Sequence IV Surveillance Panel | MINUTES

REVISION DATE: 4/5/2018 8:43:00 AM

Relevant Test:	Sequence IVA and IVB
Note Taker:	Chris Mileti
Meeting Date:	03-07-2018
Comments:	Sequence IV Surveillance Panel conference call to discuss the ongoing analysis of the Sequence IVB Precision Matrix data.

1. REVIEW OF AGENDA AND OPEN ACTION ITEMS:

1.1. Discussion about Operational Analysis with Partial Least Squares:

1.1.1. During the 03-01-2018 conference call, the statisticians reviewed their latest Sequence IVB operational data analysis (dated 02-14-2018).

1.1.2. Buscher asked if any of the Surveillance Panel members had feedback on this analysis.

1.1.2.1. No feedback was given.

1.2. Discussion about Additional 1-Hour Operational Data:

1.2.1. Each laboratory submitted operational data from the 10HR-11HR and 195HR-196HR time periods for each Precision Matrix test.

1.2.1.1. Afton submitted data from their prove-out tests.

1.2.2. The Surveillance Panel reviewed the 10HR-11HR data during the 03-01-2018 conference call.

1.2.2.1. There was not enough time to review the 195HR-196HR data.

1.2.3. Buscher asked if any of the Surveillance Panel members had a chance to review the 195HR-196HR operational data.

1.2.4. ***Comments from Intertek:***

1.2.4.1. They reviewed the 195HR-196HR operational data and identified trends and lab-to-lab differences that were like those from the 10HR-11HR data.

1.2.4.2. Intertek believes that there is good alignment between their lab and SWRI.

1.2.4.3. Small operational differences can be addressed through continuous improvement efforts.

1.2.5. ***Comments from Lubrizol:***

1.2.5.1. Lubrizol reviewed the 195HR-196HR operational data.

1.2.5.2. The following (3) parameters continue to show significant differences between laboratories:

1.2.5.2.1. AFR

1.2.5.2.2. Crankcase Pressure

1.2.5.2.3. Intake Manifold Pressure

1.2.5.2.4. Exhaust Gas Temperature

2. STATISTICAL ANALYSIS OF SEQUENCE IVB OPERATIONAL RAMPS (03-05-2018):

2.1. Slide #2:

Statistical Analysis of Operational Ramp Data

- Analysis was performed to investigate the relationship between the RPM ramps from stages (1 to 2) and (2 to 1) with respect to the Sqrt(AVLI) parameter
- Data used in analysis included all available operational PM and Afton prove out test data (includes 300,000+ test results for Hrs 10-11, 100-101, and 195-196)
- The analysis was performed using data generated with Excel's "Slope" calculation and was compiled for each Seq. IVB test result – as listed below:
  - Each ascending ramp stage 1 to 2 was divided into a part "A" and part "B" portion.
    - Part "A" included average RPM slope for Stage Times 1 to 4
    - Part "B" included average RPM slope for Stage Times 5 to 8
    - All of the part "A" and "B" 1 to 2 RPM ramp slopes were averaged by test key
  - Likewise, each descending ramp stage 2 to 1 was divided into a part "A" and part "B" portion.
    - Part "A" included average RPM slope for Stage Times 1 to 4
    - Part "B" included average RPM slope for Stage Times 5 to 8
    - All of the part "A" and "B" 2 to 1 RPM ramp slopes were averaged by test key

2.1.1. The conclusion of this analysis is that ramping does not impact test severity.

2.2. Slide #3:

Statistical Analysis of Operational Ramp Data

- The data available for the analysis is shown below:

TESTKEY	LTMSLAB	LTMSAPP	IND	AVLI	Sqrt(AVLI)	TestKey	Mean(RPM12_SlopeAvg_A)	Mean(RPM12_SlopeAvg_B)	Mean(RPM21_SlopeAvg_A)	Mean(RPM21_SlopeAvg_B)
109201-IVB	A	1	1011	1.09	1.04403065	109201-IVB	414.8722222	458.5294444	-431.2805556	-434.7763889
120739-IVB	F	1	300	1.34	1.15758369	120739-IVB	521.2520833	391.2371944	-473.0075278	-398.9306111
125183-IVB	F	1	1012	1.73	1.31529464	125183-IVB	527.1713056	390.1530278	-481.5295	-395.0464444
125184-IVB	G	1	1011	1.84	1.356466	125184-IVB	355.3573816	439.3816156	-350.2189415	-425.5649025
125879-IVB	B1	3	1011	1.8	1.34164079	125879-IVB	453.7066477	434.8160344	-413.7132887	-399.5746232
125880-IVB	A	2	1011	0.93	0.96436508	125880-IVB	437.32	460.5552778	-435.1580556	-446.2277778
125881-IVB	A	1	1011	1.37	1.17046999	125881-IVB	433.1430556	452.7713889	-424.9202778	-439.8666667
125882-IVB	A	2	1012	0.71	0.84261498	125882-IVB	426.7233333	451.1925	-434.5819444	-445.9252778
127173-IVB	B1	1	1012	1.55	1.24498996	127173-IVB	474.4950343	429.1674152	-435.6487985	-415.6947865
129752-IVB	A	1	300	1.95	1.396424	129752-IVB	419.9944444	454.0755556	-430.4694444	-445.1075
129755-IVB	A	1	1012	1.55	1.24498996	129755-IVB	428.3113889	452.4508333	-431.1077778	-441.1088889
129756-IVB	A	2	1012	1.1	1.04880885	129756-IVB	431.2725	437.8447222	-431.7386111	-455.1022222
129759-IVB	B1	2	300	1.78	1.33416641	129759-IVB	465.5698229	432.2417	-431.4507963	-423.1062297
129760-IVB	B1	1	300	2.1	1.44913768	129760-IVB	467.8832906	427.8783778	-440.3054502	-413.4002239
129762-IVB	B1	1	1011	2.05	1.43178211	129762-IVB	473.8083166	428.6092034	-432.6191069	-414.3847742
129763-IVB	B1	2	1011	1.98	1.40712473	129763-IVB	474.0588333	430.9709874	-441.7431113	-422.1739921
129764-IVB	B1	3	1011	2.35	1.53297097	129764-IVB	472.112114	428.4422819	-422.4814262	-408.5008733
129766-IVB	B1	2	1012	1.7	1.30384048	129766-IVB	467.4247179	431.2178682	-432.263019	-419.8884915
129767-IVB	B1	3	1012	0.82	0.90553851	129767-IVB	467.1650808	431.73194	-423.0178775	-413.0315413
129768-IVB	B1	1	1012	1.42	1.19163753	129768-IVB	476.2059991	425.644497	-436.58926	-423.0616691
130938-IVB	B1	2	300	3.05	1.74642492	130938-IVB	475.5974866	430.6919217	-439.6350472	-428.7717282
130939-IVB	B1	3	300	3.13	1.7691806	130939-IVB	464.4039892	426.6081732	-429.2367002	-422.6049107
130940-IVB	G	1	300	1.81	1.34536241	130940-IVB	357.4047354	434.7768802	-351.8844011	-426.0629526
130943-IVB	G	1	1011	2.03	1.42478069	130943-IVB	356.9819737	438.5256267	-351.0874652	-425.9295265
130944-IVB	G	1	1012	1.81	1.34536241	130944-IVB	330.4273776	291.437883	-342.178273	-275.3019499
130945-IVB	F	1	1012	0.93	0.96436508	130945-IVB	534.7816389	390.4550278	-481.4309444	-399.2427778
130948-IVB	A	2	300	1.27	1.12694277	130948-IVB	438.1580556	442.0269444	-420.4555556	-444.5683333
131277-IVB	A	1	300	2.06	1.43527001	131277-IVB	430.9211111	453.1658333	-428.0227778	-442.1180556
Unassigned	D	1	1012	1.04	1.0198039	Afton-D101A-0-0-RO1012	415.9272829	422.4542857	-403.464986	-411.7388235
Unassigned	D	1	300	2.4	1.54919334	Afton-D101A-0-0-RO300	444.7044444	415.4313611	-437.54175	-414.5443611

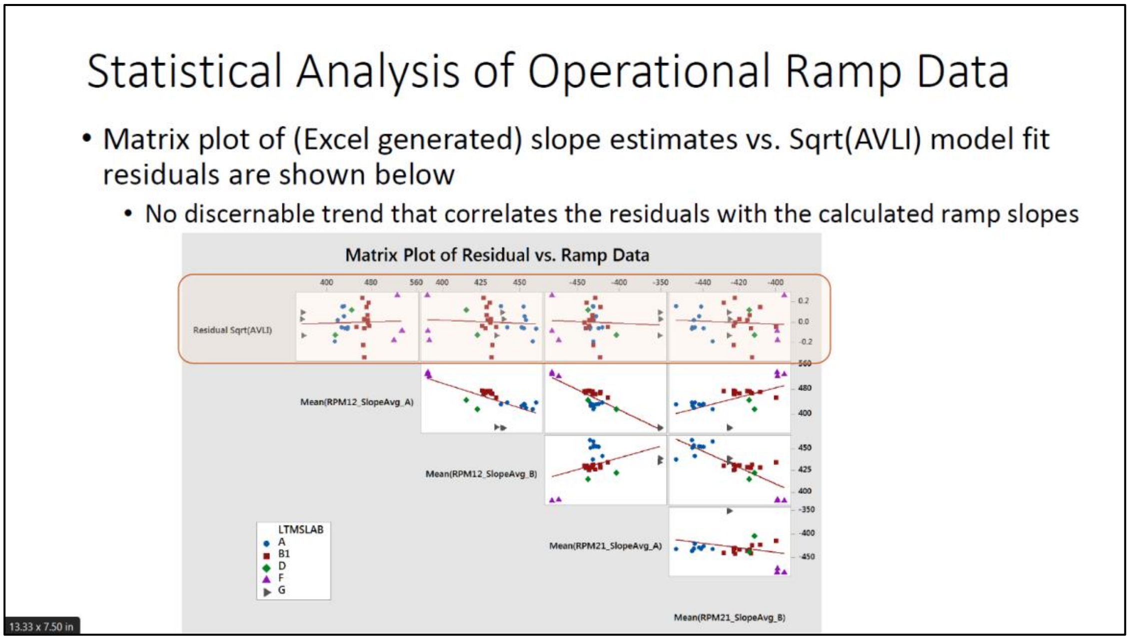
Unusual "Outlier" removed from analysis

Data appears out of Phase – please see Appendix

2.2.1. The operational data from one of the Exxon results appears to be out of phase with the data from the other tests.

2.2.2. The statisticians had to omit this test from their analysis.

2.3. Slide #5:



2.3.1. The slopes do not seem to correlate to lifter wear.

2.3.2. The statisticians agreed to take a closer look at the four anomalous parameters identified by Lubrizol (i.e. AFR, crankcase pressure, intake manifold pressure and exhaust gas temperature).

3. 200HR OPERATIONAL DATA PLOTS:

3.1. Laboratory Update:

3.1.1. Lubrizol is still trying to complete the 200HR operational data plots for its three Precision Matrix tests.

3.1.1.1. The data is compiled.

3.1.1.2. They are having a difficult time identifying an appropriate way to graph the data.

3.1.2. ***Comments from Southwest:***

3.1.2.1. They plotted their data using SAS JMP.

3.1.2.2. They used a local moving average to eliminate the “blob” of data that made graphing problematic.

3.1.2.3. Their graphs are not yet on the TMC website.

3.1.3. ***Comments from Intertek:***

3.1.3.1. IAR is trying to duplicate the methodology that SWRI used to generate their plots.

3.1.3.1.1. This includes smoothing the data.

3.1.3.2. They recently purchased the SAS JMP software.

3.1.3.3. They have plotted (7) parameters thus far.

4. STATISTICAL ANALYSIS OF N=21 PRECISION MATRIX DATA:

4.1. Background:

4.1.1. The statisticians repeated their analysis of the Precision Matrix data.

4.1.2. This time they only used data from the independent laboratories.

4.1.2.1. This reduced the dataset down to (21) valid tests.

4.1.3. Eliminating the dependent labs did little to change their conclusions.

4.2. Slide #3:

Executive Summary

Precision Matrix (PM) Analysis Highlights:

- This analysis includes the results of 21 valid precision matrix tests from the independent labs
- Data supports the use of Sqrt(AVLI) transformation
- Significant oil differences: 1012 < 300
- Lab differences are statistically significant (A < B1)
- Stand within Lab differences are not statistically significant
- Estimated within a stand test precision (r; ASTM repeatability)
  - Sqrt(AVLI) = 0.4593
- Estimated test precision across labs and stands (R; ASTM reproducibility)
  - Sqrt(AVLI) = 0.5771
- Oil means and standard deviations

Oil	Number of Tests	Target Mean Sqrt(AVLI)	Target Mean AVLI	Target Standard Deviation Sqrt(AVLI)
300	7	1.4306	2.05	0.2269
1012	7	1.1104	1.23	0.1815
1011	7	1.2373	1.53	0.2136

3

4.2.1. Separation between oils is being driven by two severe results with REO300.

4.2.1.1. There is no statistical separation between oils if these two results are eliminated from the dataset.

4.2.2. There are significant differences between Lab A and Lab B1.

4.2.3. Precision for the dataset did not improve by eliminating the dependent labs.

4.2.3.1. However, it did shift the AVLI for REO300 slightly higher and the AVLI for REO1012 slightly lower.

4.2.4. The main advantage of the N=21 dataset is that it has a slightly higher standard deviation between the highest and lowest oils.

4.2.5. It is still a concern that two of the labs do not discriminate.

*4.2.6. **Comments from Lubrizol:***

4.2.6.1. Lubrizol questioned why the Surveillance Panel is considering the exclusion of data from the dependent labs.

4.2.6.1.1. The Precision Matrix results from the dependent labs have already been declared valid.

4.2.6.1.2. The request to eliminate the dependent labs was not made at the AOAP because that panel has not yet reviewed any of the statistical presentations.

4.2.6.2. Jim Linden requested this analysis on the behalf of Toyota during the January 25th face-to-face meeting in San Antonio.

4.3. Discussion about Lab Discrimination:

4.3.1. Lab A discriminates between REO300 and REO1012.

4.3.2. Lab A and Lab B rank REO1011 differently.

4.3.3. REO300 is always the highest wearing oil at Lab A and Lab B.

4.3.4. Lab F and Lab G do not discriminate between oils.

5. UPDATE ON "POOR" PROOF-OF-PERFORMANCE OILS:

5.1. Update from Exxon:

5.1.1. ***Initial Test:***

5.1.1.1. They formulated a high wear oil specifically for the IVB test.

5.1.1.2. The results from their initial test were promising.

5.1.1.2.1. *Average Intake Lifter Volume Loss* = 2.83mm^3

5.1.1.2.2. *Average Exhaust Lifter Volume Loss* = 5.82mm^3

5.1.1.3. The exhaust lifter wear for this test was incredibly high.

5.1.2. ***Repeat Test:***

5.1.2.1. Exxon attempted to repeat their initial test.

5.1.2.2. They were forced to add oil due to timing chain rattle and excessive oil consumption.

5.1.2.3. The engine experienced a camshaft lobe failure (intake lobe #2).

5.1.2.4. The lab was, however, able to run the test until completion.

5.1.2.5. This oil produced a lot of varnish on the valve deck area.

5.1.3. ***Excessive Engine Wear:***

5.1.3.1. The high oil consumption during the repeat test may have been the result of excessive engine wear from the initial test.

5.1.3.2. Could a high wear oil impact engine performance during future tests?

5.1.3.3. Oil consumption can probably be tracked to monitor this issue.

5.1.4. ***Comments from Intertek:***

5.1.4.1. IAR has an engine with (4) Precision Matrix runs and (1) proof-of-performance run.

5.1.4.1.1. The proof-of-performance run used Lubrizol's high wear formulation.

5.1.4.2. This engine could be used to better understand whether high wear oils impact engine performance.

5.1.4.3. They proposed the following options:

5.1.4.3.1. OPTION #1: Intertek can send this (5) run engine to Exxon so that they can use it to evaluate Exxon's high wear oil.

5.1.4.3.2. OPTION #2: Exxon could send Intertek their high wear oil so that Intertek can evaluate it on the (5) run engine.

5.1.5. ***Comments from Toyota:***

5.1.5.1. The Exxon stand successfully identified a poor performing oil.

5.1.5.1.1. The iron and average intake lifter volume loss both showed discrimination [as compared to the reference oils].

5.1.5.2. The Sequence IVB was designed to generate oil degradation.

5.1.5.3. Oil degradation can result in excessive wear throughout the engine.

5.2. Update from Lubrizol:

5.2.1. The repeat test at Intertek produced almost identical results to the original "poor" proof-of-performance test at Lubrizol.

5.2.2. The "poor" proof-of-performance oil does produce severe wear on the Sequence IVA test.

5.2.3. ***Initial Test at Lubrizol:***

5.2.3.1. *End of Test Iron* = 134ppm

5.2.3.2. *Average Intake Lifter Volume Loss* = 1.39mm^3

5.2.4. ***Repeat Test at Intertek:***

5.2.4.1. End of Test Iron = 147ppm

5.2.4.2. Average Intake Lifter Volume Loss = 1.53mm^3

5.2.5. ***Comments from Toyota:***

5.2.5.1. The Sequence IVA test does not have the oil degradation component of the Sequence IVB test.

5.2.5.1.1. The Sequence IVB is more like the Sequence VE in terms of degradation.

5.2.5.2. This is probably why the high wear Lubrizol oil passed the IVB but failed the IVA.

5.2.5.3. Toyota is considering an iron pass/fail limit in addition to intake lifter volume loss.

5.2.6. ***Comments from Intertek:***

5.2.6.1. The Lubrizol and Intertek tests repeated extremely well.

5.2.6.2. The iron curves for both high wear tests match the typical iron levels for the REO1012 Precision Matrix tests at IAR.

5.2.6.3. The Lubrizol oil generated slightly lower water levels than the REO1012 Precision Matrix tests at IAR.

5.2.6.4. The ICP results indicate that the Lubrizol oil has low phosphorous and zinc levels (as they have previously mentioned).

5.2.6.5. The Intertek test had a TAN-TBN cross-over at 125HRS, and the Lubrizol test had a TAN-TBN cross-over at 115HRS.

5.2.7. ***Comments from General Motors:***

5.2.7.1. GM would like to better understand how the Lubrizol high wear oil performs on a Sequence IIIG oxidation test.

5.2.7.2. The Lubrizol formulation may have a robust oil degradation package, and this could be reducing wear in the Sequence IVB.

5.2.7.3. The fundamental question is whether the Lubrizol high wear oil will fail in the field.

5.2.8. ***Comments from Toyota:***

5.2.8.1. Toyota agreed with General Motors.

5.2.8.2. A strong anti-corrosion additive package could improve wear performance in the Sequence IVB or Sequence VE.

5.2.9. ***Comments from Lubrizol:***

5.2.9.1. Is the Sequence IVB backwards compatible if its wear mechanism is different than the Sequence IVA?

5.2.10. ***Comments from Toyota:***

5.2.10.1. REO1006-2 is a "borderline" oil on the Sequence IVA test and a "good" oil on the Sequence VE test.

5.2.10.1.1. So, there is clearly a disconnect in oil performance between the two tests.

5.2.10.2. Toyota chose to pursue a test that is more like the Sequence VE when they began development of the Sequence IVB.

5.3. Update on 3rd "Poor" Proof-of-Performance Oil:

5.3.1. IAR ran a 3rd high wear oil on one of their Precision Matrix stands.

5.3.2. This oil had a 0W-16 viscosity and was formulated specifically to generate high wear on the Sequence IVB (much like the Exxon high wear oil).

5.3.2.1. Phosphorous and zinc were in the 300-400ppm range.

5.3.3. ***Results:***

5.3.3.1. *Average Intake Lifter Volume Loss* = 2.12mm3

5.3.3.2. *Average Exhaust Lifter Volume Loss* = 1.09mm3

5.3.3.3. The end-of-test iron was higher than it was for the REO300 Precision Matrix tests at IAR.

5.3.3.4. The [unnamed] sponsor of this test was expecting a higher intake lifter volume loss result.

5.3.4. ***Comments from General Motors:***

5.3.4.1. This high wear oil must have a robust anti-oxidant package like the Lubrizol high wear oil.

5.4. Discussion about Proposed Iron Pass/Fail Parameter:

5.4.1. ***Comments from Afton:***

5.4.1.1. Iron can sometimes be a difficult parameter to use because its concentration is related to oil consumption.

5.4.2. The statisticians stated that iron is the "least significant" of the parameters that they analyzed.

5.4.3. Toyota stated that the iron limit can be discussed later.

5.4.4. ***Comments from Intertek:***

5.4.4.1. The Surveillance Panel could add an engine hour correction factor to the iron parameter.

5.4.4.2. The iron pass/fail limit would be a threshold value.

5.5. Camshaft Lobe Failures:

5.5.1. Toyota would like to include camshaft lobe failures as a pass/fail criterion for the Sequence IVB.

5.5.1.1. A passing test must have no camshaft lobe failures.

5.5.2. ***Comments from Afton and Exxon:***

5.5.2.1. How will a lab differentiate between a mechanically-induced lobe failure and a formulation-induced lobe failure?

5.5.2.2. How will lobe failures be measured?

5.5.2.2.1. Will the heel-to-toe distance be used?

5.5.2.3. What happens if a lab catches a lobe failure before it becomes catastrophic?

5.5.3. IAR and Lubrizol agree that lobe failures need to be more clearly defined.

5.5.4. The consensus during the meeting was that more work needs to be done before lobe failures can be considered as a pass/fail parameter.

6. ACTION ITEMS AND MOTIONS:

6.1. Action Items Identified by Surveillance Panel Chair:

6.1.1. This action item list was compiled during the 03-01-2018 and 03-07-2018 conference calls.

6.1.2. ***ACTION ITEM #1***: The Surveillance Panel is to further review the four anomalous operational parameters identified by Lubrizol (AFR, exhaust gas temperature, crankcase pressure and intake manifold pressure).

6.1.3. ***ACTION ITEM #2:*** The statisticians are to perform an analysis on AFR, exhaust gas temperature, crankcase pressure and intake manifold pressure ramps.

6.1.3.1. The goal is to determine whether these ramps correlate to test severity.

6.1.4. ***ACTION ITEM #3:*** Lubrizol is to provide additional information to the Surveillance Panel regarding the anti-oxidant package in its "poor" proof-of-performance oil.

6.1.4.1. Are there any Sequence IIIG test results available for this formulation?

6.1.5. ***ACTION ITEM #4:*** IAR is to request additional information from the sponsor of the 2.12mm^3 high wear candidate oil.

6.1.5.1. This information will be provided to the Surveillance Panel.

6.1.6. ***ACTION ITEM #5:*** The statisticians are to perform an analysis of oil discrimination with respect to iron.

6.1.6.1. End-of-test iron and the rate-of-change of iron during the test will both be considered.

6.1.6.2. Results from the 2nd Precision Matrix will be used.

6.1.7. ***ACTION ITEM #6:*** The statisticians are to investigate the viability of an engine hour correction for iron.

6.1.7.1. End-of-test iron and the rate-of-change of iron during the test will both be considered.

6.1.7.2. Results from the 2nd Precision Matrix will be used.

6.1.8. ***ACTION ITEM #7:*** The Surveillance Panel is to clearly define a camshaft lobe failure.

6.1.8.1. This definition needs to be added to the Sequence IVB draft procedure.

6.1.9. ***ACTION ITEM #8:*** The TMC is going to investigate whether reference oil suppliers will be willing to provide new and used calcium data for REO300, REO1012 and REO1011.

6.1.10. ***ACTION ITEM #9:*** The reference oil calcium data will be provided to the statisticians for analysis (pending approval by the TMC).

6.1.11. ***ACTION ITEM #10:*** The statisticians are to develop an LTMS system for the Sequence IVB test.

6.1.12. ***ACTION ITEM #11:*** The Surveillance Panel will review (and eventually vote to approve) the proposed LTMS system.

6.1.13. ***ACTION ITEM #12:*** The Surveillance Panel will review and update Appendix K for the Sequence IVB Test.

6.2. Motion to Approve the Sequence IVB Test:

6.2.1. There was a lot of debate regarding the wording of this motion.

6.2.2. ***FINAL MOTION:*** "The Sequence IV Surveillance Panel, having secured hardware supply, test fuel and reference oils for a test procedure that measures the performance of passenger car motor oil for low temperature engine wear, recommends to the Passenger Car Engine Oil Classification Panel, the Auto Oil Advisory Panel and the American Chemistry Council that the Sequence IVB test is ready for inclusion in ILSAC GF-6 and that the Sequence IVB procedure be published as an ASTM method. Realizing that the test parameters (AVLI and Fe content) need to be finalized and the LTMS still needs to be developed."

6.2.3. This motion was made by Toyota and seconded by Ford.

6.2.4. ***The motion passed:*** 11 approvals, 2 negatives, 8 waives

6.2.5. ***Approving votes:*** OHT, IAR, General Motors, Toyota, TEI, Total, Haltermann, Honda, Ford, Nissan and Chrysler

6.2.6. ***Negative votes:*** Lubrizol and BP

Action Items	Person responsible	Completion Date

Follow-up Notes/Updates	Initials	Date Added

Attendees	Organization	Contact Information

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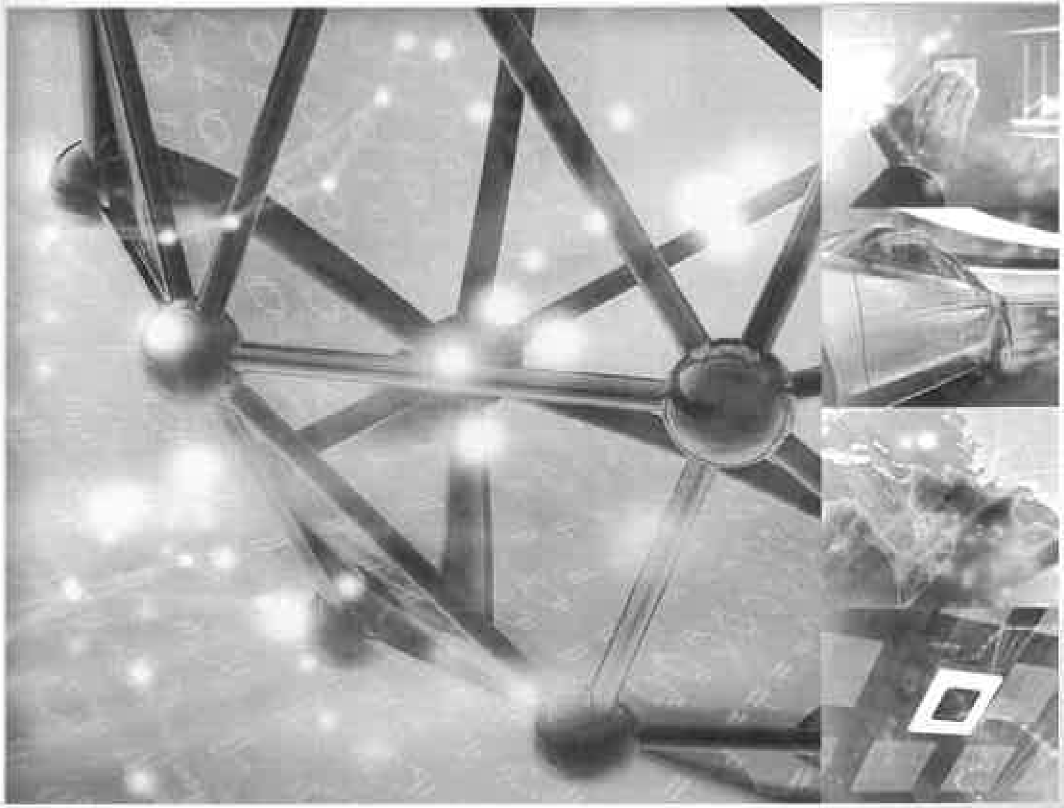


IVB Results on Lubrizol's "Poor" Wear Oil

March 2018

IVB Poor Prove of Performance Study: Oil Selection

SUCCESS TOGETHER

- Oil selected for IVB "Poor" Proof of Performance is a GF-5/SN formulation type with reduced ZDP and FM removed.
- It is a baseline formulation used to evaluate anti-wear components
- Study was run the Seq IVA
- It is a 5W-20, blended in a conventional Gp II base stock with OCP VM.

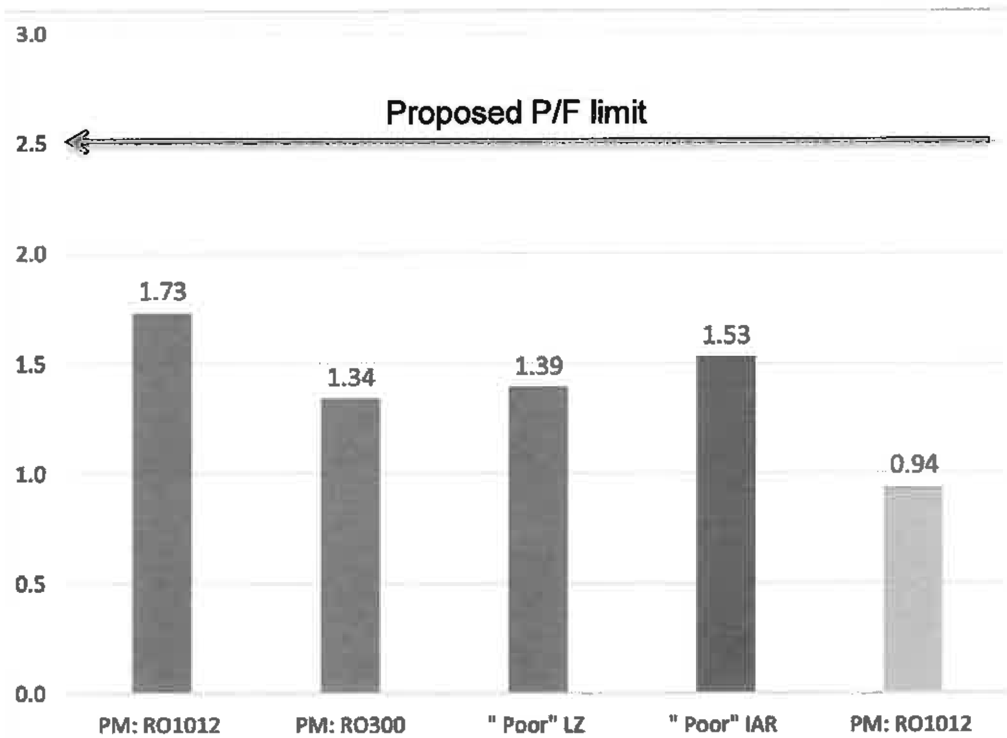
Oil Property	Result
KV 100	8.91cSt
HTHS	2.7cP
CCS (-30)	5849 cP
BOV	~4.5 cSt
% P	300 ppm
Seq IVA Result	256.07 µm

The oil has demonstrated poor VTW in the Seq IVA and Per our statistical Seq VE model, is predicted to fail both Max and Avg Cam Wear

Lubrizol

"Poor" Proof-of-Performance Oil vs. Lubrizol's Precision Matrix Oils
Average Intake Lifter Volume Loss

SUCCESS TOGETHER



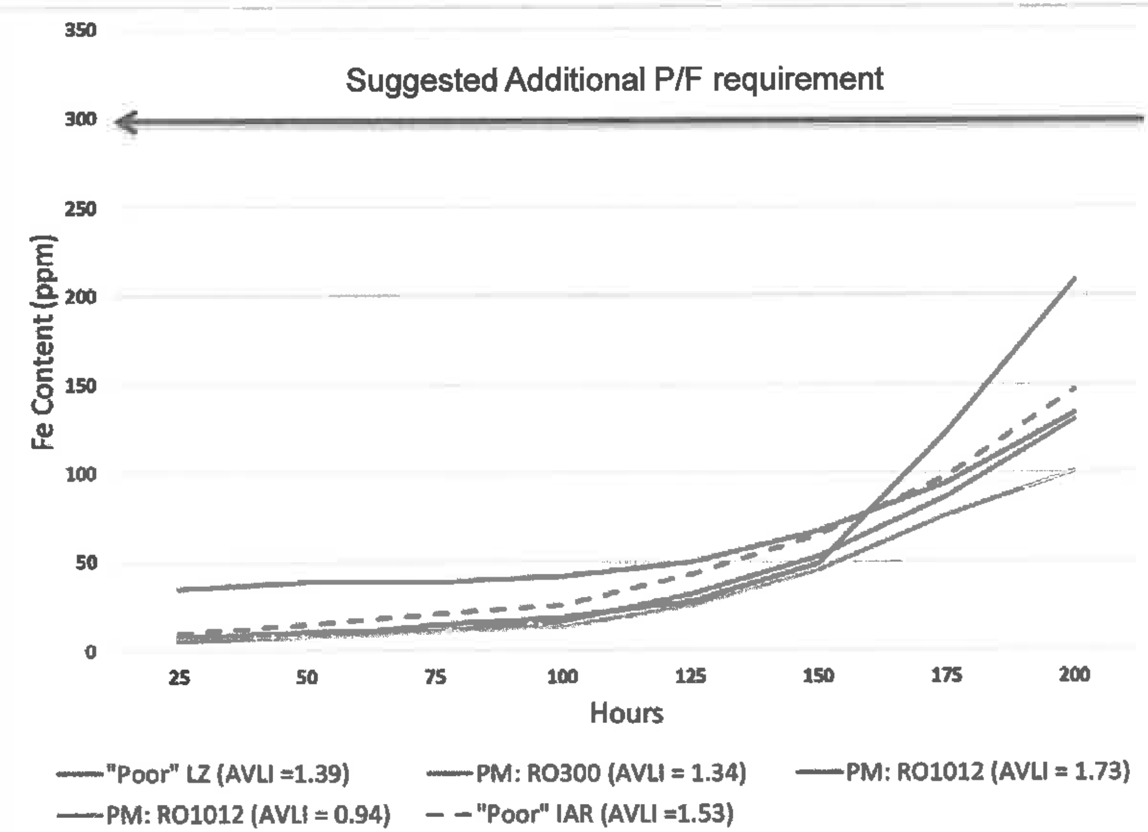
Lubrizol oil was originally run at our lab in the same stand as our matrix oils. It was subsequently repeated at Intertek. The results align and fall between our repeat matrix results on RO1012 (the original "Good" oil)

Note: As the test is currently defined, all Lubrizol matrix runs were considered to by operationally valid by the Surveillance Panel

Lubrizol

"Poor" Proof-of-Performance Oil vs. Lubrizol's Precision Matrix Oils
Drain Iron (new P/F Parameter proposed Mar 7)

SUCCESS TOGETHER



On the March 7 Seq VI Surveillance Panel call an additional P/F wear parameter was suggested – EOT Drain Fe. Lubrizol's "Poor" Wear Oil comfortably meets this target.

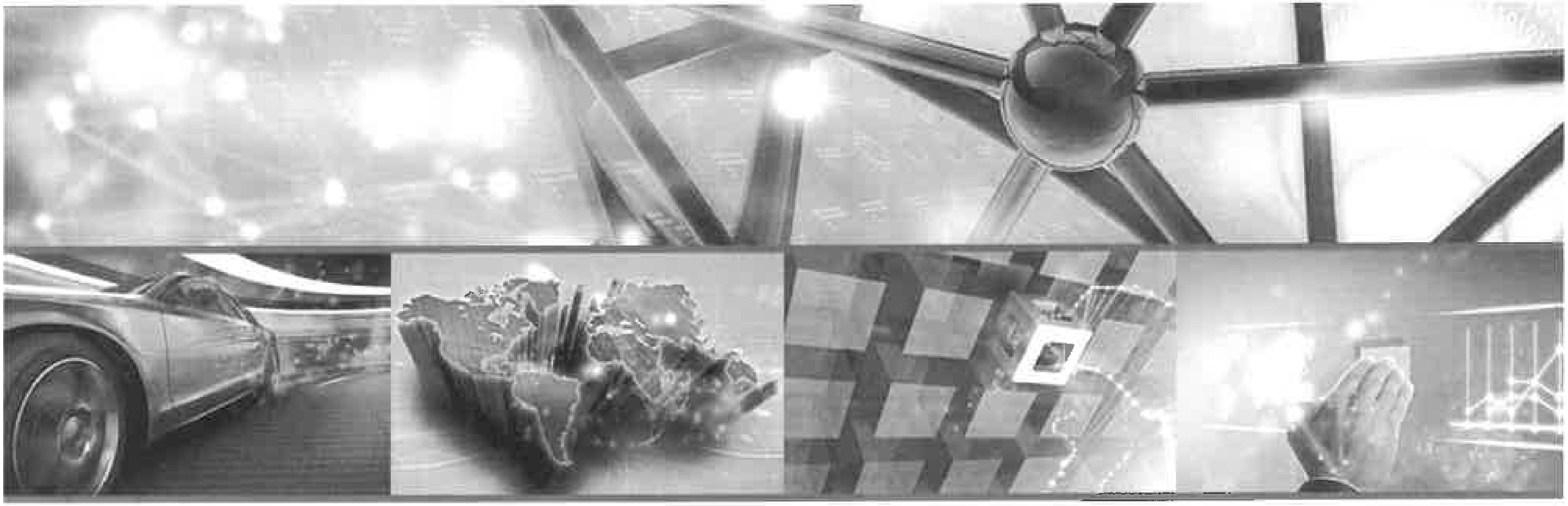
Lubrizol

Why Lubrizol voted Negative at the Surveillance Panel (SP)

SUCCESS TOGETHER

- The Surveillance Panel needs more time to consider key developments introduced during today's meeting, particularly the addition of end-of-test iron as a pass/fail parameter.
- Concerns identified by the Statistician Group (and documented in their 01-25-2018 report) about the Precision Matrix have not been addressed:
  - Discrimination is not consistent among stands.
  - Different stands rank oils differently.
  - Variability is large compared to the observed range of measurements.
  - LTMS would likely allow for the calibration of stands that do not discriminate between oils.
  - The statistical separation between REO300 and REO1012 is driven by two test results at a single lab.
- It is still unclear why two of the three high-wear proof-of-performance oils (one submitted by Lubrizol and the other submitted by an unnamed oil marketer or additive company) delivered what would likely be "passing" IVB results.
  - The Lubrizol oil was run at both Lubrizol and Intertek and delivered intake lifter wear and end-of-test iron results similar to REO1012.
  - The speculation that these two oils performed well (on the IVB test) because of their resistance to oil degradation should be confirmed.
- There are four operational parameters that have shown significant stand-to-stand or lab-to-lab differences during the past five operational data reviews: AFR, crankcase pressure, exhaust gas temperature and intake manifold pressure.
  - No corrective action has been taken to mitigate these differences (although the variability in exhaust gas temperature may be the result of measurement hardware).
  - The Statistician Group identified the Top-20 test parameters that correlate to test severity in their 02-14-2018 report.
  - The Top-3 parameters involve camshaft metrology measurements.
  - None of these three parameters have been specifically discussed by the Surveillance Panel.

Lubrizol



SUCCESS
TOGETHER

Working together, achieving great things

When your company and ours combine energies, great things can happen. You bring ideas, challenges and opportunities. We'll bring powerful additive and market expertise, unmatched testing capabilities, integrated global supply and an independent approach to help you differentiate and succeed.

Lubrizol

ExxonMobil

March 5th, 2018

ExxonMobil Sequence IVB Test Development - High Wear Oil

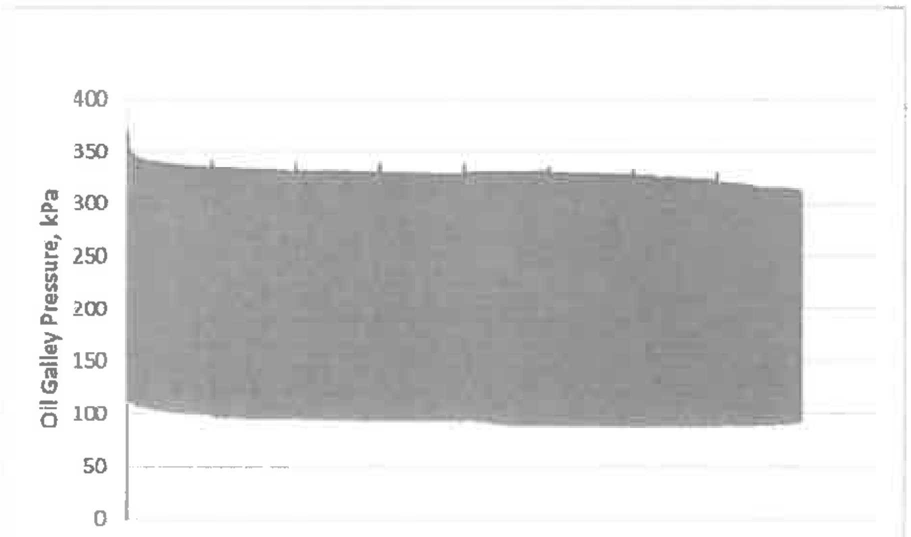
Clifford Salvesen
Paulsboro Technology Center

ProveOut/Precision Matrix Data

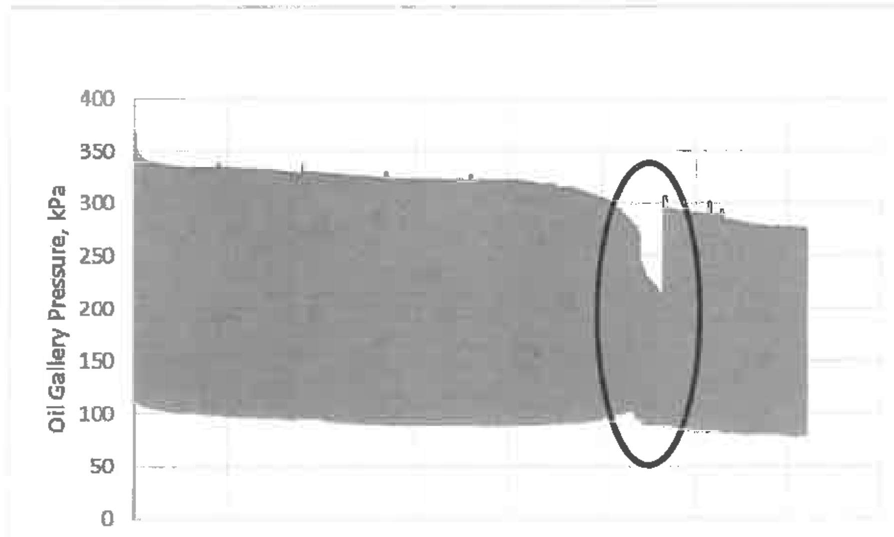
	Oil	Intake Wear mm^3	Exhaust Wear mm^3	Intake Mass Loss g	Exhaust Mass Loss g	EOT Iron ppm
ProveOut 1	300	1.53	N/A			176
ProveOut 2	1012	1.31	N/A			108
PrecisionMatrix 1	1012	1.81	N/A	20.1	8.6	212
PrecisionMatrix 2	1011	1.84	.93	15.7	9.6	154
PrecisionMatrix 3	1011	2.03	1.10	20.4	11.3	186
PrecisionMatrix 4	300	1.81	0.85	18.1	8.8	173
HighWearOil 1	HW1	2.83	5.82	24.81	49.25	699
HighWearOil 2	HW1	1.89	2.84	15.95	28.98	416

Differences between High Wear Oil Runs – Oil Pressure

High Wear Oil Test 1



High Wear Oil Test 2

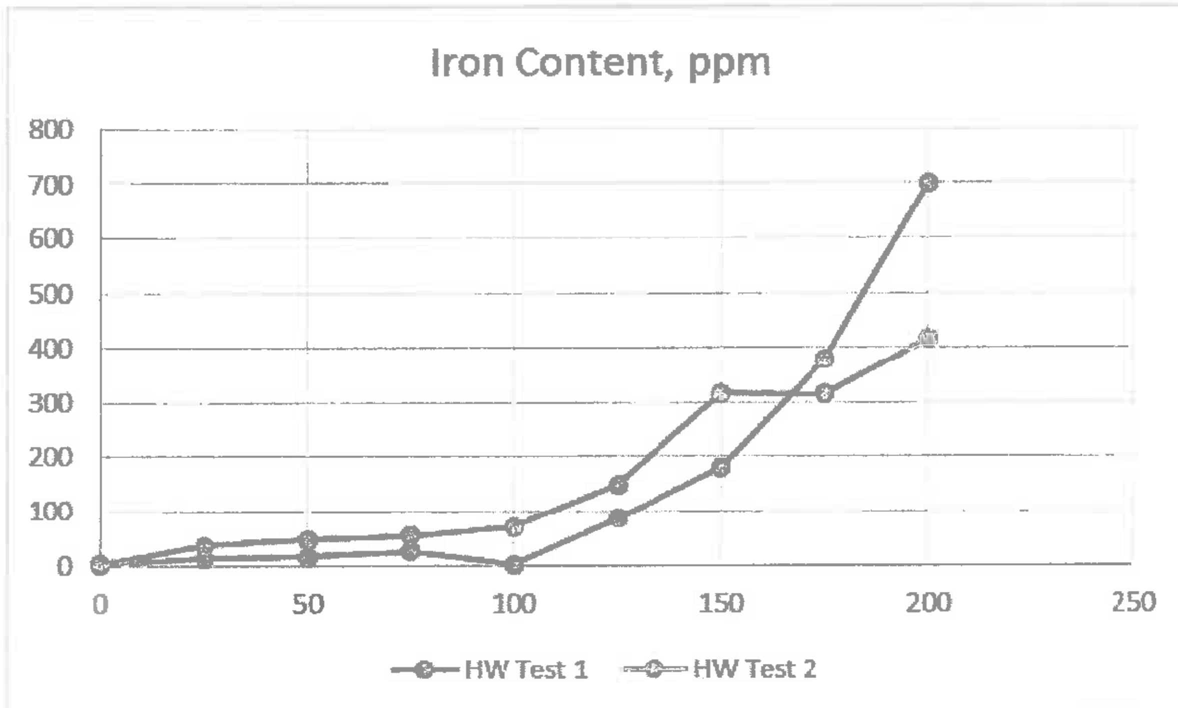


Timing chain rattle and low oil pressure observed at 171 hours, oil topped up (800 mL) and pressure returned to normal

ExxonMobil

Iron Content Comparison

Hour	HW Test 1	HW Test 2
0	1	2
25	12	36
50	16	48
75	25	55
100	1	71
125	87	148
150	180	316
175	378	314
200	699	416



Differences between High Wear Oil Runs – Oil Pressure

From procedure:

11.4.1 Optional *oil level procedure*— After 200 h of test operation and the final oil sample, allow the engine to run at stage 1 conditions for 10 min before shutting down. Let the engine rest turned off for 10 min and then measure the end-of-test oil level using the OHT IVB dipstick (see Fig. 10) inserted into the side of the oil pan.

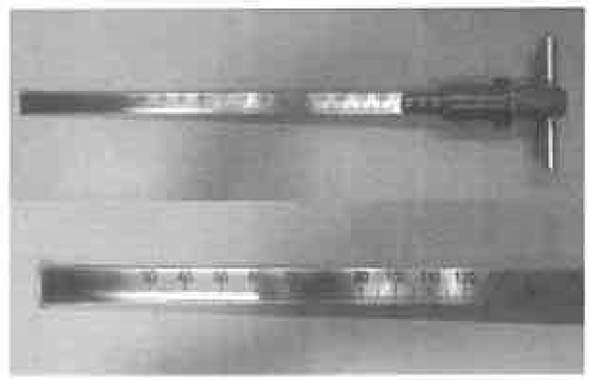


Figure 10

High Wear Oil Test 1

EOT Dipstick Level: 55

Total Oil Consumption: 684g

High Wear Oil Test 2

Hour 171 Dipstick Level:	42
Hour 171 Post 800mL Addition:	70
EOT Dipstick Level:	44
Total Oil Consumption:	1470g

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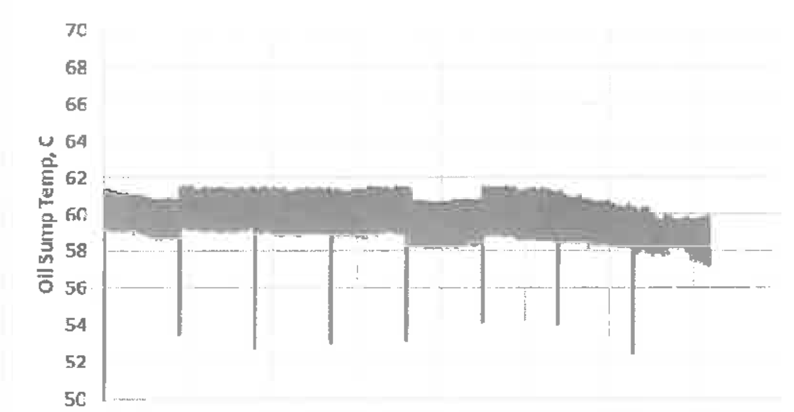
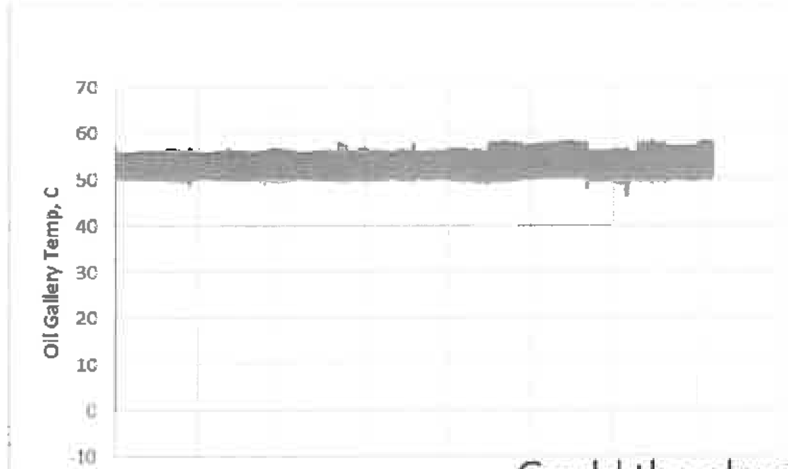
Differences between High Wear Oil Runs – Oil Temps

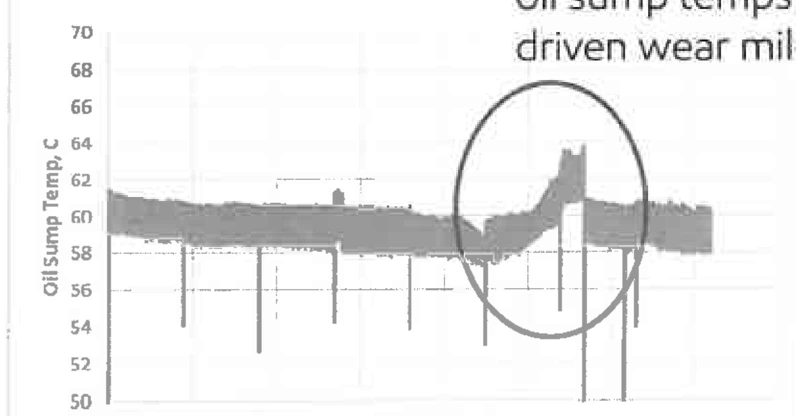
High Wear Oil Test 1



High Wear Oil Test 2



Could the elevated oil sump temps have driven wear mild?



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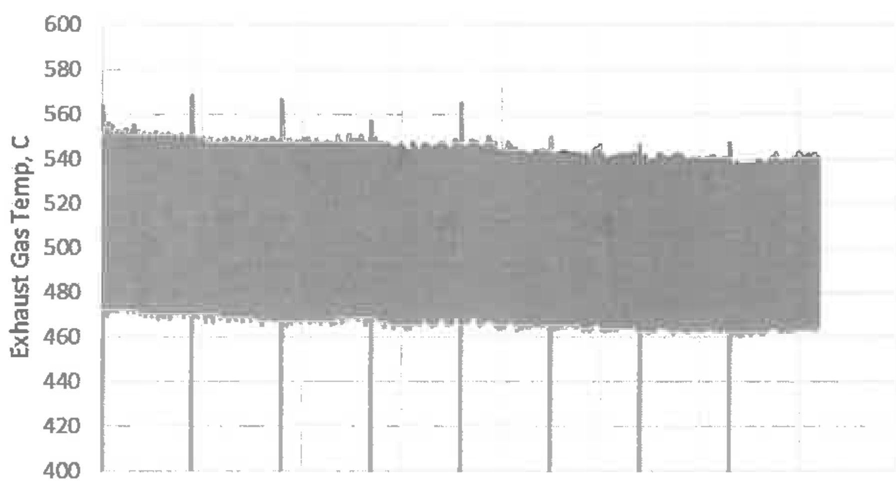
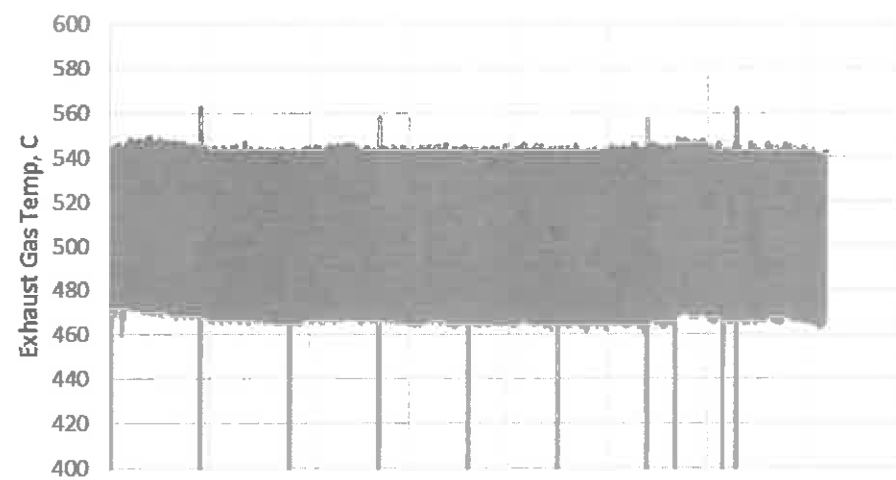
Differences between High Wear Oil Runs – Exhaust Temp

High Wear Oil Test 1



High Wear Oil Test 2



No large exhaust temp differences observed

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Differences between High Wear Oil Runs - QIs

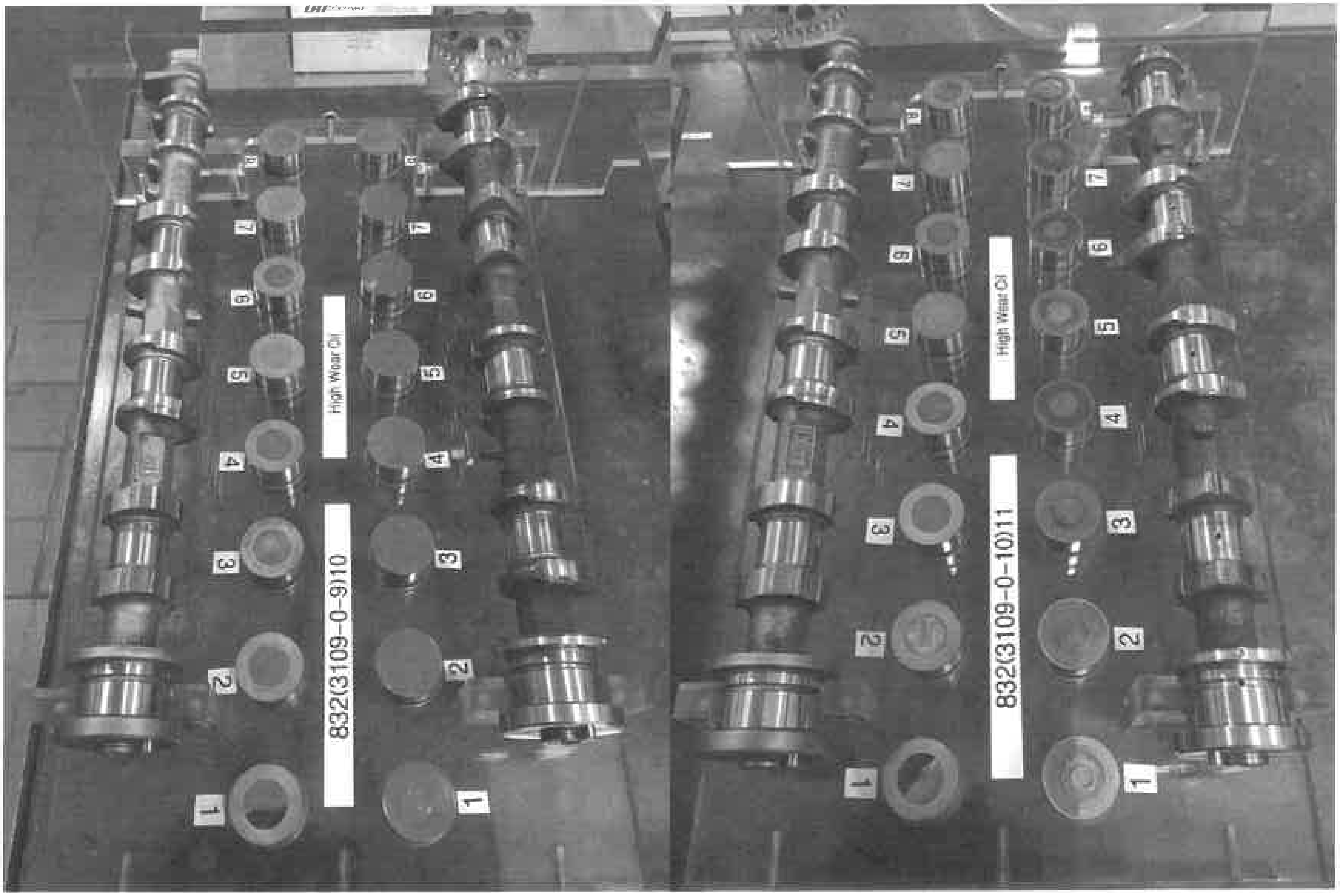
High Wear Oil Test 1

Parameter	Units	QI Threshold	EOT QI
Speed	r/min	0.000	Pending
Torque	n·m	0.000	0.745
Engine Oil Gallery	°C	0.000	0.802
Engine Coolant Out	°C	0.000	0.793
Engine Coolant Flow	L/min	0.000	0.939
Engine Coolant Pressure	kPa	0.000	0.7870
RAC Coolant Out	°C	0.000	1.0
Load Cell	°C	0.000	0.9600
RAC Flow	L/min	0.000	0.7
Intake Air	°C	0.000	0.895
Intake Air Pressure	kPa	0.000	0.986
Intake Air Humidity	g/kg	0.000	0.922
Fuel Rail Temperature	°C	0.000	0.698
Blowby Gas	°C	0.000	0.869
Fuel Rail Pressure	kPa	0.000	0.910
Exhaust Backpressure	kPaA	0.000	-0.605

High Wear Oil Test 2

Parameter	Units	QI Threshold	EOT QI
Speed	r/min	0.000	Pending
Torque	n·m	0.000	0.740
Engine Oil Gallery	°C	0.000	0.823
Engine Coolant Out	°C	0.000	0.805
Engine Coolant Flow	L/min	0.000	0.925
Engine Coolant Pressure	kPa	0.000	0.865
RAC Coolant Out	°C	0.000	992
Load Cell	°C	0.000	0.9600
RAC Flow	L/min	0.000	0.701
Intake Air	°C	0.000	0.971
Intake Air Pressure	kPa	0.000	0.987
Intake Air Humidity	g/kg	0.000	0.932
Fuel Rail Temperature	°C	0.000	0.919
Blowby Gas	°C	0.000	0.951
Fuel Rail Pressure	kPa	0.000	0.885
Exhaust Backpressure	kPaA	0.000	-0.665

Photos from EOT - Valvetrain



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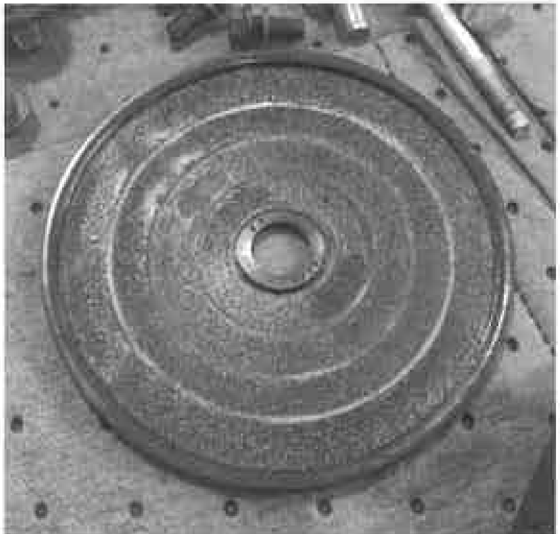
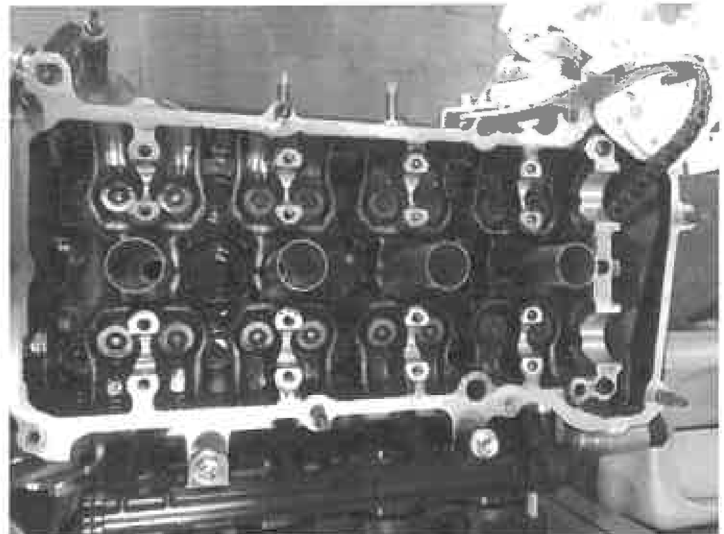
Both runs are Batch C Intake, and Batch D Exhaust hardware

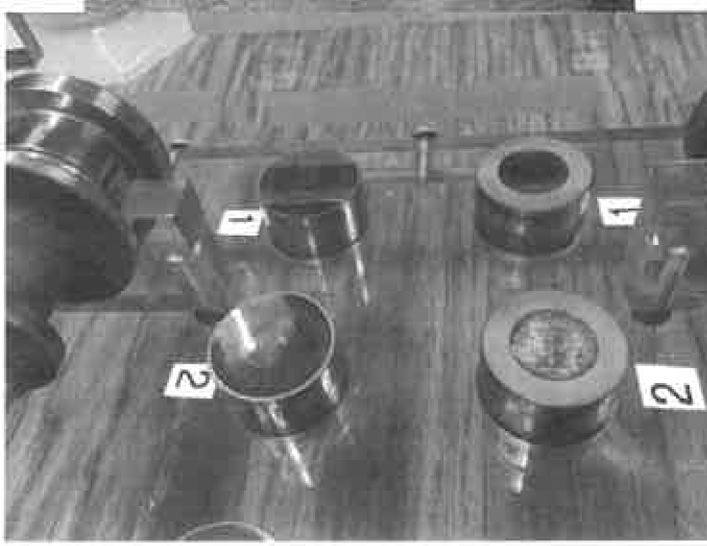
Photos from EOT Test 2

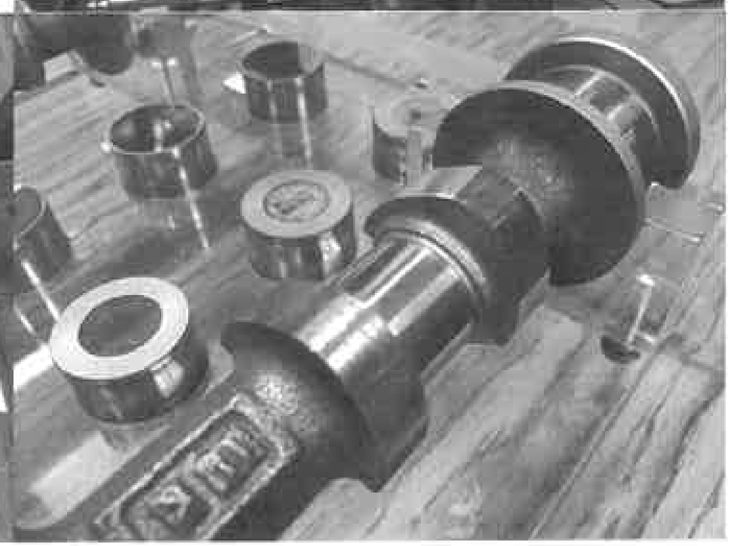
Filter and Valve Deck



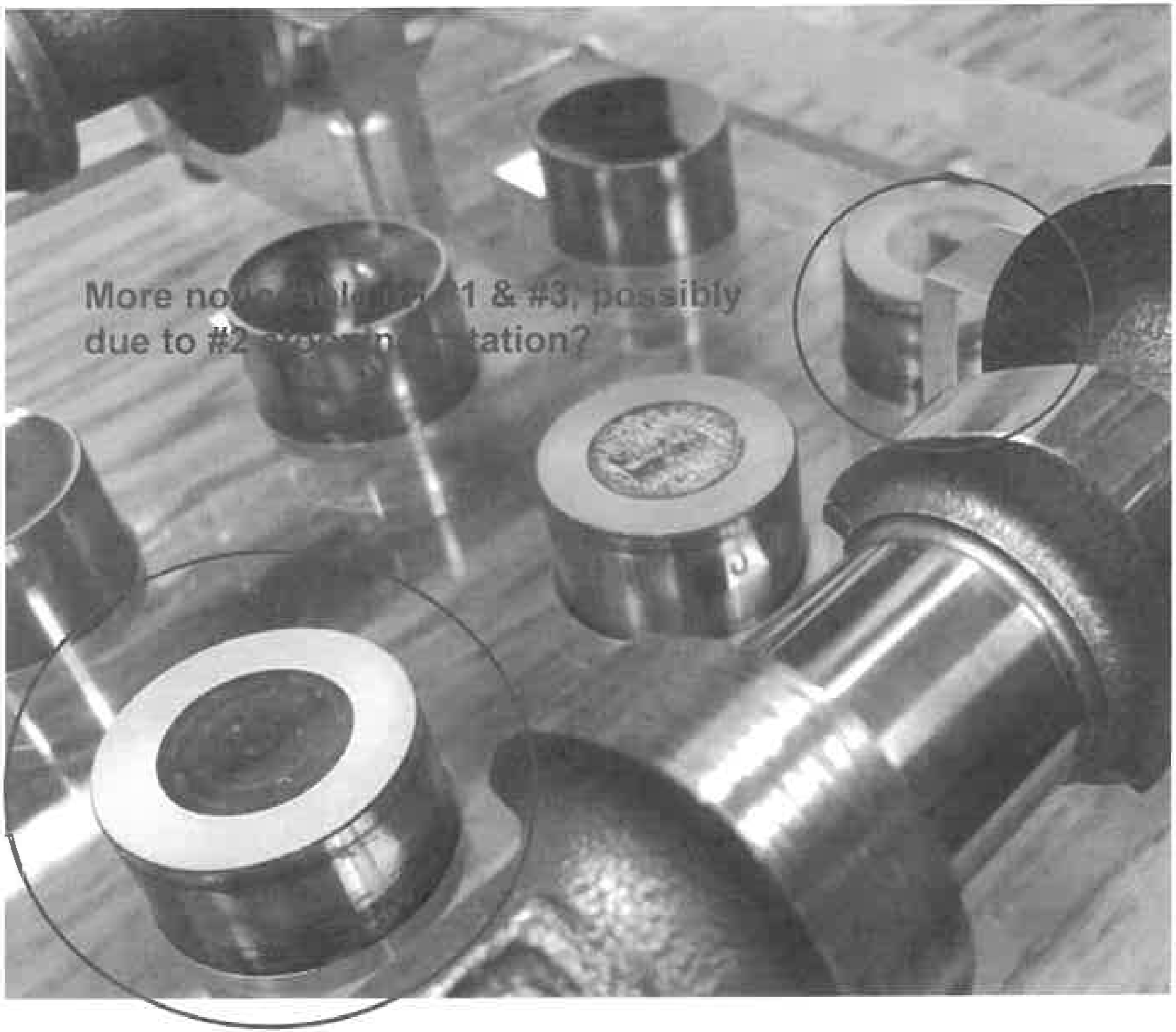


Lifters and Cam Lobe (Square markers and lobe wear on Intake position #2)





Photos from EOT Test 2 – Lifter Side Varnish



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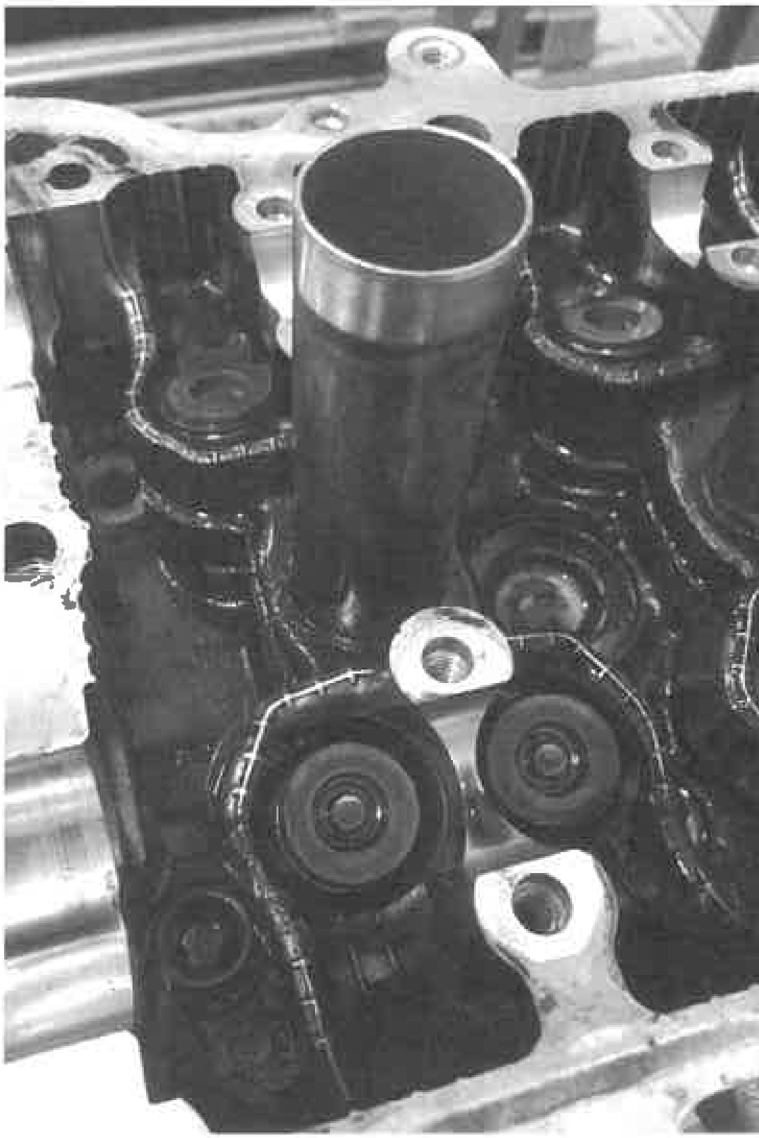
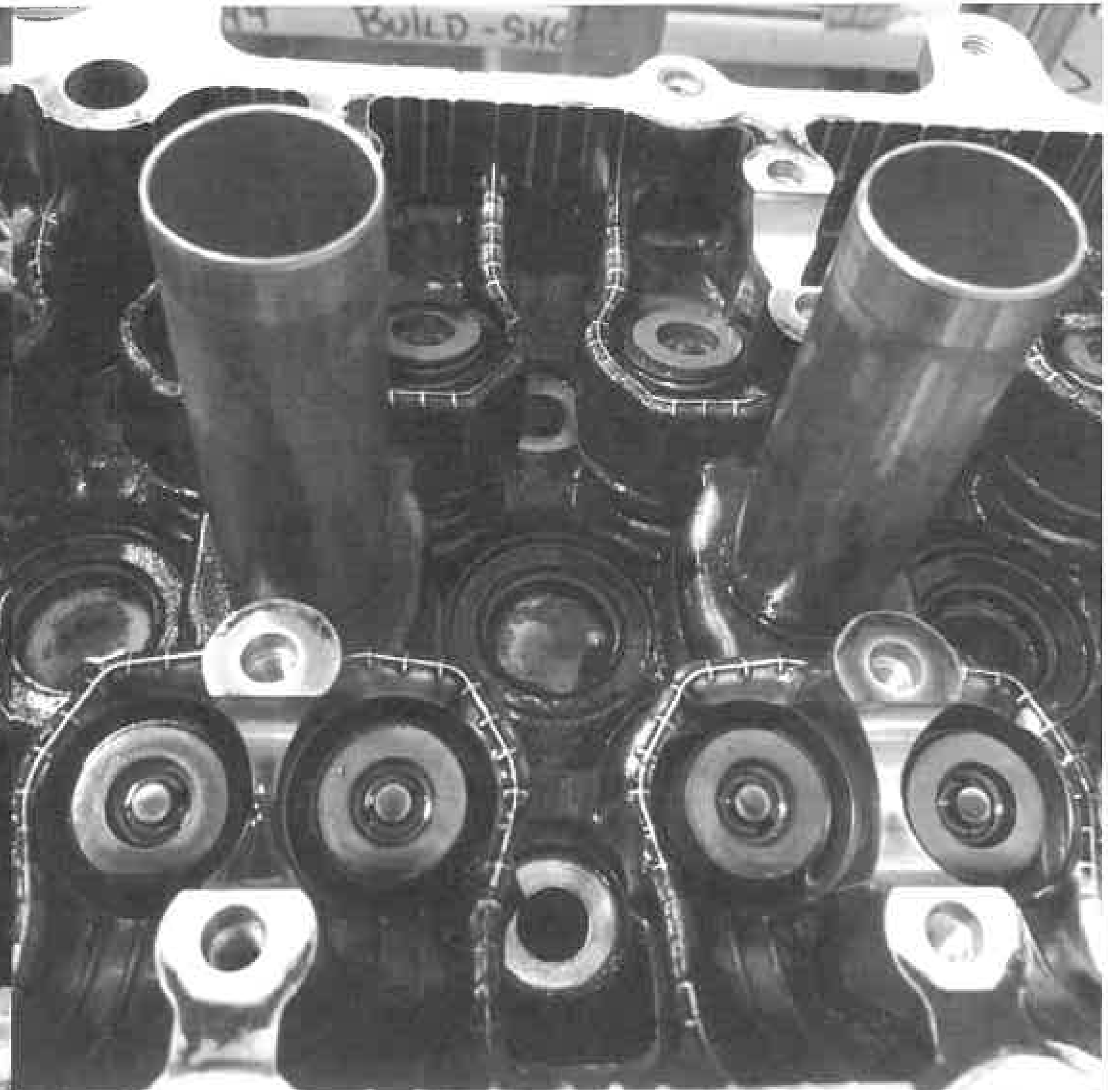
Photos from EOT Test 2 – Cylinder Head





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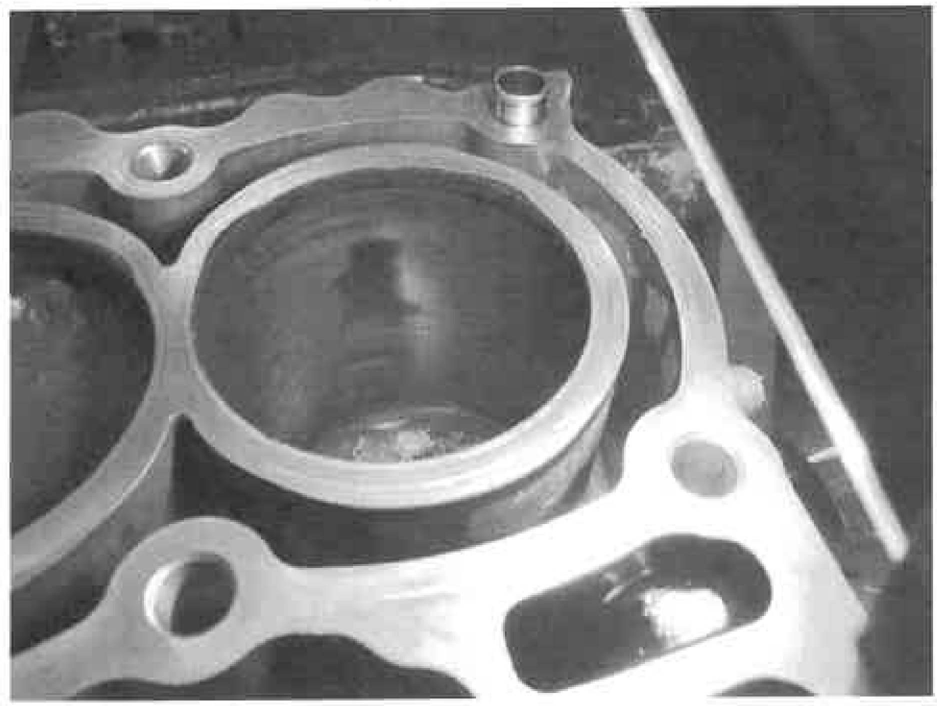
Photos from EOT Test 2– Cylinder Bores

Cylinder 1

Cylinder 4



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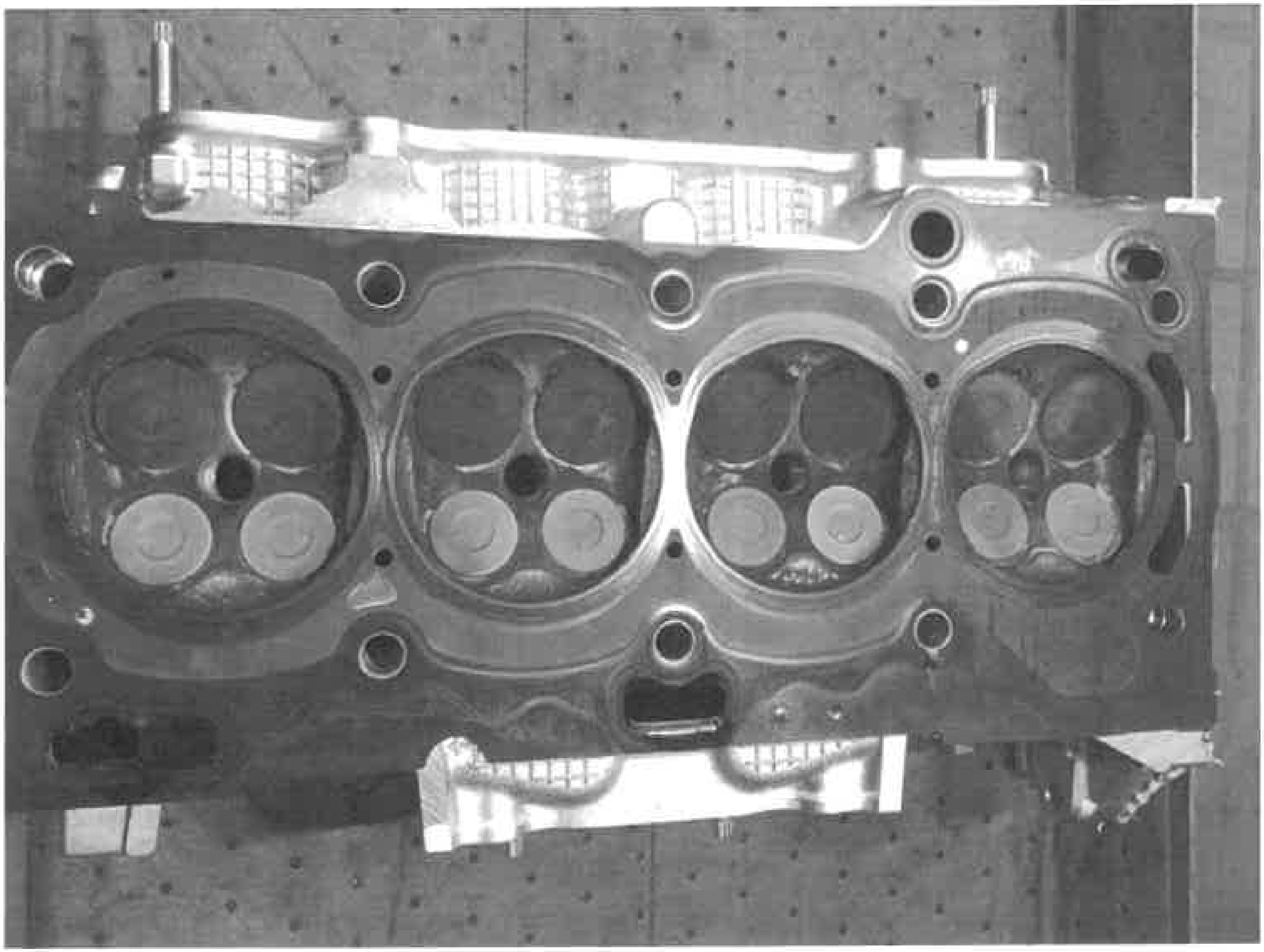
Photos from EOT Test 2– Combustion Chambers



Sequence IV Surveillance Panel

Conference Call
March 7, 2018
8:00 a.m. - 12:00 p.m.

AGENDA

1. Chairman comments
2. Membership changes
3. Feedback on Sequence IVB Precision Matrix 2 statistical analysis: correlation analysis and conclusions
4. Feedback on Sequence IVB Precision Matrix 2 1-hour operational data analysis (10–11, 101–102 and 195–196 hour plots)
5. Sequence IVB Precision Matrix 2 ramps operational data analysis
6. Sequence IVB Precision Matrix 2 200-hour operational data analysis (JMP plots)
7. Sequence IVB Precision Matrix 2 statistical analysis review:
   - Analysis and conclusions only including independent Labs (N = 21)
8. Sequence IVB high wear candidate oil results review
9. Vote on recommendation to the PCEOCP and AOAP to accept the Sequence IVB test for use in ILSAC GF-6
10. Motion and action item review
11. Next meeting
12. Adjourn

MEMBERSHIP
SEQUENCE IV SURVEILLANCE PANEL

March 7, 2018

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SEQUENCE IV SURVEILLANCE PANEL

March 7, 2018

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SEQUENCE IV SURVEILLANCE PANEL

March 7, 2018

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SEQUENCE IV SURVEILLANCE PANEL

March 7, 2018

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SEQUENCE IV SURVEILLANCE PANEL

March 7, 2018

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SEQUENCE IV SURVEILLANCE PANEL

March 7, 2018

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March 7, 2018

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NON-MEMBER MAILING LIST
SEQUENCE IV SURVEILLANCE PANEL

March 7, 2018

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NON-MEMBER MAILING LIST
SEQUENCE IV SURVEILLANCE PANEL

March 7, 2018

NAME	COMPANY-ADDRESS-PHONE-FAX-EMAIL	SIGNATURE
THOM SMITH	VALVOLINE Phone No.: Fax No.: Email:	✓
ANGELA WILLIS	GM Phone No.: Fax No.: Email:	✓
SCOTT LINDHOLM	SHELL Phone No.: Fax No.: Email:	✓
JOSH FREDERICK	VALVOLINE Phone No.: Fax No.: Email:	✓
	Phone No.: Fax No.: Email:	
	Phone No.: Fax No.: Email:	
	Phone No.: Fax No.: Email:	
	Phone No.: Fax No.: Email:	

Sequence IV Surveillance Panel
March 7, 2018
8:00AM – 12:00PM
<u>Conference Call</u>

Motions and Action Items
As Recorded at the Meeting by Bill Buscher

1. Action Item – Sequence IV surveillance panel, or a sub-group of the surveillance panel, to further review four operational data parameters identified by Lubrizol, including AFR, exhaust gas temperature, crankcase pressure and intake manifold pressure.

2. Action Item – SG to repeat the statistical correlation analysis, which was performed on engine speed ramps, on AFR, exhaust gas temperature, crankcase pressure and intake manifold pressure.

3. Action Item – Lubrizol to investigate the anti-oxidant additive package and/or other aspects of their high wear IVA oil, and to check to see if any Sequence IIIG data exists for this oil, and report back to the surveillance panel.

4. Action Item – Intertek to request the same information from the supplier of the 2.12 mm^3 AVLI high wear candidate oil, and have it reported back to the surveillance panel.

5. Action Item – SG to perform a statistical analysis for oil discrimination, on the Fe at EOT and Fe rate of change data from Precision Matrix 2

6. Action Item – SG to perform a statistical correlation analysis of Fe at EOT and Fe rate of change to engine hours/runs, using the Precision Matrix 2 data sets.

7. Action Item – Surveillance panel to define what a lobe failure is and add this information to the Sequence IVB draft procedure.

8. Action Item – The TMC to investigate the acceptability or request approval from the reference oil suppliers to gather and distribute new and

used oil calcium data from the Sequence IVB Precision Matrix 2 reference oils.

9. Action Item – If deemed acceptable, the surveillance panel chair to request and gather the calcium data from Precision Matrix 2, then provide this data to the SG for statistical analysis.

10. Action Item – SG to develop an LTMS for the Sequence IVB test.

11. Action Item – Surveillance panel to review and approve an LTMS for the Sequence IVB test.

12. Action Item – Surveillance panel to review and update Appendix K for the Sequence IVB test.

13. Motion – The Sequence IV Surveillance Panel, having secured hardware supply, test fuel and reference oils for a test procedure that measures the performance of passenger car motor oil for low temperature engine wear, recommends to the Passenger Car Engine Oil Classification Panel, the Auto Oil Advisory Panel and the American Chemistry Council that the Sequence IVB test is ready for inclusion in ILSAC GF-6 and that the Sequence IVB procedure be published as an ASTM method. Realizing that the test parameters (AVLI and Fe content) need to be finalized and the LTMS still needs to be developed.
    Teri Kowalski / Ron Romano / Passed 11 – 2 – 8

MOTION

MEMBERSHIP
SEQUENCE IV SURVEILLANCE PANEL

March 7, 2018

NAME	COMPANY-ADDRESS-PHONE-FAX-EMAIL	SIGNATURE
Bowden, Jason	OH Technologies, Inc. 9300 Progress Parkway P.O. Box 5039 Mentor, OH 44061-5039 Phone No.: 440-354-7007 Fax No.: 440-354-7080 Email: jhbowden@ohtech.com	YES
Buscher III, William	Intertek Automotive Research 5404 Bandera Road San Antonio, TX 78238 Phone No.: 210-647-9489 or 210-240-8990 cell Fax No.: 210-684-6074 Email: william.buscher@intertek.com	YES
~~Buscher, Jr., William~~	~~Buscher Consulting Services P.O. Box 112 Hopewell Jct., NY 12533 Phone No.: 914-897-8069 Fax No.: 914-897-8069 Email: buschwa@aol.com~~	
Grundza, Rich	ASTM Test Monitoring Center 6555 Penn Avenue Pittsburgh, PA 15206 Phone No.: 412-365-1031 Fax No.: 412-365-1047 Email: reg@astmtmc.cmu.edu	WAIVE
~~Hopp, Meryn~~ ANGELA WILLIS	GM Powertrain Mail Code 483-730-322 823 Joslyn Rd. Pontiac, MI 48340-2920 Phone No.: 228-318-7303 Fax No.: Email: Meryn.hopp@gm.com	YES
~~Hosseini, Mahboobeh~~ ROBERT STOCKWELL	Chevron Oronite Company LLC 100 Chevron Way, 71-7548 P.O. Box 1627 Richmond, CA 94802-0627 Phone No.: 510-242-3462 Fax No.: Email: Mahboob.Hosseini@chevron.com	WAIVE
~~Hsu, Jeffery~~ SCOTT LINDHOLM	Shell Global Solutions 3333 Highway 6 South Houston, TX 77082 Phone No.: 281-544-8619 Fax No.: 281-544-8150 Email: j.hsu@shell.com	WAIVE
Kowalski, Teri	Toyota Motor North America, Inc. 1555 Woodridge Ann Arbor, MI 48105 Phone No.: 734- 995-4032 or 734-355-8082 cell Fax No.: 734- 995-9049 Email: teri.kowalski@tema.toyota.com	YES

MEMBERSHIP
SEQUENCE IV SURVEILLANCE PANEL

March 7, 2018

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~~Overaker, Mark~~ PRASAD TUMATI	Haltermann Solutions 15635 Jacintoport Blvd. Houston, TX 77345 Phone No.: 832-376-2202 Fax No.: Email: mhoveraker@jhaltermann.com	YES
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Proctor, Robert	Honda R&D Americas, Inc. Phone No.: 937-309-9321 Fax No.: Email: rproctor@oh.hra.com	YES
Rais, Khaled	Southwest Research Institute 6220 Culebra Road P.O. Drawer 28510 San Antonio, TX 78228-0510 Phone No.: 210-522-3842 Fax No.: 210-684-7523 Email: khaled.rais@swri.org	WAIVE
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MEMBERSHIP
SEQUENCE IV SURVEILLANCE PANEL

March 7, 2018

NAME	COMPANY-ADDRESS-PHONE-FAX-EMAIL	SIGNATURE
Romano, Ron	Ford Motor Company 1800 Fairlane Drive Allen Park, MI 48101 Phone No.: 313-845-4068 Fax No.: 313-323-8042 Email: rromano@ford.com	YES
Sagawa, Takumaru	Nissan Motor Co., Ltd. 560-2, Okatsukoku, Atsugi city Kanagawa 243-0192 Phone No.: 046-270-1515 Fax No.: 046-270-1585 Email: t-sagawa@mail.nissan.co.jp	YES
Salvensen, Cliff	ExxonMobil Research & Engineering Co. 600 Billingsport Road P.O. Box 480 Paulsboro, NJ 08066-0480 Phone No.: 856-224-2954 Fax No.: Email: clifford.r.salvesen@exxonmobil.com	WAIVE
~~Savant, Amol~~ JOSH FREDERICK	Valvoline 22nd & Front Streets Ashland, KY 41114 Phone No. Fax No.: Email: ACSavant@valvoline.com	WAIVE
Tang, Haiying	Chrysler Group LLC 800 Chrysler Drive Auburn Hills, MI Phone No.: Fax No.: Email: haiying.tang@fcagroup.com	YES
Tarry, Preston	BP 1500 Valley Road Wayne, NJ 07470 Phone No.: Fax No.: Email: Preston.Tarry@bp.com	NO
	YES 11 Phone No.: NO 2 Fax No.: Email: WAIVE 8	PASSING 11-2-8
	Phone No.: Fax No.: Email:	

Sequence IVB High Wear Oil

Statistics Group

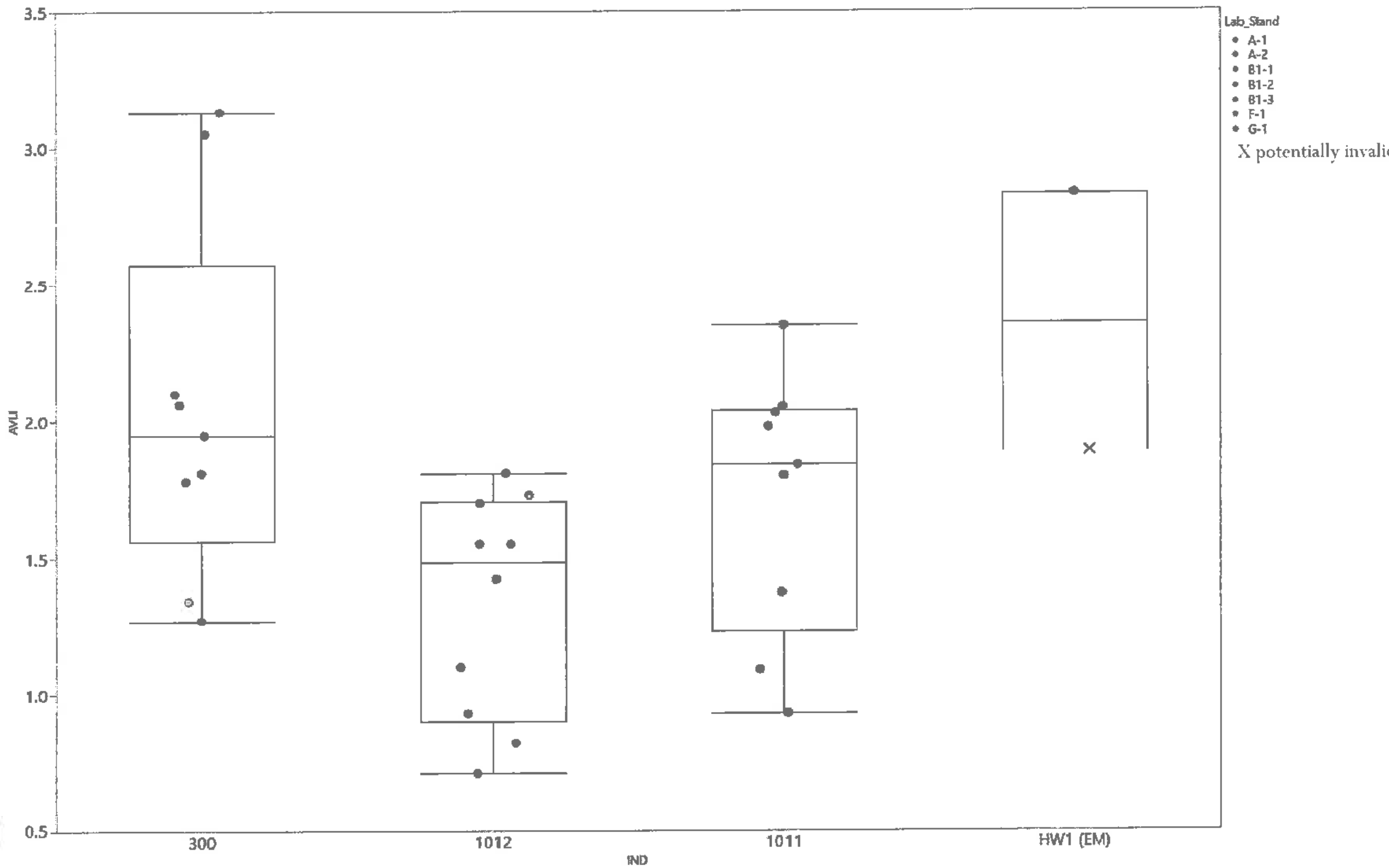
March 5, 2018

Statistics Group

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

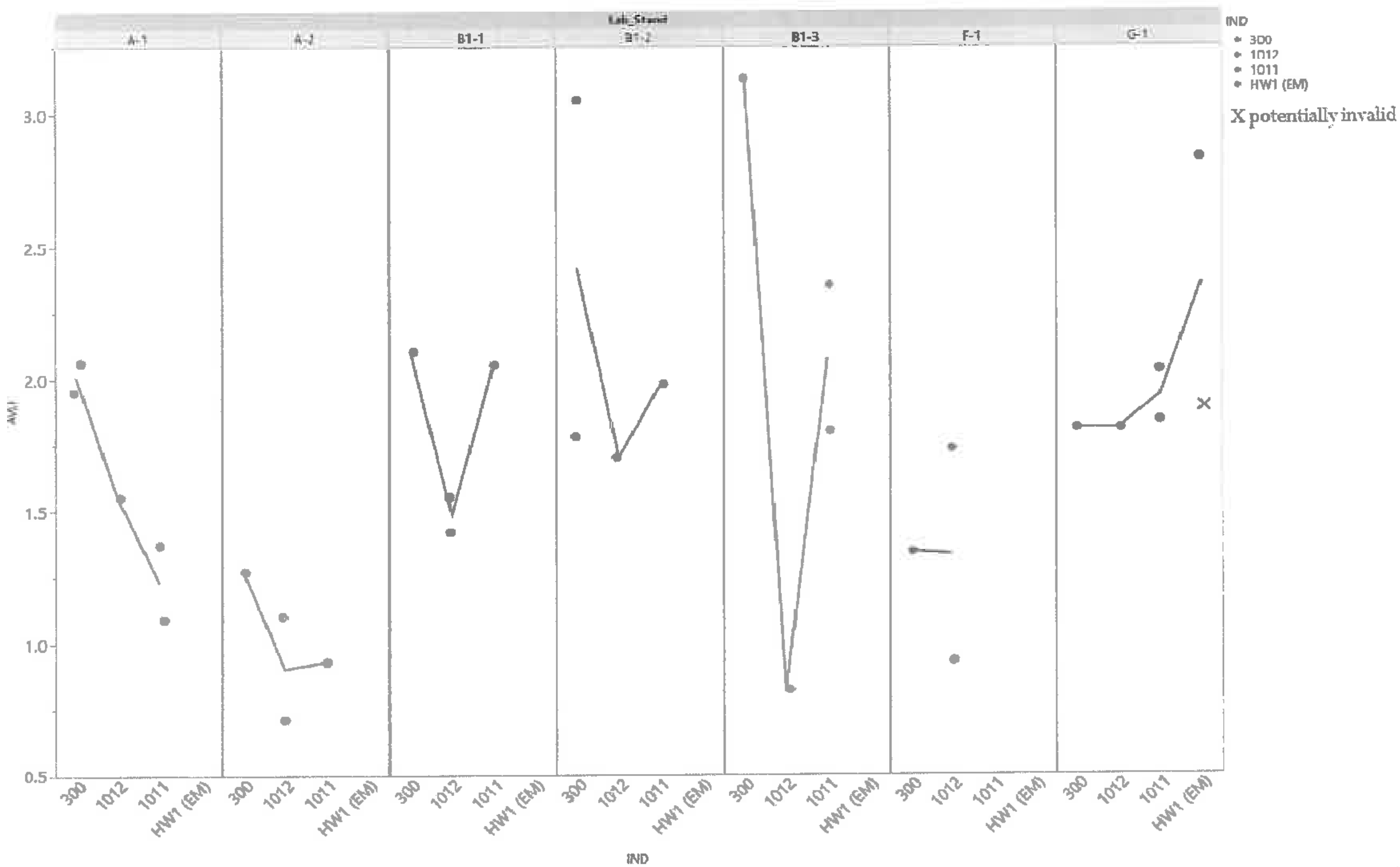
Average Intake Volume Loss by Oil

- The below plot summarizes the AVLI test result data by oil.



Average Intake Volume Loss by Stand

- The below plot summarizes the AVLI test result data by oil within the stand.



Statistical Analysis of Sequence IVB Operational Ramp Data

By: Industry Stats Team

03-05-18

tatistical Analysis of Operational Ramp Data

Analysis was performed to investigate the relationship between the RPM ramps from stages (1 to 2) and (2 to 1) with respect to the Sqrt(AVLI) parameter

Data used in analysis included all available operational PM and Afton prove out test data (includes $300{,}000^{+}$ test results for Hrs 10-11, 100-101, and 195-196)

The analysis was performed using data generated with Excel's "Slope" calculatic and was compiled for each Seq. IVB test result – as listed below:

- Each ascending ramp stage 1 to 2 was divided into a part "A" and part "B" portion.
  - Part "A" included average RPM slope for Stage Times 1 to 4
  - Part "B" included average RPM slope for Stage Times 5 to 8
  - All of the part "A" and "B" 1 to 2 RPM ramp slopes were averaged by test key
- Likewise, each descending ramp stage 2 to 1 was divided into a part "A" and part "B" portic
  - Part "A" included average RPM slope for Stage Times 1 to 4
  - Part "B" included average RPM slope for Stage Times 5 to 8
  - All of the part "A" and "B" 2 to 1 RPM ramp slopes were averaged by test key

tatistical Analysis of Operational Ramp Data

'he data available for the analysis is shown below:

TESTKEY	LTMSLAB	LTMSAPP	IND	AVLI	Sqrt(AVLI)	TestKey	Mean(RPM12_SlopeAvg_A)	Mean(RPM12_SlopeAvg_B)	Mean(RPM21_SlopeAvg_A)	Mean(RPM21_SlopeAvg_B)
09201-IVB	A	1	1011	1.09	1.04403065	109201-IVB	414.8722222	458.5294444	-431.2805556	-434.7763889
20739-IVB	F	1	300	1.34	1.15758369	120739-IVB	521.2520833	391.2371944	-473.0075278	-398.9306111
25183-IVB	F	1	1012	1.73	1.31529464	125183-IVB	527.1713056	390.1530278	-481.5295	-395.0464444
25184-IVB	G	1	1011	1.84	1.356466	125184-IVB	355.3573816	439.3816156	-350.2189415	-425.5649025
25879-IVB	B1	3	1011	1.8	1.34164079	125879-IVB	453.7066477	434.8160344	-413.7132887	-399.5746232
25880-IVB	A	2	1011	0.93	0.96436508	125880-IVB	437.32	460.5552778	-435.1580556	-446.2277778
25881-IVB	A	1	1011	1.37	1.17046999	125881-IVB	433.1430556	452.7713889	-424.9202778	-439.8666667
25882-IVB	A	2	1012	0.71	0.84261498	125882-IVB	426.7233333	451.1925	-434.5819444	-445.9252778
27173-IVB	B1	1	1012	1.55	1.24498996	127173-IVB	474.4950343	429.1674152	-435.6487985	-415.6947865
29752-IVB	A	1	300	1.95	1.396424	129752-IVB	419.9944444	454.0755556	-430.4694444	-445.1075
29755-IVB	A	1	1012	1.55	1.24498996	129755-IVB	428.3113889	452.4508333	-431.1077778	-441.1088889
29756-IVB	A	2	1012	1.1	1.04880885	129756-IVB	431.2725	437.8447222	-431.7386111	-455.1022222
29759-IVB	B1	2	300	1.78	1.33416641	129759-IVB	465.5698229	432.2417	-431.4507963	-423.1062297
29760-IVB	B1	1	300	2.1	1.44913768	129760-IVB	467.8832906	427.8783778	-440.3054502	-413.4002239
29762-IVB	B1	1	1011	2.05	1.43178211	129762-IVB	473.8083166	428.6092034	-432.6191069	-414.3847742
29763-IVB	B1	2	1011	1.98	1.40712473	129763-IVB	474.0588333	430.9709874	-441.7431113	-422.1739921
29764-IVB	B1	3	1011	2.35	1.53297097	129764-IVB	472.112114	428.4422819	-422.4814262	-408.5008733
29766-IVB	B1	2	1012	1.7	1.30384048	129766-IVB	467.4247179	431.2178682	-432.263019	-419.8884915
29767-IVB	B1	3	1012	0.82	0.90553851	129767-IVB	467.1650808	431.73194	-423.0178775	-413.0315413
29768-IVB	B1	1	1012	1.42	1.19163753	129768-IVB	476.2059991	425.644497	-436.58926	-423.0616691
30938-IVB	B1	2	300	3.05	1.74642492	130938-IVB	475.5974866	430.6919217	-439.6350472	-428.7717282
30939-IVB	B1	3	300	3.13	1.7691806	130939-IVB	464.4039892	426.6081732	-429.2367002	-422.6049107
30940-IVB	G	1	300	1.81	1.34536241	130940-IVB	357.4047354	434.7768802	-351.8844011	-426.0629526
30943-IVB	G	1	1011	2.03	1.42478069	130943-IVB	356.9819737	438.5256267	-351.0874652	-425.9295265
30944-IVB	G	1	1012	1.81	1.34536241	130944-IVB	330.4273776	291.437883	-342.178273	-275.3019492
30945-IVB	F	1	1012	0.93	0.96436508	130945-IVB	534.7816389	390.4550278	-481.4309444	-399.2427778
30948-IVB	A	2	300	1.27	1.12694277	130948-IVB	438.1580556	442.0269444	-420.4555556	-444.5683333
31277-IVB	A	1	300	2.06	1.43527001	131277-IVB	430.9211111	453.1658333	-428.0227778	-442.1180556
nassigned	D	1	1012	1.04	1.0198039	Afton-D101A-0-0-RO1012	415.9272829	422.4542857	-403.464986	-411.7388235
nassigned	D	1	300	2.4	1.54919334	Afton-D101A-0-0-RO300	444.7044444	415.4313611	-437.54175	-414.5443611

Unusu
remo

Data
Phase
Appe

tatistical Analysis of Operational Ramp Data

₹esiduals from the below Lab, Stand[Lab], and Oil model were evalu against the (Excel generated) ramp slopes

Response Sqrt(AVLI)

Whole Model

Actual by Predicted Plot

Effect Summary

Source	LogWorth	PValue
IND	2.110	0.00777
LTMSLAB	1.396	0.04014
LTMSAPP[LTMSLAB]	0.385	0.41210

Remove Add Edit FDR

Lack Of Fit

Residual by Predicted Plot

Summary of Fit

RSquare	0.629471
RSquare Adj	0.453957
Root Mean Square Error	0.171408
Mean of Response	1.27811
Observations (or Sum Wgts)	29

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	9	0.9483494	0.105372	3.5864
Error	19	0.5582333	0.029381	Prob > F
C. Total	28	1.5065827		0.0092*

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	1.2645597	0.040354	31.34	<.0001*
LTMSLAB [A]	-0.134088	0.060044	-2.23	0.0378*
LTMSLAB [B1]	0.1236432	0.055655	2.22	0.0387*
LTMSLAB [F]	-0.073093	0.09001	-0.81	0.4268
LTMSLAB [G]	0.0652576	0.093083	0.70	0.4918
LTMSLAB [A]:LTMSAPP[1]	0.0996702	0.058549	1.70	0.1050
LTMSLAB [B1]:LTMSAPP[1]	-0.023697	0.071051	-0.33	0.7424
LTMSLAB [B1]:LTMSAPP[2]	0.0237381	0.0709	0.33	0.7414
IND[1011]	-0.003318	0.050698	-0.07	0.9485
IND[1012]	-0.140475	0.049229	-2.85	0.0102*

Effect Tests

Source	Nparm	DF	Sum of Squares	F Ratio	Prob > F
LTMSLAB	4	4	0.36447212	3.1013	0.0401*
LTMSAPP[LTMSLAB]	3	3	0.08859693	1.0052	0.4121
IND	2	2	0.37266241	6.3420	0.0078*

LTMSLAB

Leverage Plot

Least Squares Means Table

Level	Least Sq Mean	Std Error	Mean
A	1.1304718	0.05750516	1.14155
B1	1.3882029	0.04948122	1.38820
F	1.1914668	0.10330576	1.14575
G	1.3298173	0.10330576	1.37554
D	1.2828397	0.12382618	1.28450

LTMSAPP[LTMSLAB]

Leverage Plot

Least Squares Means Table

Level	Least Sq Mean	Std Error
[A]1	1.2301419	0.07728570
[A]2	1.0308016	0.08658315
[B1]1	1.3645055	0.08658315
[B1]2	1.4119410	0.08645943
[B1]3	1.3881622	0.08663612
[F]1	1.1914668	0.10330576
[G]1	1.3298173	0.10330576
[D]1	1.2828397	0.12382618

IND

Leverage Plot

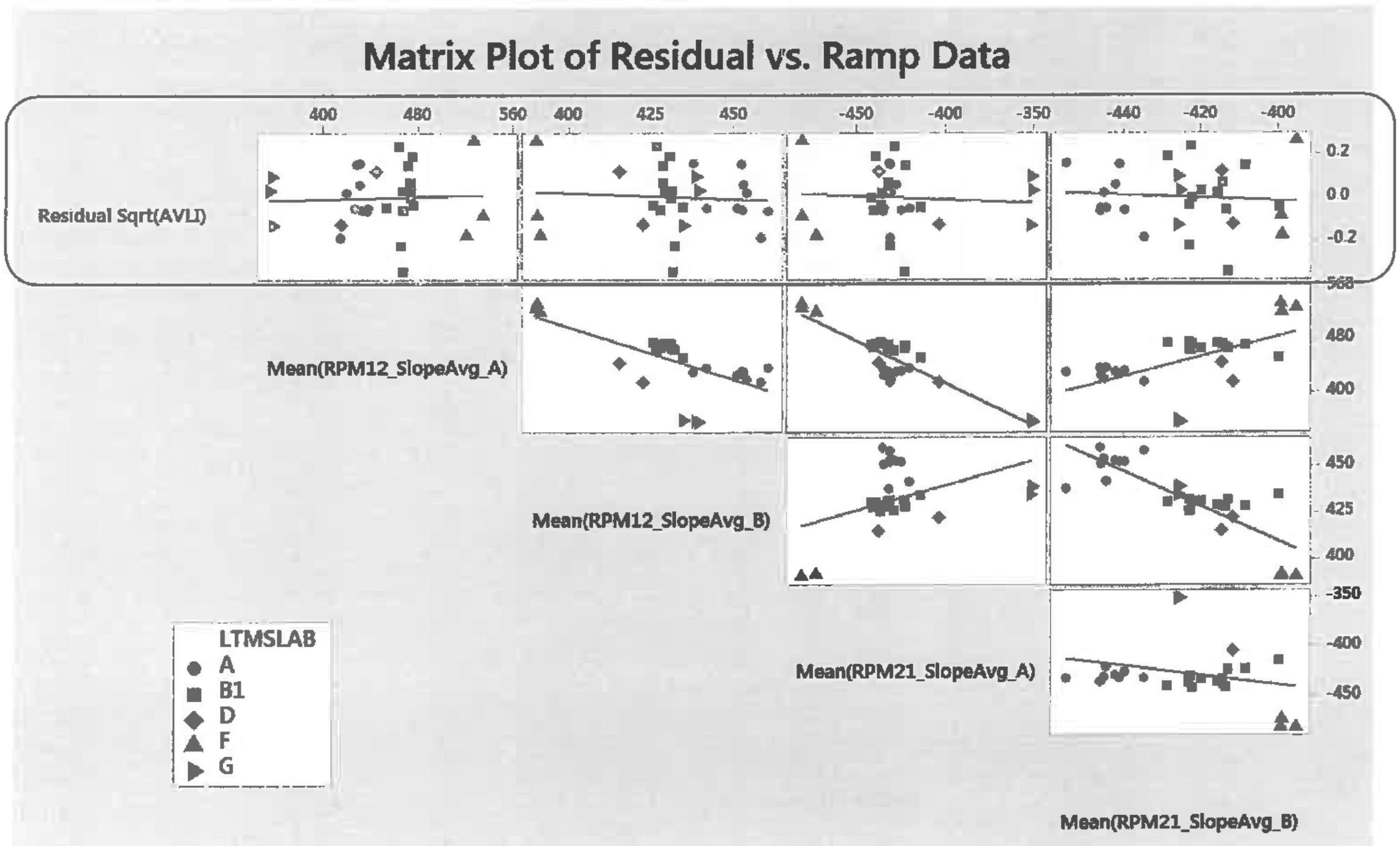
Least Squares Means Table

Level	Least Sq Mean	Std Error	Mean
1011	1.2612419	0.06875598	1.29707
1012	1.1240848	0.06112639	1.10819
300	1.4083524	0.05912952	1.43097

tatistical Analysis of Operational Ramp Data

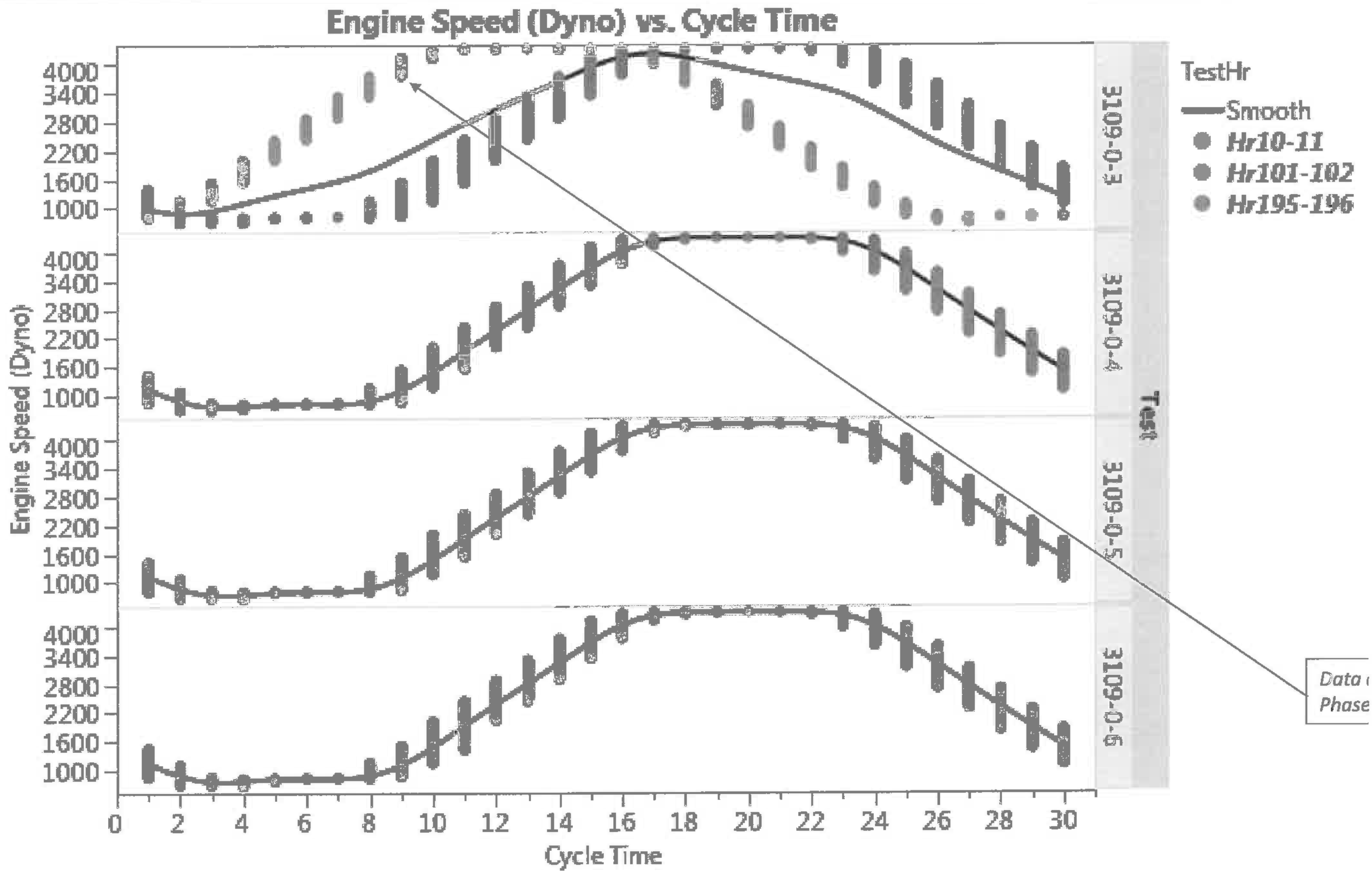
Matrix plot of (Excel generated) slope estimates vs. Sqrt(AVLI) model esiduals are shown below

- No discernable trend that correlates the residuals with the calculated ramp s



Appendix

Graph Builder



Where(LAB = ExxonMobil)

Sequence IVB Precision Matrix Analysis (n=21)

Statistics Group

March 5, 2018

Statistics Group

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

Executive Summary

Precision Matrix (PM) Analysis Highlights:

- This analysis includes the results of 21 valid precision matrix tests from the independent labs
- Data supports the use of Sqrt(AVLI) transformation
- Significant oil differences: 1012 < 300
- Lab differences are statistically significant (A < B1)
- Stand within Lab differences are not statistically significant
- Estimated within a stand test precision (r; ASTM repeatability)
  - Sqrt(AVLI) = 0.4593
- Estimated test precision across labs and stands (R; ASTM reproducibility)
  - Sqrt(AVLI) = 0.5771
- Oil means and standard deviations

Oil	Number of Tests	Target Mean Sqrt(AVLI)	Target Mean AVLI	Target Standard Deviation Sqrt(AVLI)
300	7	1.4306	2.05	0.2269
1012	7	1.1104	1.23	0.1815
1011	7	1.2373	1.53	0.2136

PM Analysis Concerns

- The two high results on Oil 300 at stands B1-2 and B1-3 have large influence on discrimination between oils 300 and 1012. Without these two tests, differences between oils are not statistically significant.

- Discrimination is not consistent among the stands.
  - Stands rank oils differently
  - This could be an issue if the same phenomenon is observed in candidate oils

- Test precision is large compared to the observed range of measurements; the high and low oils differ by 1.9 standard deviations (lowest of any GF6 test).
  - Discriminating future oils in the test will be difficult; especially with only one test result

Data Utilized

- Precision Matrix Data:
  - 2 Labs {A, B1}, independent labs only
  - 3 Reference Oils {300, 1012, and 1011}
  - 5 Stands {A-1, A-2, B1-1, B1-2, B1-3}
  - Total number of tests = 21

- Precision Matrix Data Table from Rich Grundza's 20180115 IVB Matrix update.

Run order	B1-1	B1-2	B1-3	A-1	A-2	F-1	G-1	[illegible]-1
1	1012 127173-IVB	300 129759-IVB	1011 125879-IVB	300 129752-IVB	1012 125882-IVB	[illegible]	[illegible]	[illegible]
2	1011 129762-IVB	1012 129766-IVB	1012 129767-IVB	1011 109201-IVB 1011* 125881-IVB	300 130948-IVB	[illegible]	[illegible]	[illegible]
3	300 129760-IVB	1011 129763-IVB	300 129761-IVB 300 130939-IVB	1012 129755-IVB	1011 125880-IVB	[illegible]	[illegible]	300
4	1012 129768-IVB	300 130938-IVB	1011 129764-IVB	300 131277-IVB	1012 129756-IVB	[redacted]	300# 130940-IVB	[redacted]
Reported			Invalid			[redacted]	[redacted]	[redacted]

* Laboratory is running additional test because of Lean AFR and lower fuel flow on original matrix test

Additional test donated by lab

Reference Oil Discrimination Comparison

The table below compares the numbers of standard deviations of separation between the highest and lowest reference oil across GF-6 test types. The median is approx. 3.3 and the mean (without PHOS) is 3.4.

Test	Parameter	Oil 1	Oil 2	Range	Test S_r	SDs of Separation
IIIH	Ln(PVIS)	4.7191	3.3289	1.3902	0.4641	**3.0**
IIIH	WPD	4.63	3.66	0.97	0.47	**2.1**
IIIHA	Ln(MRV)	11.1107	9.7854	1.3253	0.4214	**3.1**
IIIHB	PHOS	94.15	78.92	15.23	1.53	**10.0**
VIE	FEI 1	2.56	1.3	1.26	0.29	**4.3**
VIE	FEI 2	1.82	1.41	0.41	0.12	**3.4**
VIF	FEI 1	2.23	1.45	0.78	0.21	**3.7**
VIF	FEI 2	2.25	1.41	0.84	0.19	**4.4**
IX (LSPI)	Sqrt(AvPIE + 0.5)	4.2644	3.3819	0.8825	0.2856	**3.1*1**
VH	AES	8.43	6.47	1.96	0.5	**3.9**
VH	Ln(10-RCS)	0.9155	-0.5294	1.4449	0.2194	**6.6**
VH	AEV50	9.26	8.77	0.49	0.25	**2.0**
VH	APV50	8.67	7.35	1.32	0.53	**2.5**
X (CW)	Ln(CHST)	-2.10574	-2.63174	0.526	0.14148	**3.7*2**
IVB	Sqrt(AVLI)	1.4306	1.1104	0.3202	0.1657	**1.9**

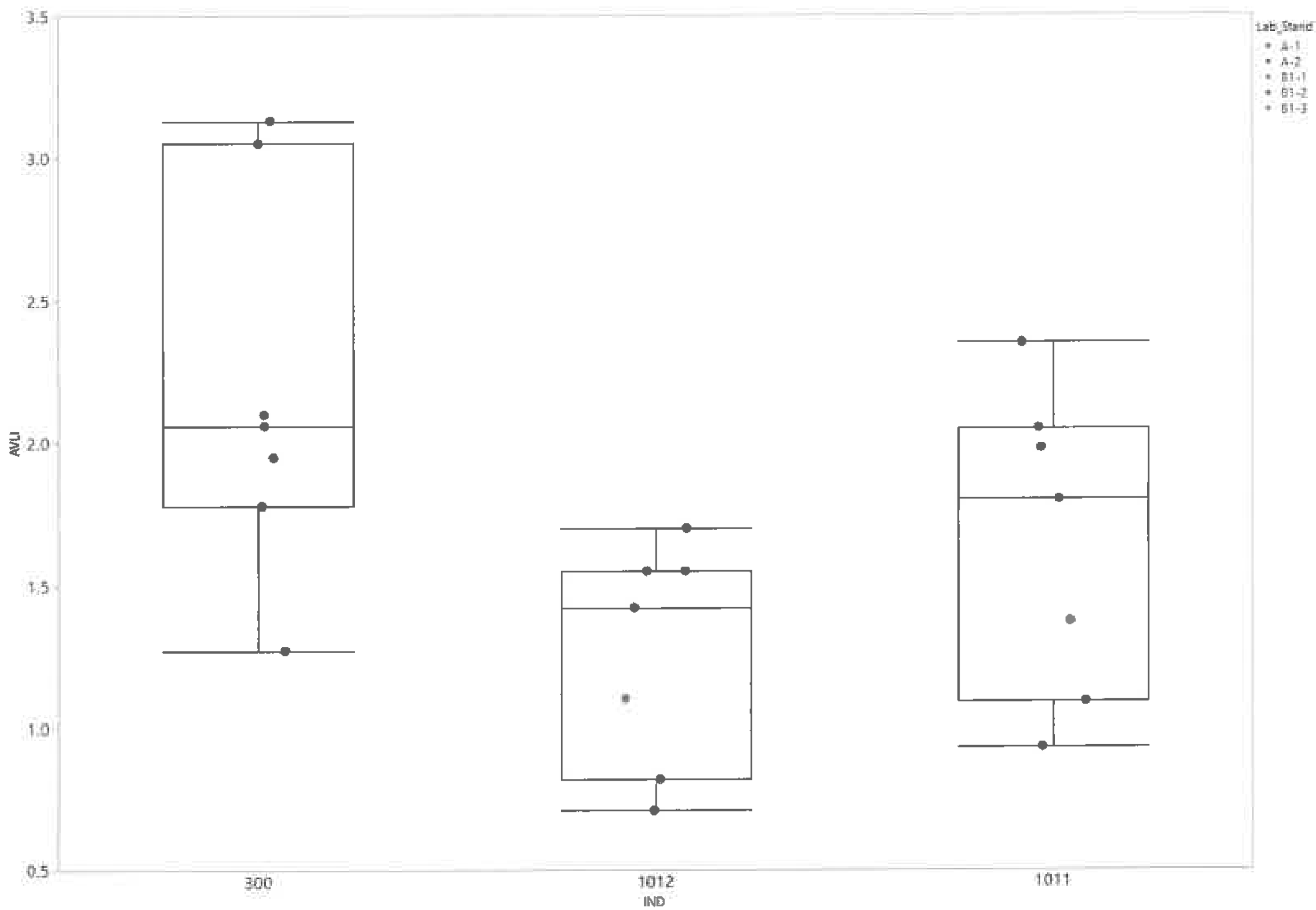
*1: Oil 220 not used as a reference oil. Including this oil would yield approx. 12 SDs of separation between 220 and 222.
*2: 271 vs. 1011

Analysis of Sqrt(AVLI)

Average volume loss, Intake

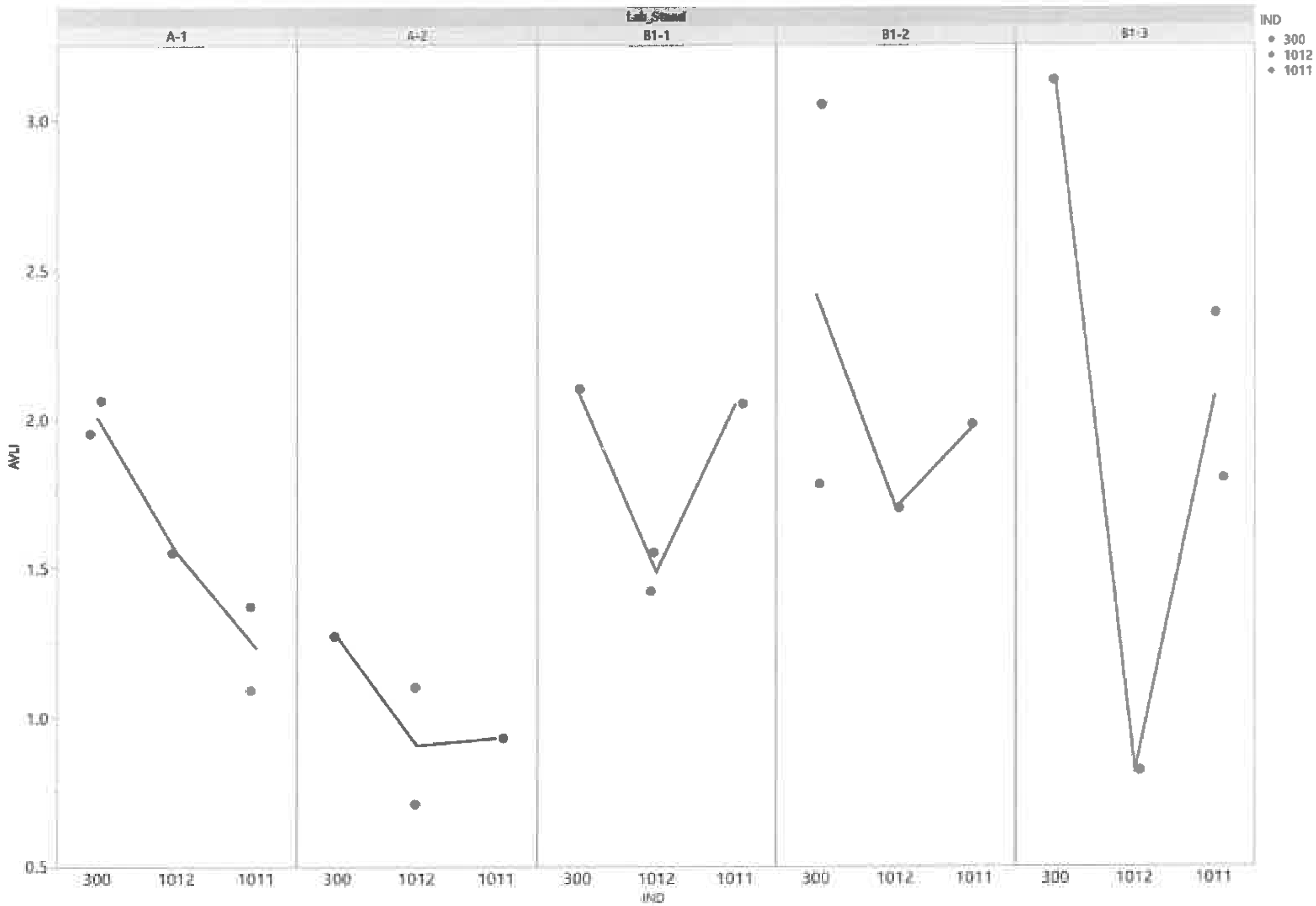
Average Intake Volume Loss by Oil

- The below plot summarizes the AVLI test result data by reference oil.



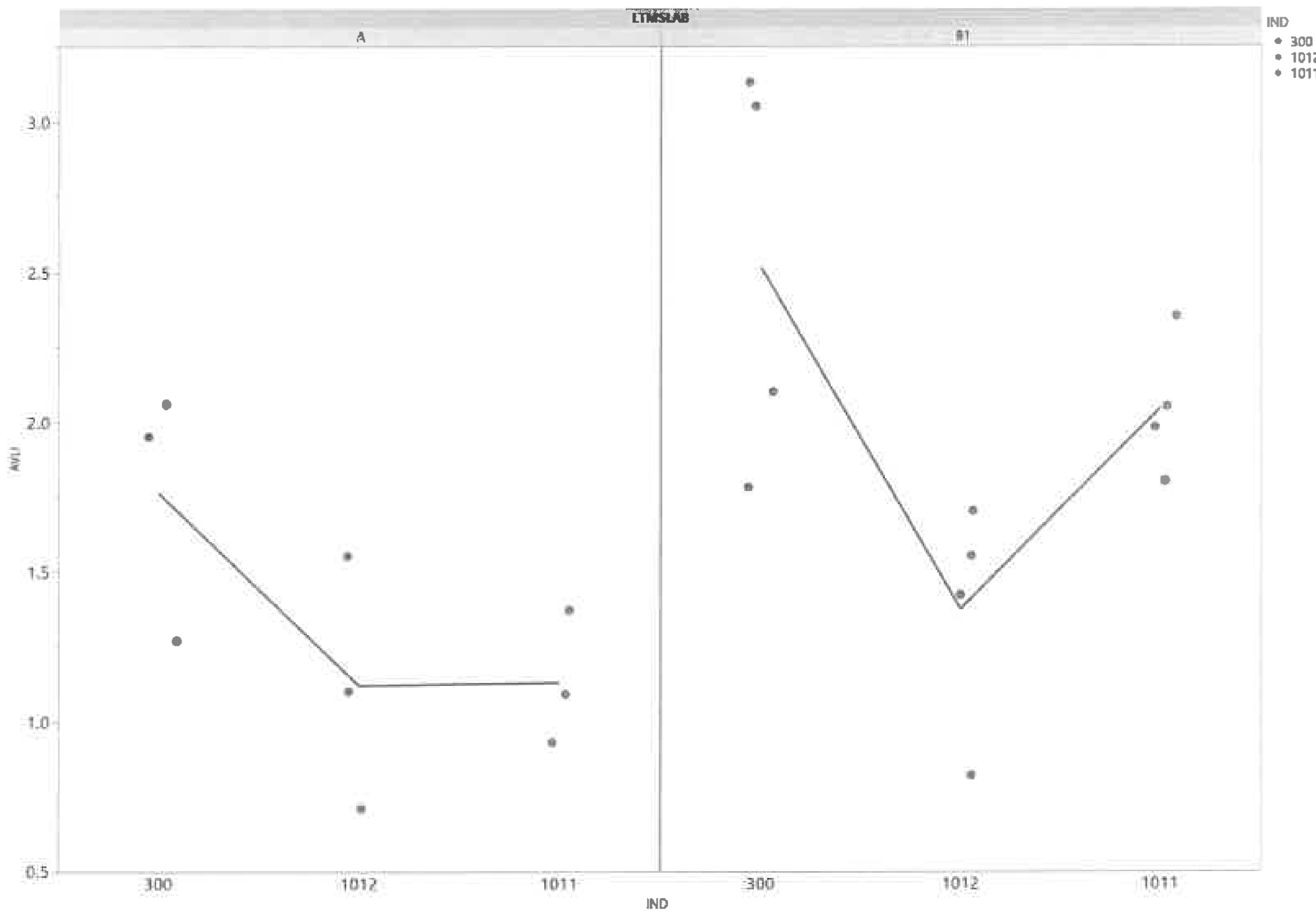
Average Intake Volume Loss by Stand

- It appears that oil discrimination is not consistent among the stands; Stands rank oils differently



Average Intake Volume Loss by Lab

- Below plot summarizes the AVLI test result data by test Lab and reference oil



Sqrt(AVLI) ANOVA Full Model

<u>Statistically significant differences:</u>

- Oil
- Lab

<u>Not significantly different:</u>

- Stands within Labs

Summary of Fit

RSquare	0.68481
RSquare Adj	0.549729
Root Mean Square Error	0.165693
Mean of Response	1.282493
Observations (or Sum Wgts)	21

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	6	0.8350926	0.139182	5.0696
Error	14	0.3843584	0.027454	Prob > F
C. Total	20	1.2194510		0.0058*

Parameter Estimates

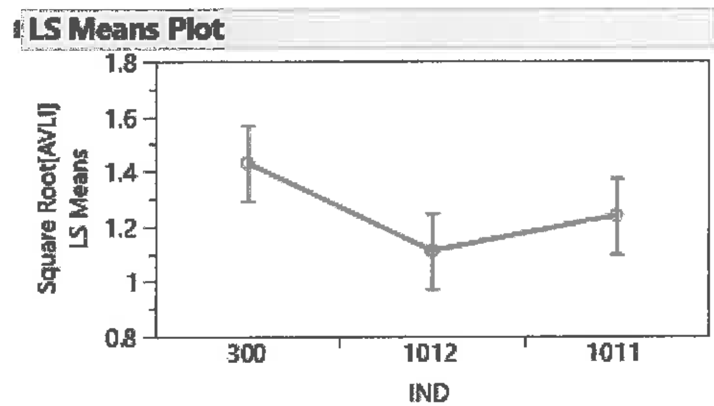
Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	1.2594442	0.036668	34.35	<.0001*
IND[300]	0.1711474	0.052374	3.27	0.0056*
IND[1012]	-0.14902	0.05327	-2.80	0.0143*
LTMSLAB[A]	-0.128759	0.036668	-3.51	0.0035*
LTMSLAB[A]:LTMSAPP[1]	0.0977475	0.056853	1.72	0.1076
LTMSLAB[B1]:LTMSAPP[1]	-0.021561	0.068942	-0.31	0.7591
LTMSLAB[B1]:LTMSAPP[2]	0.0168994	0.068899	0.25	0.8098

Effect Tests

Source	Nparm	DF	Sum of Squares	F Ratio	Prob > F
IND	2	2	0.34092566	6.2090	0.0117*
LTMSLAB	1	1	0.33851939	12.3303	0.0035*
LTMSAPP[LTMSLAB]	3	3	0.08306396	1.0085	0.4182

Sqrt(AVLI) Oil Differences

- Model is Sqrt(AVLI) ~ Oil, Lab, Stand(Lab)
- Oils significantly differ
  - Oil 300 is statistically significantly different than oil 1012
  - Oil 1011 is not statistically significantly different than oils 300 and 1012
- Plot shows Sqrt(AVLI) LSMeans by Oil, with 95% confidence intervals



LSMeans by Oil

Oil	Least Sq Mean	AVLI LSMean
300	1.4306	2.05
1012	1.1104	1.23
1011	1.2373	1.53

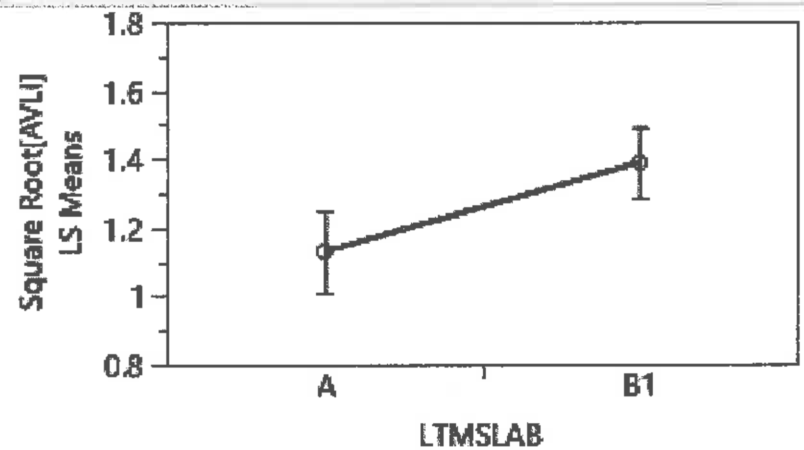
LSMeans Differences Between Oils

Oil1	Oil2	Sqrt(AVLI) LSMean Difference	p-Value
300	1012	0.3202	0.01
300	1011	0.1933	0.12
1011	1012	0.1269	0.38

Sqrt(AVLI) Lab Differences

- Model is Sqrt(AVLI) ~ Oil, Lab, Stand(Lab)
- Plot below of Sqrt(AVLI) LSMeans by Lab, with 95% confidence intervals
- Lab A is statistically significantly different than Lab B1.

LS Means Plot



LSMeans by Lab

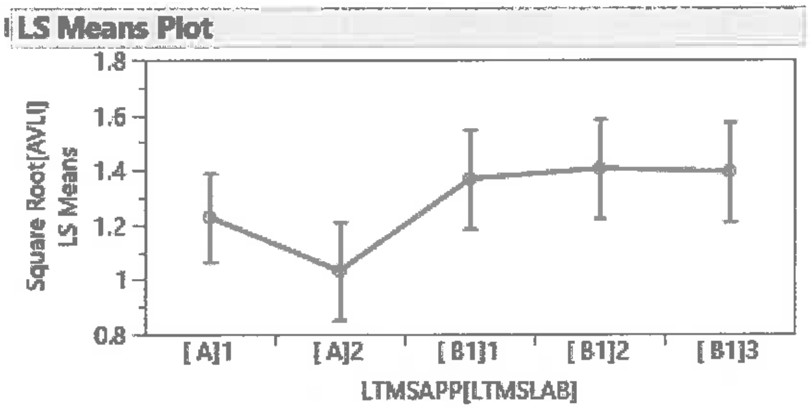
Level	Sqrt (AVLI) LSMean	AVLI LSMean
A	1.1307	1.28
B1	1.3882	1.93

LSMeans Difference Between Labs

Lab1	Lab2	Sqrt(AVLI) LSMean Difference	p-Value
B1	A	0.2575	0

Sqrt(AVLI) Stand within Lab Differences

- Model is Sqrt(AVLI) ~ Oil, Lab, Stand(Lab)
- Plot below of Sqrt(AVLI) LSMeans by Stand, with 95% confidence intervals
- Stands within labs are not statistically significantly different from each other



LSMeans by Stand

Stand	Sqrt(AVLI) LSMean	AVLI LSMean
[A]1	1.2284	1.51
[A]2	1.0329	1.07
[B1]1	1.3666	1.87
[B1]2	1.4051	1.97
[B1]3	1.3929	1.94

LSMeans Differences Between Labs

Stand1	Stand2	LSMean Difference	p-Value
[A]1	[A]2	0.1955	0.45
[B1]2	[B1]1	0.0385	1
[B1]3	[B1]1	0.0262	1
[B1]2	[B1]3	0.0122	1

Sqrt(AVLI) Precision

Repeatability Model: Sqrt(AVLI) ~ Oil, Lab, Stand(Lab)
Reproducibility Model: Sqrt(AVLI) ~ Oil

Model RMSE

- $s_r = 0.1657$

Repeatability

- $s_r = 0.1657$
- $r = 0.4593$

Reproducibility

- $s_R = 0.2082$
- $R = 0.5771$

Based upon the AVLI pooled standard deviation (s_r) and ASTM's repeatability (r), there is no significant difference between an AVLI *result*[1] of 2.00 and 3.51.

Note 1: An AVLI result of 2.00 was arbitrarily selected for comparison

Reference Oil Targets

Model: Sqrt(AVLI) ~ Oil, Lab, Stand(Lab)

Average Intake Volume Loss (AVLI)

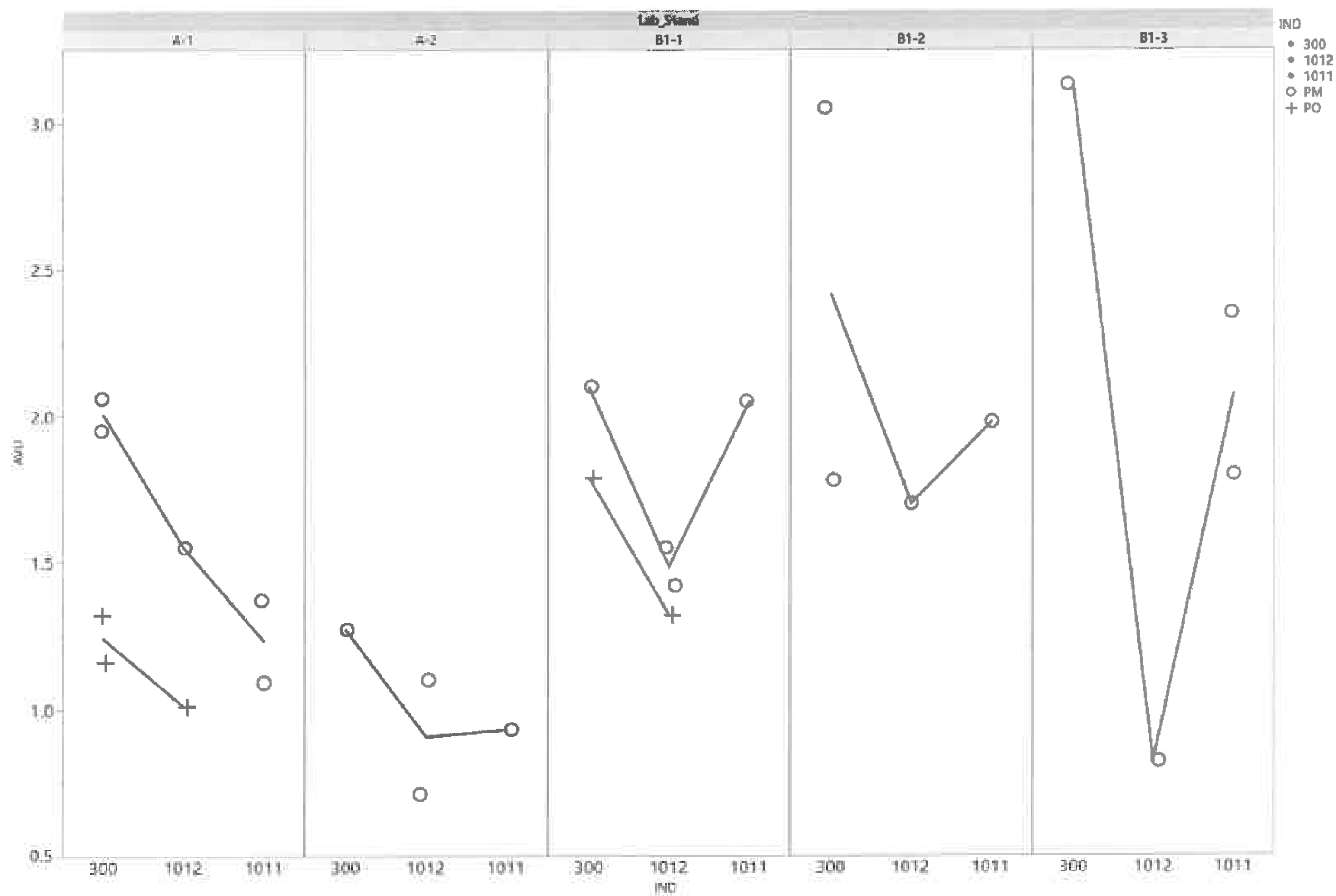
Unit of Measure: Sqrt(AVLI)

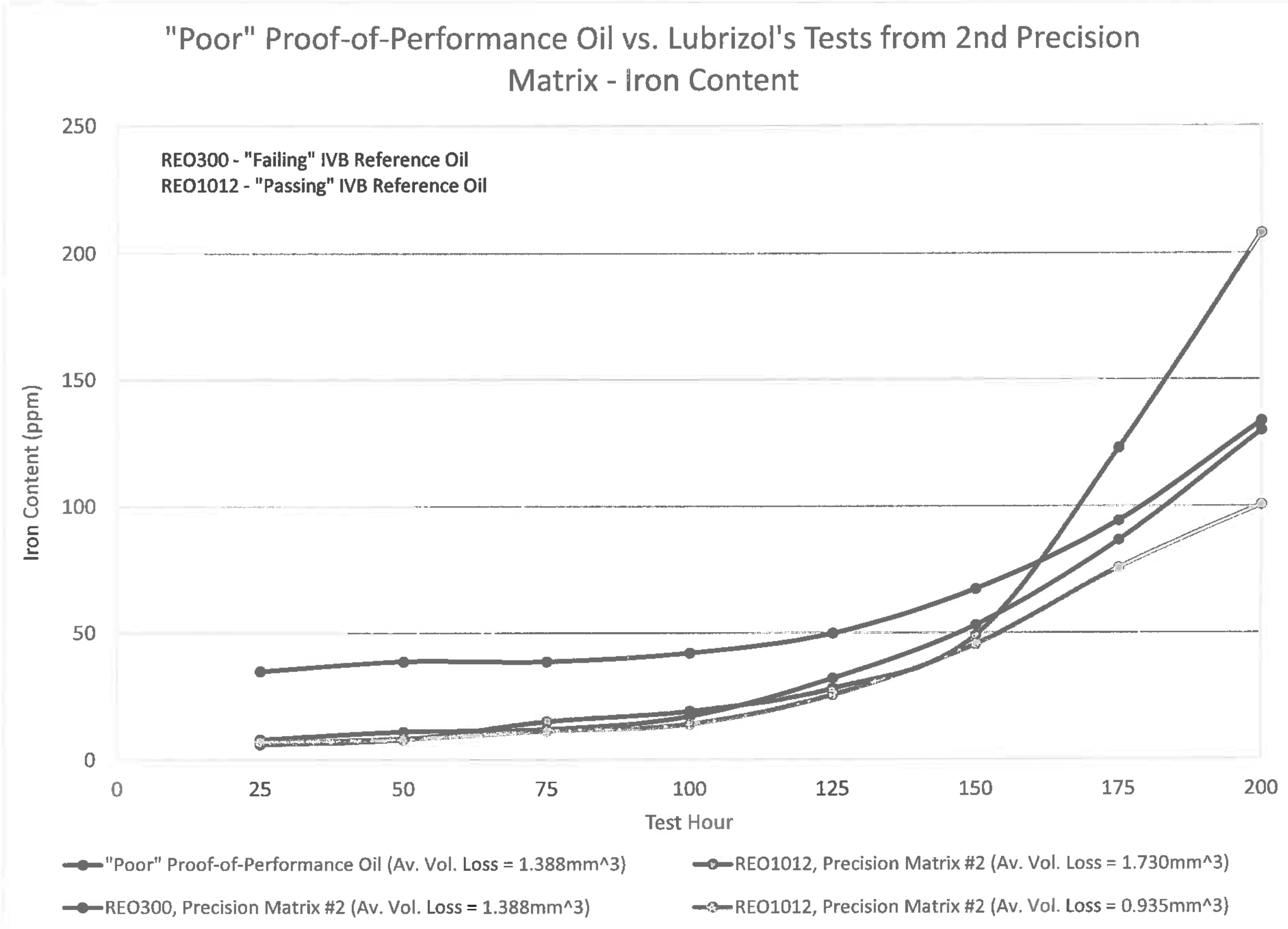
Ref. Oil	Target Mean Sqrt(AVLI)	Target Mean AVLI	St. Dev
300 (n=7)	1.4306	2.05	0.2269
1012 (n=7)	1.1104	1.23	0.1815
1011 (n=7)	1.2373	1.53	0.2136

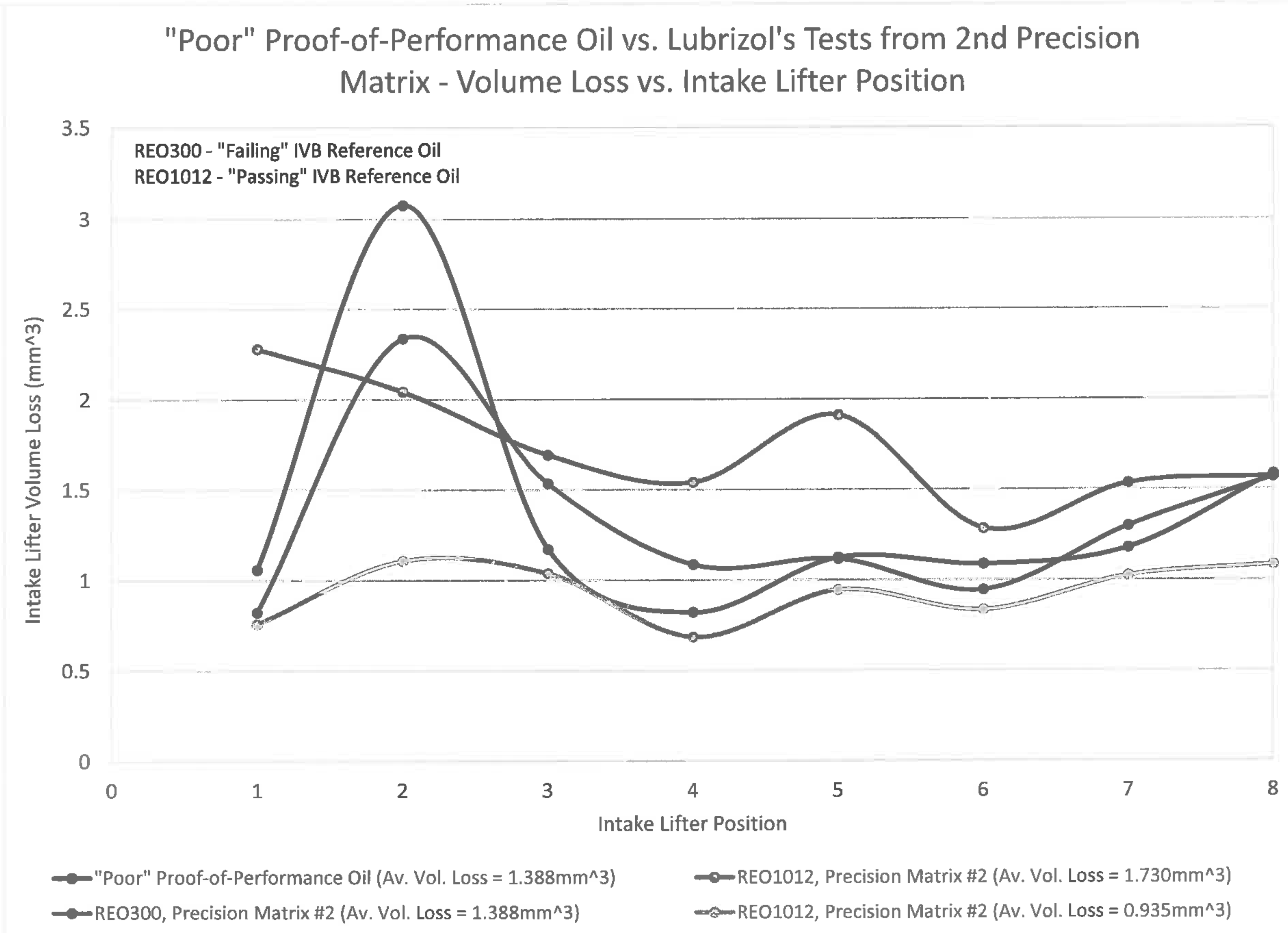
Target Means are the Oil LSMeans from the Model and Standard Deviations are calculated straight from Sqrt(AVLI).

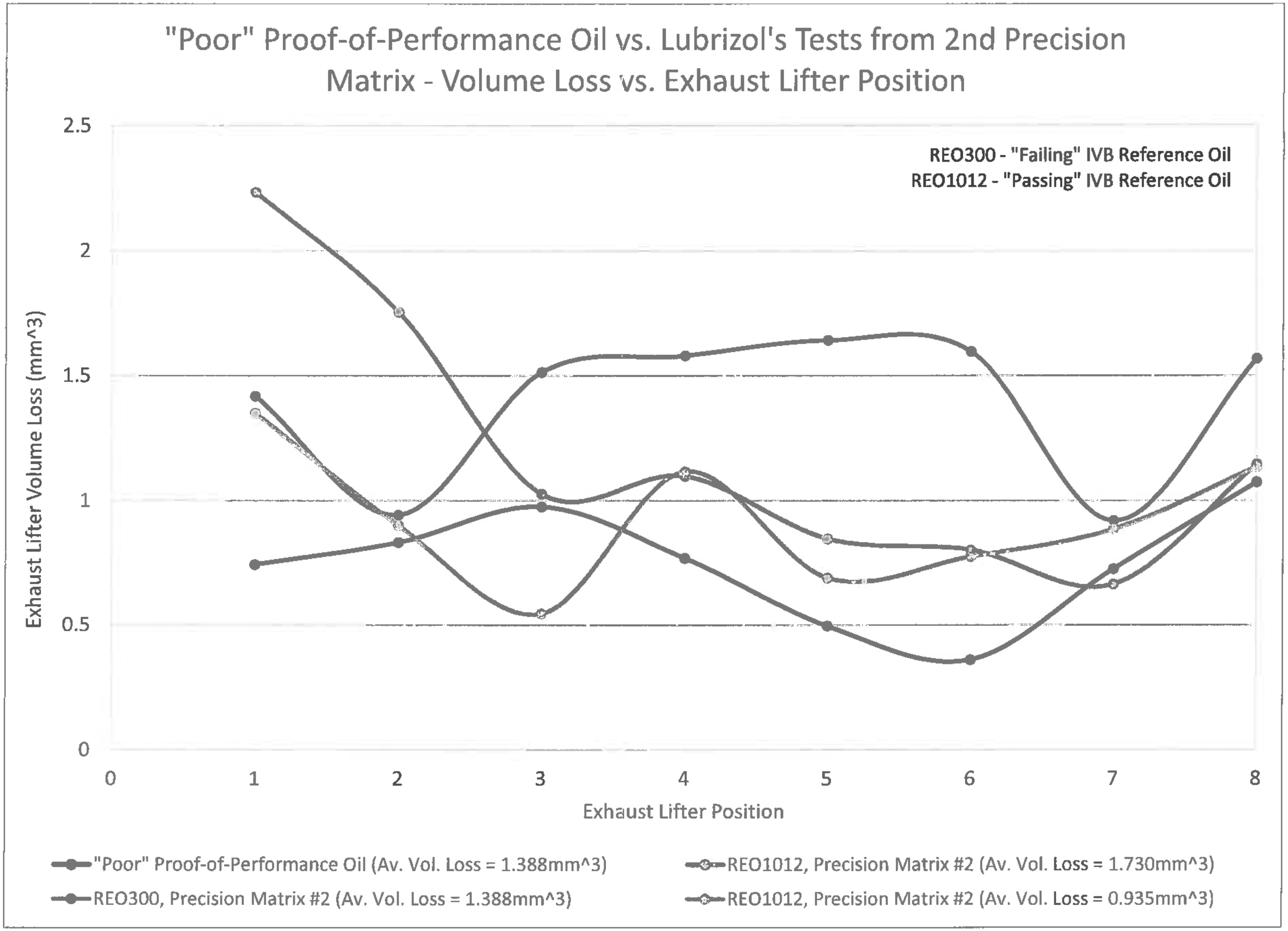
APPENDIX

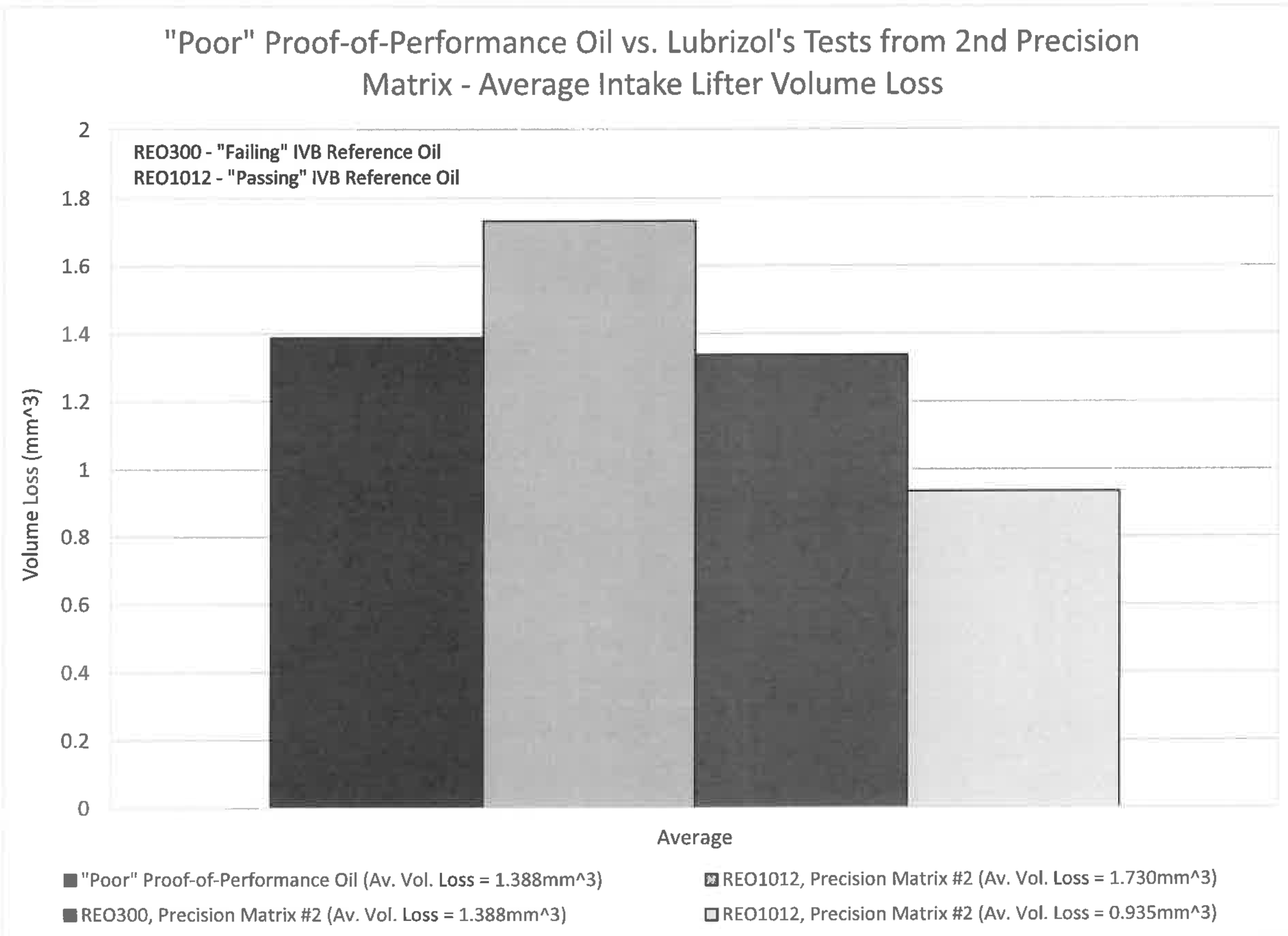
AVLI with Prove-out tests

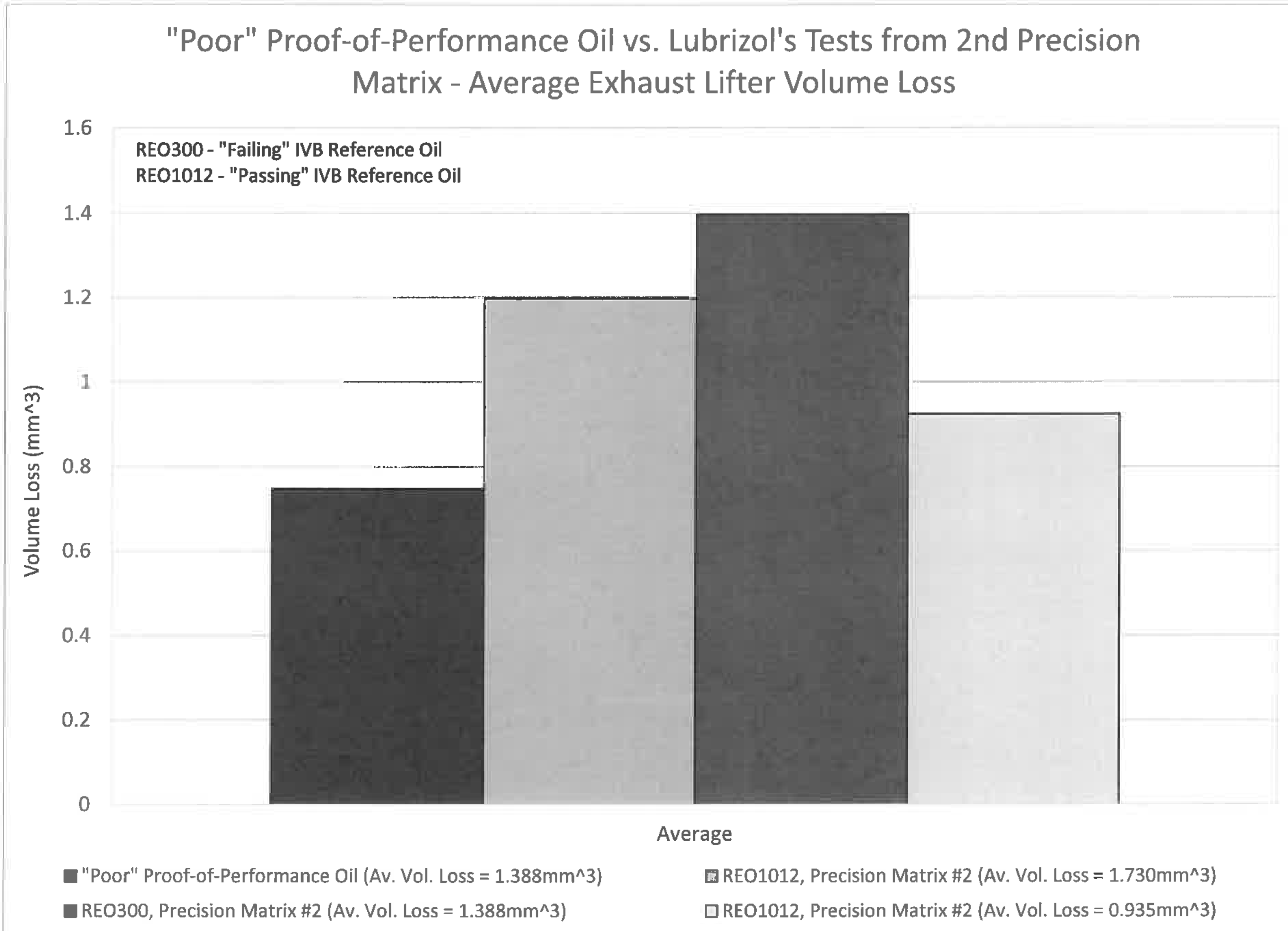



"Poor" Proof-of-Performance Oil vs. Lubrizol's Tests from 2nd Precision Matrix - Iron Content
REO300 - "Failing" IVB Reference Oil
REO1012 - "Passing" IVB Reference Oil
Iron Content (ppm)
250
200
150
100
50
0
0
25
50
75
100
125
150
175
200
Test Hour
"Poor" Proof-of-Performance Oil (Av. Vol. Loss = 1.388mm^3)
REO1012, Precision Matrix #2 (Av. Vol. Loss = 1.730mm^3)
REO300, Precision Matrix #2 (Av. Vol. Loss = 1.388mm^3)
REO1012, Precision Matrix #2 (Av. Vol. Loss = 0.935mm^3)


"Poor" Proof-of-Performance Oil vs. Lubrizol's Tests from 2nd Precision Matrix - Volume Loss vs. Intake Lifter Position
REO300 - "Failing" IVB Reference Oil
REO1012 - "Passing" IVB Reference Oil
Intake Lifter Volume Loss (mm^3)
3.5
3
2.5
2
1.5
1
0.5
0
0
1
2
3
4
5
6
7
8
Intake Lifter Position
"Poor" Proof-of-Performance Oil (Av. Vol. Loss = 1.388mm^3)
REO300, Precision Matrix #2 (Av. Vol. Loss = 1.388mm^3)
REO1012, Precision Matrix #2 (Av. Vol. Loss = 1.730mm^3)
REO1012, Precision Matrix #2 (Av. Vol. Loss = 0.935mm^3)


"Poor" Proof-of-Performance Oil vs. Lubrizol's Tests from 2nd Precision Matrix - Volume Loss vs. Exhaust Lifter Position
REO300 - "Failing" IVB Reference Oil
REO1012 - "Passing" IVB Reference Oil
Exhaust Lifter Volume Loss (mm^3)
2.5
2
1.5
1
0.5
0
0
1
2
3
4
5
6
7
8
Exhaust Lifter Position
"Poor" Proof-of-Performance Oil (Av. Vol. Loss = 1.388mm^3)
REO300, Precision Matrix #2 (Av. Vol. Loss = 1.388mm^3)
REO1012, Precision Matrix #2 (Av. Vol. Loss = 1.730mm^3)
REO1012, Precision Matrix #2 (Av. Vol. Loss = 0.935mm^3)


"Poor" Proof-of-Performance Oil vs. Lubrizol's Tests from 2nd Precision Matrix - Average Intake Lifter Volume Loss
REO300 - "Failing" IVB Reference Oil
REO1012 - "Passing" IVB Reference Oil
Volume Loss (mm^3)
2
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
Average
"Poor" Proof-of-Performance Oil (Av. Vol. Loss = 1.388mm^3)
REO300, Precision Matrix #2 (Av. Vol. Loss = 1.388mm^3)
REO1012, Precision Matrix #2 (Av. Vol. Loss = 1.730mm^3)
REO1012, Precision Matrix #2 (Av. Vol. Loss = 0.935mm^3)


"Poor" Proof-of-Performance Oil vs. Lubrizol's Tests from 2nd Precision Matrix - Average Exhaust Lifter Volume Loss
REO300 - "Failing" IVB Reference Oil
REO1012 - "Passing" IVB Reference Oil
Volume Loss (mm^3)
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
Average
"Poor" Proof-of-Performance Oil (Av. Vol. Loss = 1.388mm^3)
REO300, Precision Matrix #2 (Av. Vol. Loss = 1.388mm^3)
REO1012, Precision Matrix #2 (Av. Vol. Loss = 1.730mm^3)
REO1012, Precision Matrix #2 (Av. Vol. Loss = 0.935mm^3)