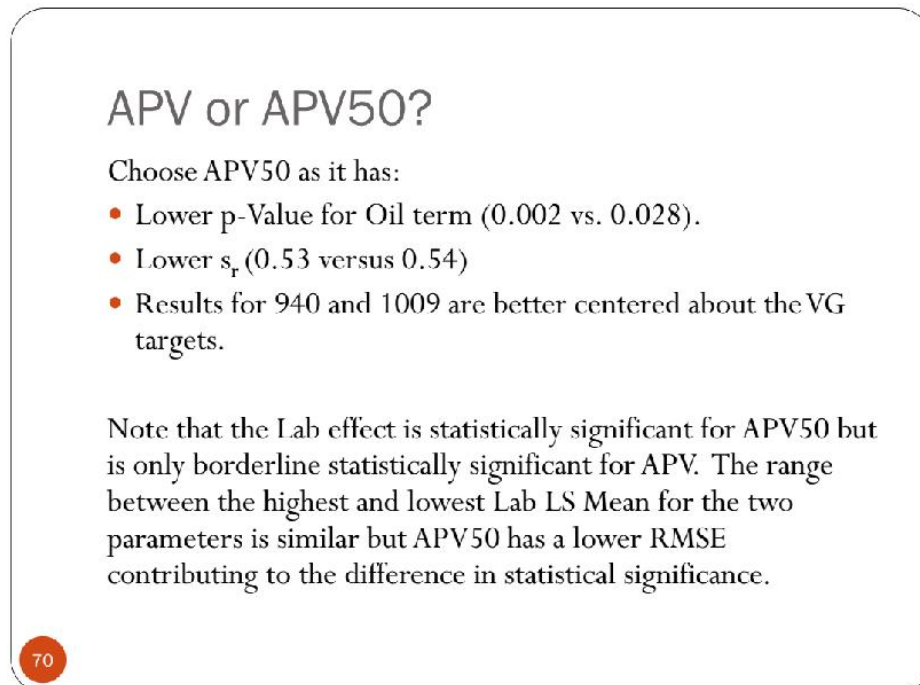
- The APV50 results for REO940 and REO1009 are centered on the Sequence VG targets.
- The REO940 and REO1009 results for Lab A are lower than those of the other labs.
  - This is not the case with REO1011.
- There may be an oil and lab interaction with the APV50 data.
  - This is very concerning and could lead to problems with the LTMS model.

### hh) Slide #69:



i) The APV standard deviation for the Sequence VH test is much higher than for the Sequence VG test.

**ii) Slide #70:**



i) The statisticians are recommending the use of APV50 instead of APV.

**jj) Slide #73:**

# Parameter Correlation

Correlation Coefficients of Raw Data					Correlation Coefficients of Residuals				
	AES	Ln[10 - RCS]	AEV50	APV50		AES	Ln[10 - RCS]	AEV50	APV50
AES	1	-0.86	0.40	0.62	AES	1	-0.56	-0.24	0.14
Ln[10 - RCS]	-0.86	1	-0.39	-0.58	Ln[10 - RCS]	-0.56	1	0.10	-0.17
AEV50	0.40	-0.39	1	0.86	AEV50	-0.24	0.10	1	0.76
APV50	0.62	-0.58	0.86	1	APV50	0.14	-0.17	0.76	1

- Residuals are from models of parameters regressed on Oil and Lab.
- Both methods indicate high (absolute) correlations within Sludge and Varnish pairs.
- Appendix K suggests redundant parameters are characterized by correlation coefficients exceeding 0.85.
  - This would indicate that there is redundancy within the pair of RCS and AES as well as the pair AEV50 and APV50.

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- i) There are high correlations between AES and RCS, and also between AEV50 and APV50. (1) These correlations come as no surprise.
- ii) **Ford's comments:**  
 (1) Ford would like to keep all of these parameters in place (even though some may be redundant).

kk) **Slide #85:**

## AES

Model: AES ~ Oil

Model RMSE <sup>1</sup>	Repeatability <sup>1</sup>	Reproducibility
<ul style="list-style-type: none"> <li>• <math>S_r = 0.48</math></li> <li>• VG LTMS <math>s = 0.45</math></li> </ul>	<ul style="list-style-type: none"> <li>• <math>S_r = 0.48</math></li> <li>• <math>r = 1.33</math></li> </ul>	<ul style="list-style-type: none"> <li>• <math>S_R = 0.48</math></li> <li>• <math>R = 1.33</math></li> </ul>

Based upon the AES pooled standard deviation ( $S_r$ ) and ASTM's repeatability ( $r$ ), there is no significant difference between an AES result of 6.67 and 8.00.

Note 1: Model RMSE from model with effects of Oil and Lab was higher (0.51) than Oil only model (0.48). Industry statistics group determined RMSE from Oil only model was more appropriate to represent test repeatability.

Note 2: An AES result of 8.00 was arbitrarily selected as the comparison test result.

Note 3:  $r$  and  $R$  are calculated as  $2.77 \times s$  where  $s$  is  $s_r$  or  $s_R$  as applicable.

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- i) The presence of the Lab E data does not have a large impact on the standard deviation of AES.
- ii) As a result, there is not a strong case for removing the Lab E data.

II) **Concluding Remarks by D. Boese:**

- i) The Sequence VH test shows oil discrimination.
- ii) There are no significant differences among the stands within a given lab.
- iii) There are no strong reasons to hold back this test.

**iv) Lubrizol's comments:**

- (1) Lubrizol reminded the group that the statisticians did identify a varnish interaction between an oil and a lab.
- (2) This is a concern in terms of the LTMS model.

Action Items	Person responsible	Completion Date
Schedule a follow-up conference call to discuss crankcase pressure vs. PCV clogging and blowby flow rate.	VH Development Task Force	

Follow-up Notes/Updates:	Initials	Date Added