



Cummins ISB Industry Severity

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June 2020

Passion for Solutions®

Agenda

- ▲ Executive Summary
- ▲ Review of Current Status
 - ▲ As of June 23, 2020
- ▲ Modeling Overview
- ▲ Camshaft Plots Over Time
 - ▲ Uncorrected Results
 - ▲ Corrected Results
- ▲ ACSW Analyses
 - ▲ Camshaft Wear vs Lab, Oil nested with Hardware (CAM/TAP)
 - ▲ Camshaft Wear vs Lab and Oil
- ▲ Tappet Weight Loss Plots Over Time
 - ▲ Uncorrected Results
 - ▲ Corrected Results
- ▲ ATWL Analyses
 - ▲ Tappet Weight Loss vs Oil nested with Hardware (CAM/TAP)
 - ▲ Tappet Weight Loss vs Lab and Oil

Executive Summary

 The data suggests a change is needed for ACSW

 New target for oil blend 831-4

- ▶ Target and Standard Deviation for 831-4 was set in October 2017 from 3 runs at one lab
- ▶ More recent data points to increased severity with 831-4

 Consider update to Industry Correction Factor for ACSW

- ▶ Still using (add -18.5) from K cams and D tappets
 - Slight difference between L and K cams
- ▶ Minor or Major options depending on path group decides
- ▶ Suggest further review if/when new data becomes available

Modeling Overview

- ▲ Use Only Chartable Data
- ▲ Missing hardware data in LTMS data set requires subset for modeling
- ▲ Not enough degrees of freedom to model lab, oil, and hardware
 - ▲ When modeling both ACSW with Lab and Oil nested with Hardware variables included are
 - PC10B/831 and matrix hardware
 - 831-4 KD CAM/TAP hardware
 - 831-4 LE CAM/TAP hardware

Current State of LTMS for ISB

Values used in LTMS calculations for the ISB

LUBRICANT TEST MONITORING SYSTEM CONSTANTS

| | | EWMA Chart | | Stand Prediction Error | |
|-------------|------------|------------|-------------|------------------------|-------------|
| Chart Level | Limit Type | Lambda | Alarm | Limit Type | Limit |
| Stand | Level 1 | 0.3 | 0.000 | Level 2 | ± 1.734 |
| | Level 2 | | ± 1.800 | Level 3 | ± 2.066 |
| Industry | Level 1 | 0.2 | ± 0.775 | -- | -- |
| | Level 2 | | ± 0.859 | -- | -- |

Current State of LTMS for ISB

Correction factors are currently in place for:

- ▲ Average Tappet Weight Loss (ATWL)
- ▲ Average Camshaft Wear (ACSW)

| | | | | |
|-----|-------------------|-------------------|--|---|
| ISB | April 21, 2011 | October 18, 2017 | All tests using batch B tappets with batch E, F, and G cams | Multiply ATWL by 0.637; Add -9.5 to ACSW |
| | December 11, 2011 | November 12, 2012 | All tests using batch C tappets with batch H cams | Multiply ATWL by 0.637; Add -9.5 to ACSW |
| | November 13, 2012 | October 18, 2017 | All tests using batch C tappets with batch H and J cams | Multiply ATWL by 0.711; Add -5.6 to ACSW |
| | None | October 18, 2017 | All test using batch D tappets and batch K cams | Multiply ATWL by 1; Add -11.3 to ACSW |
| | October 19, 2017 | *** | All tests using batch K cams with batch D tappets and batch E crossheads | Multiply ATWL by 0.7851; Add -18.5 to ACSW |

Current State of LTMS for ISB

History of Reference Oil Targets

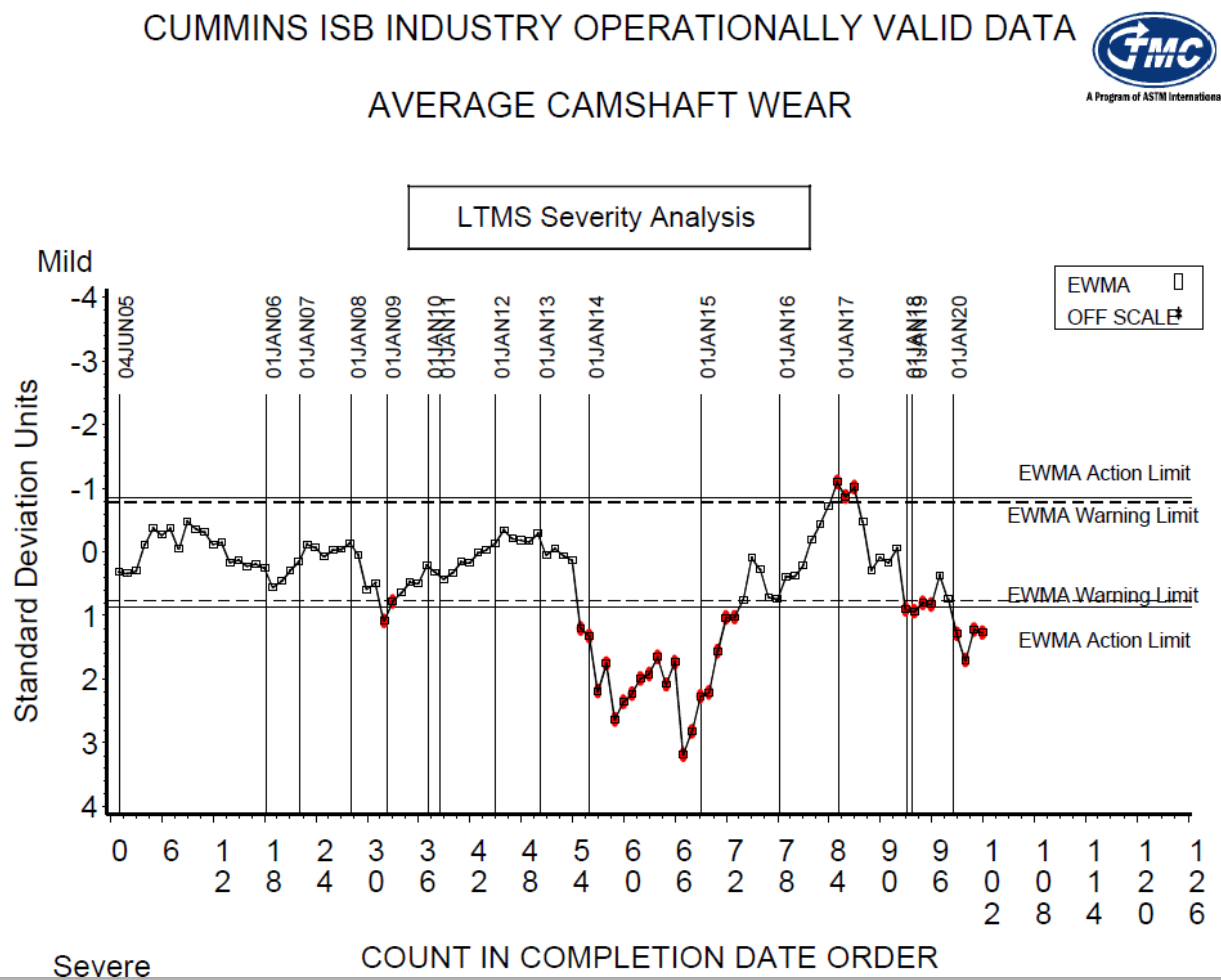
| ISB Reference Oil Targets | | | | | | | |
|---------------------------|----|-----------------|-----------------|-----------------------|-----|----------------------------|------|
| Oil | n | Effective Dates | | Average Camshaft Wear | | Average Tappet Weight Loss | |
| | | From | To ¹ | \bar{X} | s | \bar{X} | s |
| 821 (PC10E) | 6 | 6-4-05 | 12-31-05 | 34.6 | 4.6 | 56.2 | 9.6 |
| 830-2 | 6 | 6-4-05 | 12-31-05 | 39.8 | 9.0 | 85.9 | 16.0 |
| 831 (PC10B) | 6 | 6-4-05 | 1-24-07 | 41.9 | 5.6 | 88.7 | 15.9 |
| | 10 | 1-25-07 | 8-6-07 | 42.8 | 5.4 | 94.9 | 15.3 |
| | 14 | 8-7-07 | *** | 42.5 | 5.0 | 97.2 | 14.8 |
| 831-1 ² | -- | 8-7-07 | 10-18-17 | 42.5 | 5.0 | 97.2 | 14.8 |
| 831-1 ² | -- | 10-19-17 | *** | 42.5 | 8.7 | 97.2 | 14.8 |
| 831-2 ² | -- | 8-6-13 | 10-18-17 | 42.5 | 5.0 | 97.2 | 14.8 |
| 831-2 ² | -- | 10-19-17 | *** | 42.5 | 8.7 | 97.2 | 14.8 |
| 831-3 ² | -- | 8-11-15 | 10-18-17 | 42.5 | 5.0 | 97.2 | 14.8 |
| 831-3 ² | -- | 10-19-17 | *** | 42.5 | 8.7 | 97.2 | 14.8 |
| 831-4 ² | -- | 6-14-17 | 10-18-17 | 42.5 | 5.0 | 97.2 | 14.8 |
| 831-4 ² | -- | 10-19-17 | *** | 42.5 | 8.7 | 97.2 | 14.8 |

1 *** = currently in effect

2 Targets based on oil 831

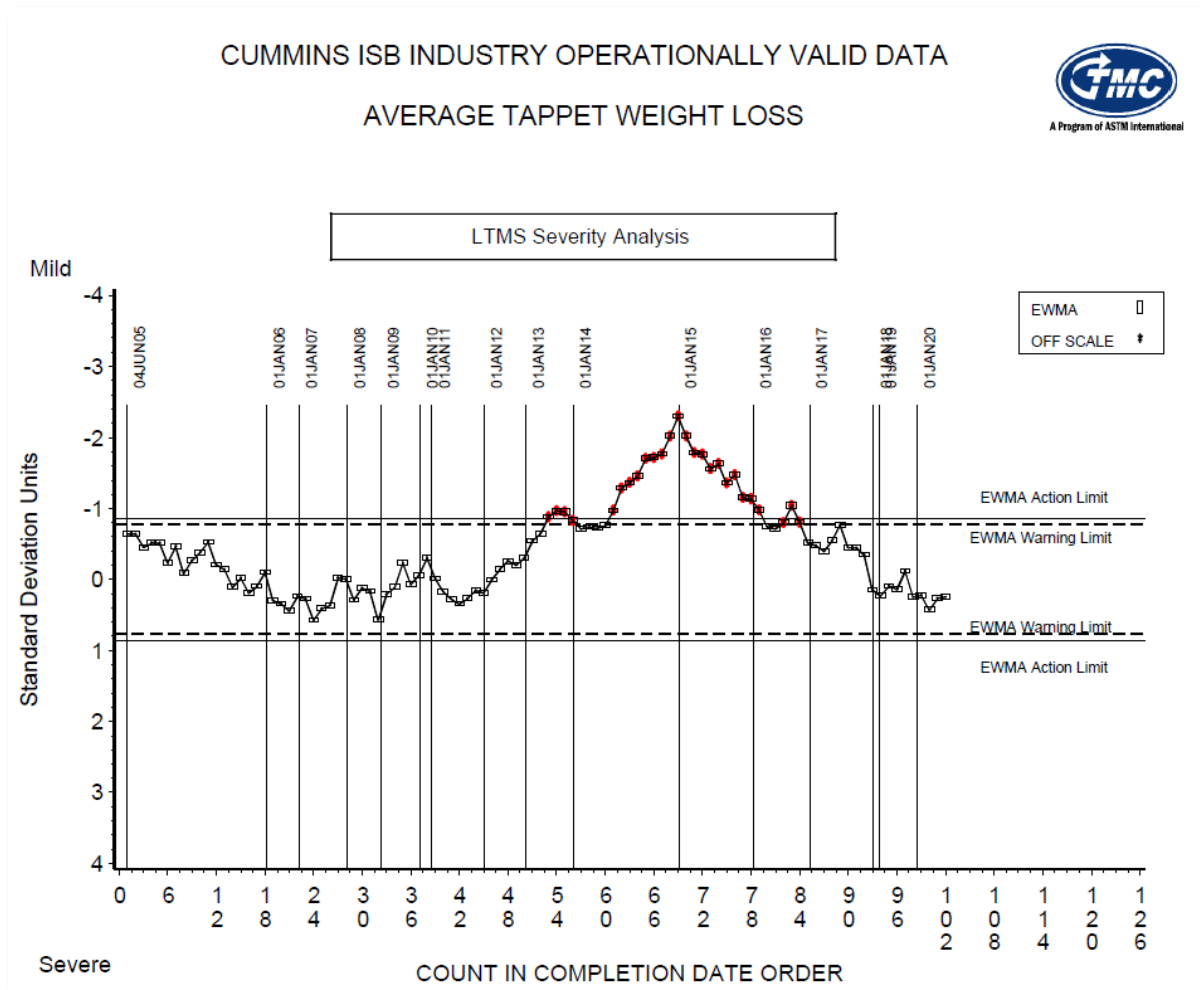
Average Camshaft Wear: ACSWzi EWMA Control Chart

Chart indicates ACSW is trending severe since the end of 2017



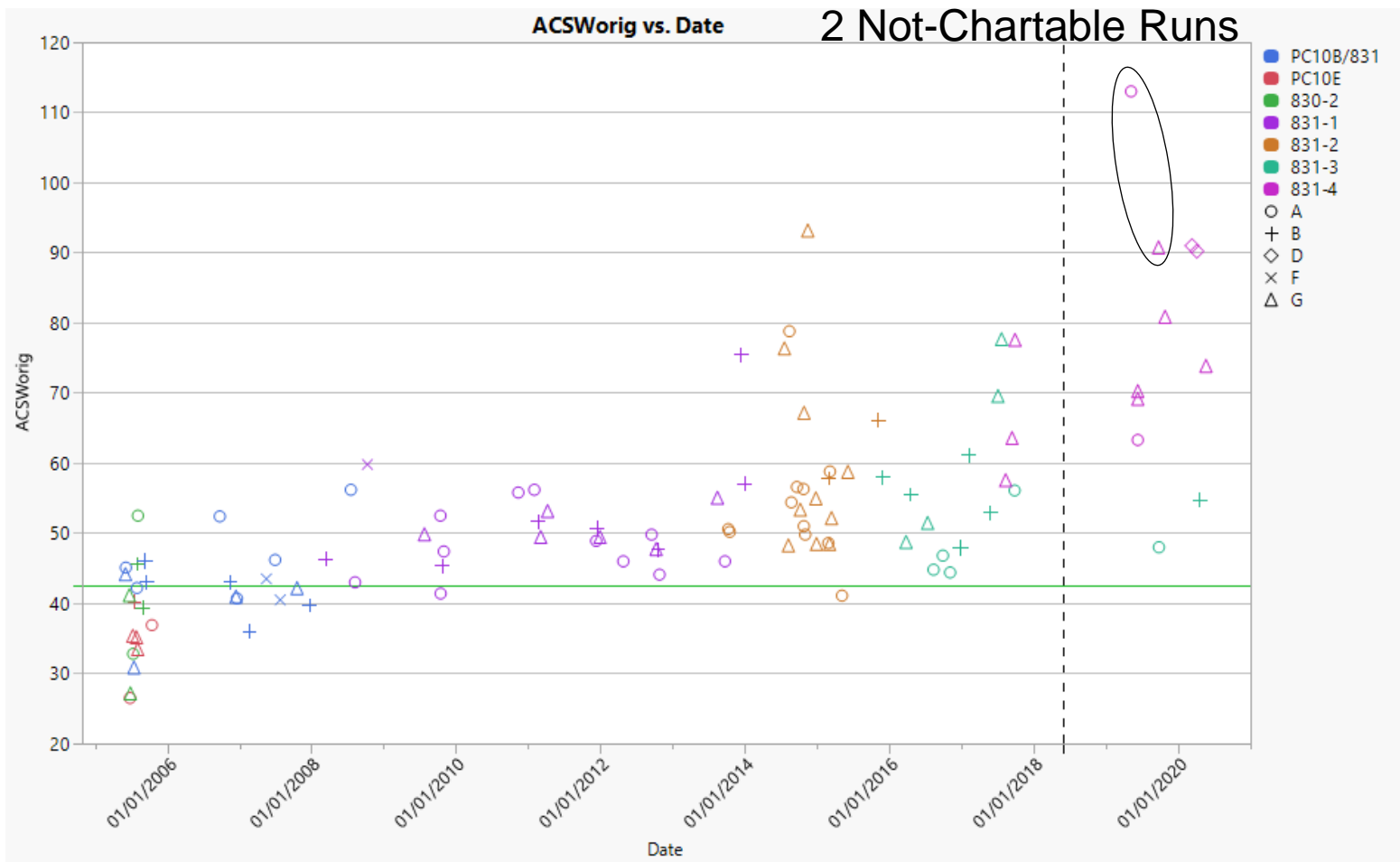
Average Tappet Weight Loss: ATWLzi EWMA Control Chart

Chart indicates Tappet Weight Loss appears to be performing on target

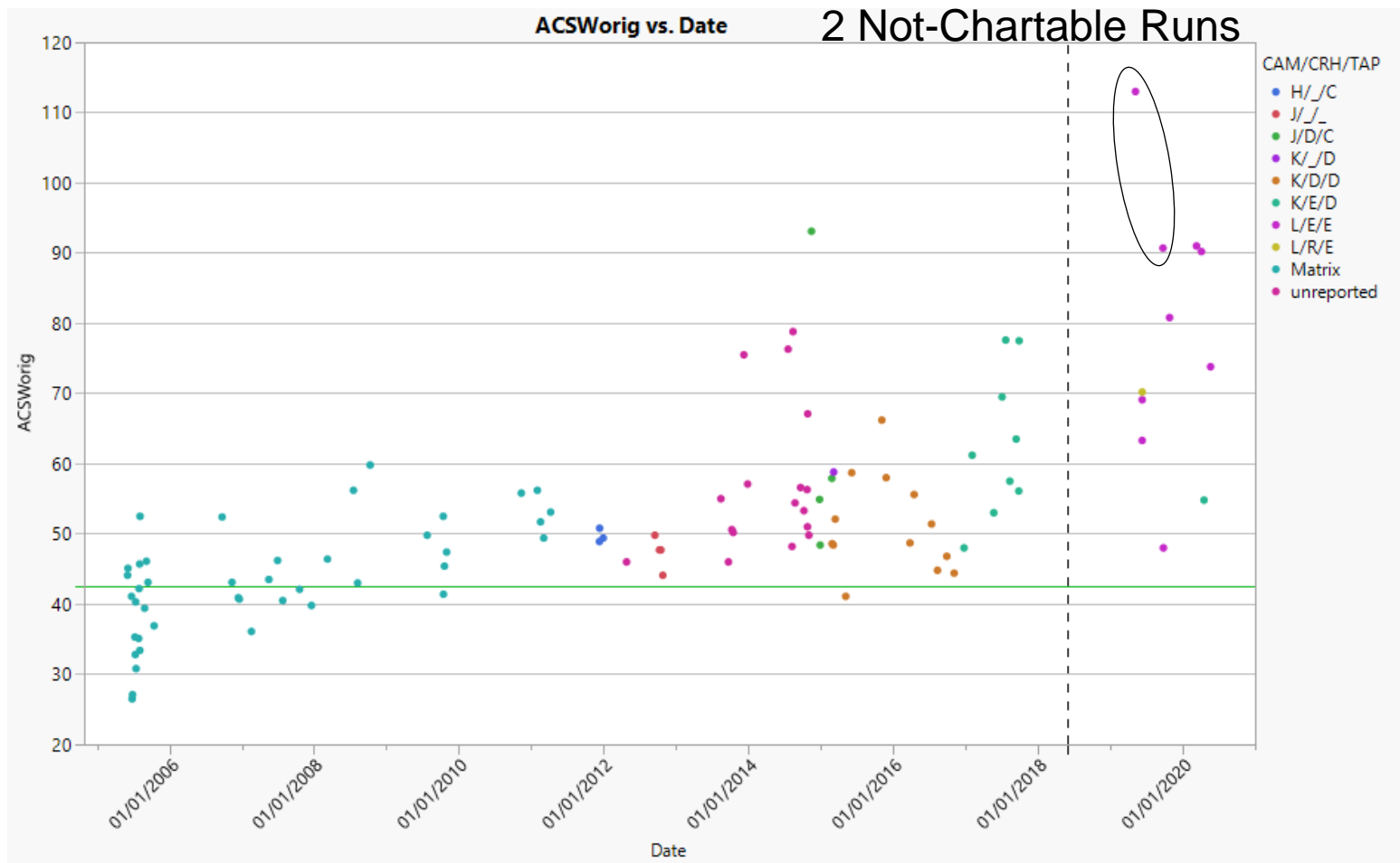


AVERAGE CAMSHAFT WEAR UNCORRECTED ORIGINAL RESULTS

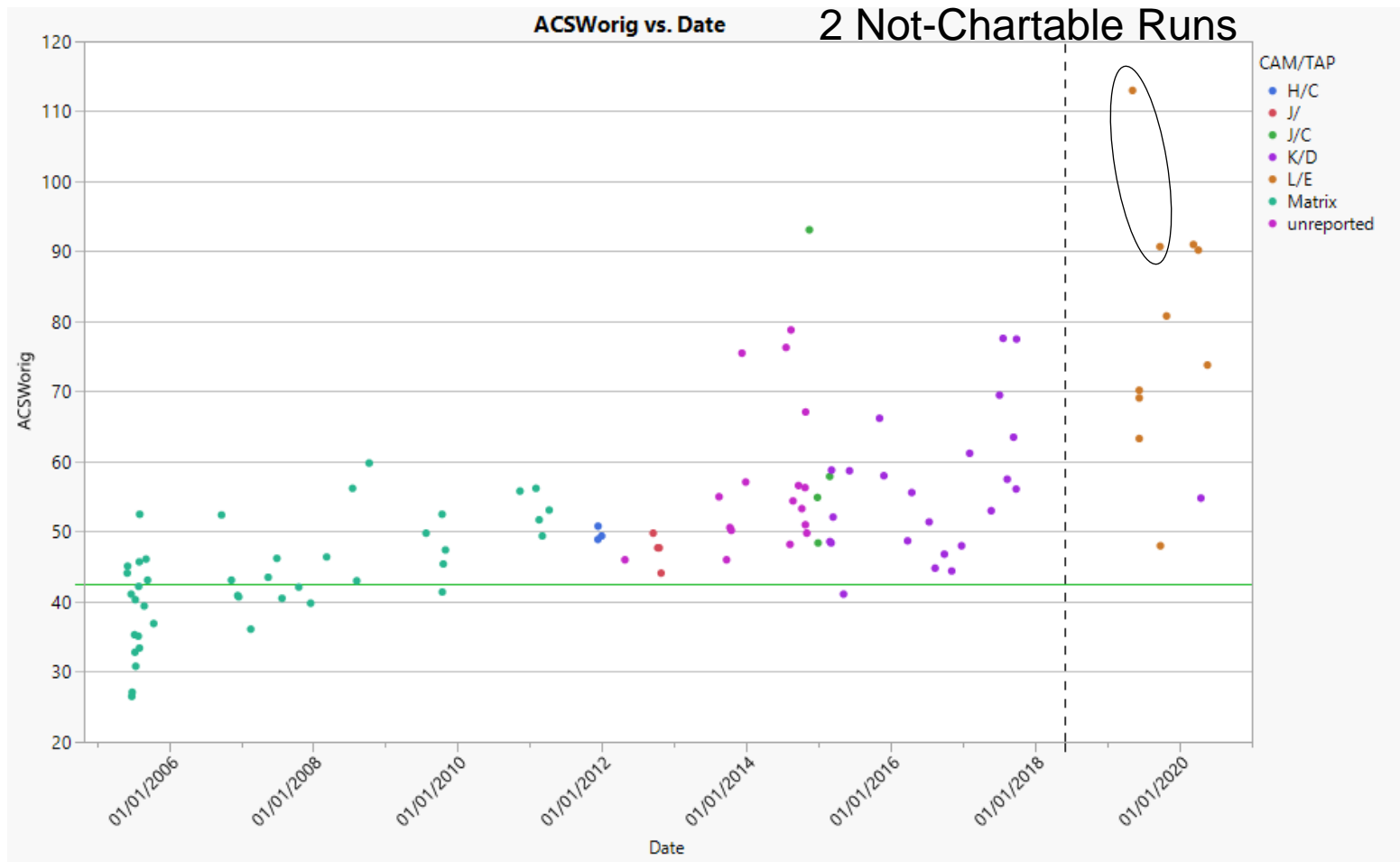
Average Camshaft Wear (ACSWorig): IND/LAB



Average Camshaft Wear (ACSWorig): CAM/CRH/TAP ID

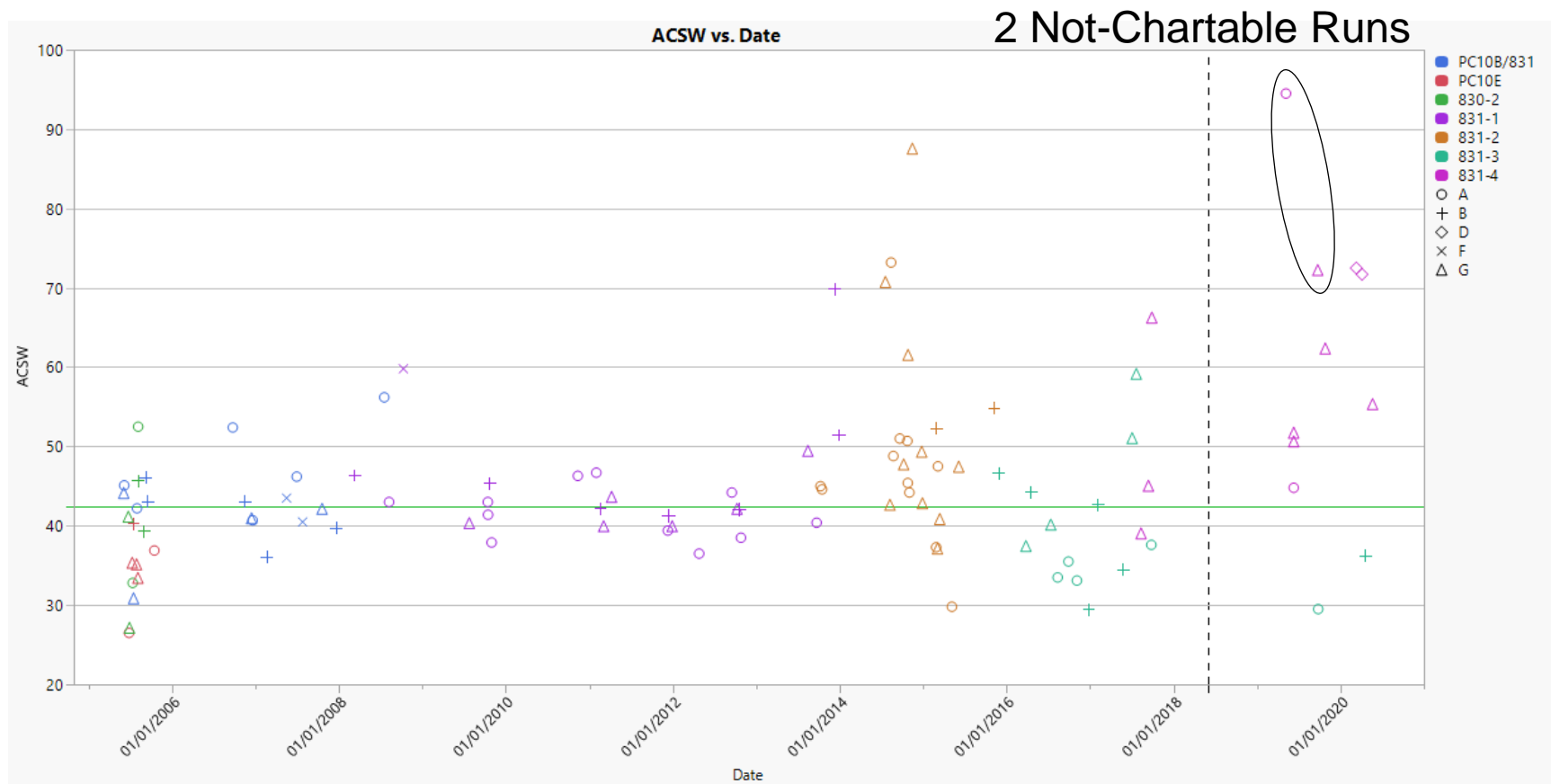


Average Camshaft Wear (ACSWorig): CAM/TAP ID

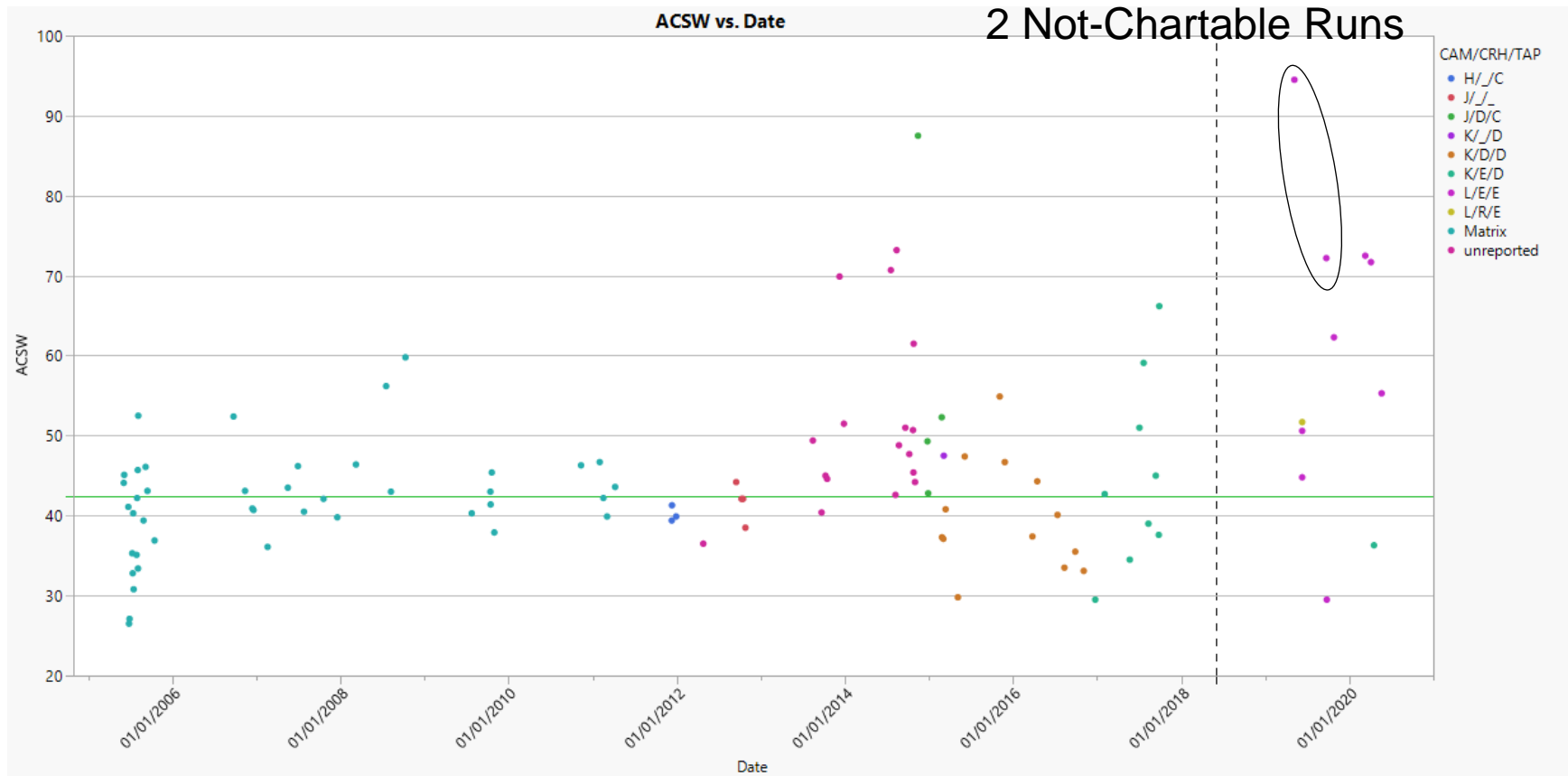


AVERAGE CAMSHAFT WEAR CORRECTION FACTORS APPLIED

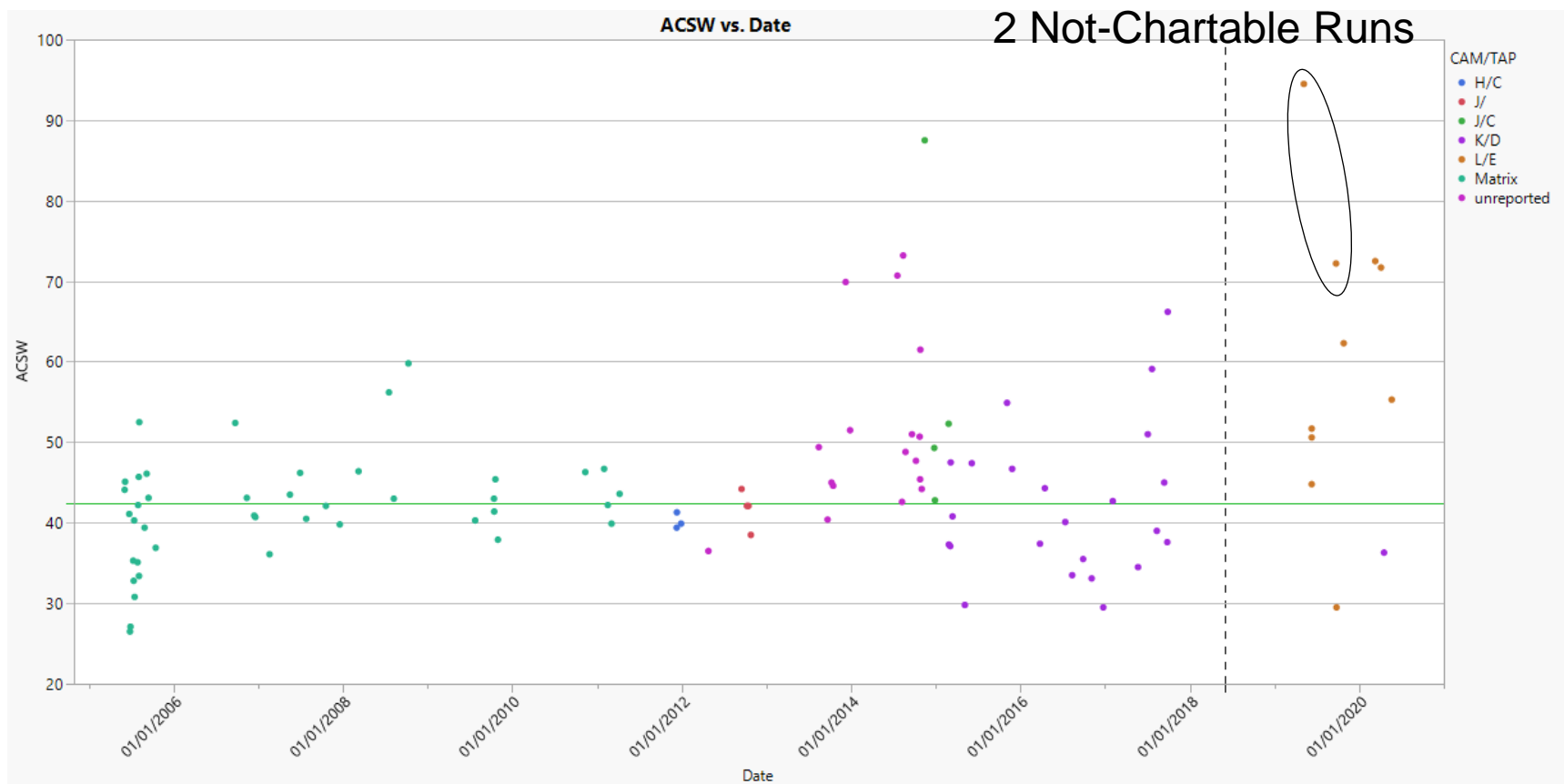
Average Camshaft Wear Correction Factors Applied (ACSW): IND/LAB



Average Camshaft Wear Correction Factors Applied (ACSW): CAM/CRH/TAP ID



Average Camshaft Wear Correction Factors Applied (ACSW): CAM/TAP ID



Camshaft Wear vs Lab, Oil nested with Hardware (CAM/TAP)

▲ A model of ACSW (corrected results) with Lab and Oil/CAMBID/TAPBID

▲ The model includes:

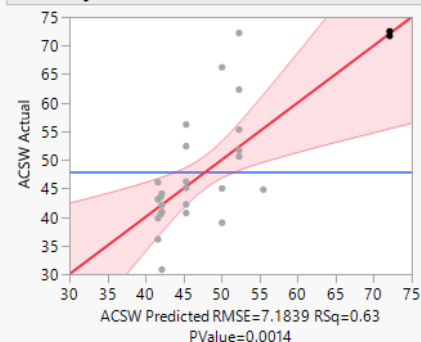
- ▲ Lab
 - ▲ Not enough runs for both oil and hardware batches
 - 831 Precision Matrix/original hardware
 - 831-4 nested with KD CAM/TAP hardware
 - 831-4 nested with LE CAM/TAP hardware
 - ▲ Oil/Hardware Batch is marginally significant
 - 831-4_LE is significantly different 831 Precision Matrix
 - ▲ Lab is slightly significant
 - D is significantly higher than all labs but results very similar to 2 unchartable tests

Camshaft Wear vs Lab, Oil nested with Hardware (CAM/TAP)

A model of ACSW (corrected results)

Whole Model

Actual by Predicted Plot



Summary of Fit

| | |
|----------------------------|----------|
| RSquare | 0.629981 |
| RSquare Adj | 0.518975 |
| Root Mean Square Error | 7.183884 |
| Mean of Response | 47.85185 |
| Observations (or Sum Wgts) | 27 |

Analysis of Variance

| Source | DF | Sum of Squares | Mean Square | F Ratio |
|----------|----|----------------|-------------|----------|
| Model | 6 | 1757.3237 | 292.887 | 5.6752 |
| Error | 20 | 1032.1637 | 51.608 | Prob > F |
| C. Total | 26 | 2789.4874 | | 0.0014* |

Parameter Estimates

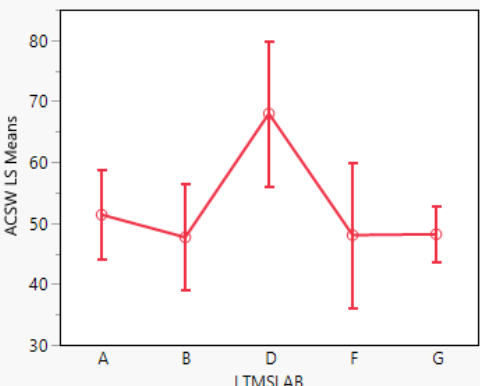
| Term | Estimate | Std Error | t Ratio | Prob> t |
|------------------------------------|-----------|-----------|---------|---------|
| Intercept | 52.640222 | 2.308468 | 22.80 | <.0001* |
| LTMSLAB[A] | -1.268 | 2.84195 | -0.45 | 0.6603 |
| LTMSLAB[B] | -4.978 | 3.342629 | -1.49 | 0.1520 |
| LTMSLAB[D] | 15.332 | 5.162909 | 2.97 | 0.0076* |
| LTMSLAB[F] | -4.618 | 4.523565 | -1.02 | 0.3195 |
| RefOil_Hardware[PC10B/831_MATRIX] | -6.022222 | 2.672809 | -2.25 | 0.0356* |
| RefOil_Hardware[831-4_KD] | 1.8944444 | 3.242341 | 0.58 | 0.5656 |

Effect Tests

| Source | Nparm | DF | Sum of Squares | F Ratio | Prob > F |
|-----------------|-------|----|----------------|---------|----------|
| LTMSLAB | 4 | 4 | 579.68922 | 2.8081 | 0.0533 |
| RefOil_Hardware | 2 | 2 | 311.96833 | 3.0225 | 0.0713 |

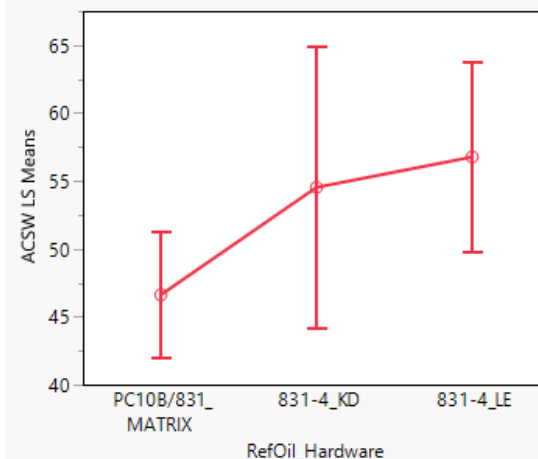
Least Squares Means Table

| Level | Least Sq Mean | Std Error | Mean |
|-------|---------------|-----------|---------|
| A | 51.372222 | 3.5078097 | 46.8000 |
| B | 47.662222 | 4.1791802 | 41.6400 |
| D | 67.972222 | 5.7400350 | 72.1000 |
| F | 48.022222 | 5.7400350 | 42.0000 |
| G | 48.172222 | 2.1859862 | 48.0000 |



Least Squares Means Table

| Level | Least Sq Mean | Std Error | Mean |
|------------------|---------------|-----------|---------|
| PC10B/831_MATRIX | 46.618000 | 2.2316339 | 43.1118 |
| 831-4_KD | 54.534667 | 4.9632959 | 50.0667 |
| 831-4_LE | 56.768000 | 3.3426295 | 58.4143 |



| Level | Least Sq Mean |
|-------|---------------|
| D A | 67.972222 |
| A B | 51.372222 |
| G B | 48.172222 |
| F B | 48.022222 |
| B B | 47.662222 |

Levels not connected by same letter are significantly different.

| Level | Least Sq Mean |
|--------------------|---------------|
| 831-4_LE A | 56.768000 |
| 831-4_KD A B | 54.534667 |
| PC10B/831_MATRIX B | 46.618000 |

Camshaft Wear vs Lab and Oil

▲ A model of ACSW (corrected results) with Lab and Oil

▲ The model includes:

▲ All Labs

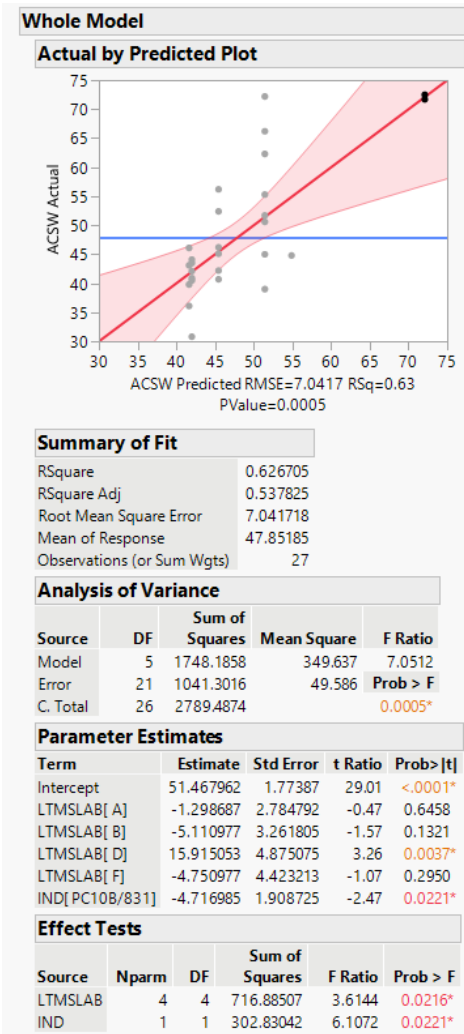
- D is significantly higher than all labs but results very similar to 2 unchartable tests

▲ PC10B/831 and 831-4

- 831-4 is significantly higher than PC10B/831
- Difference in LS Mean is about 10

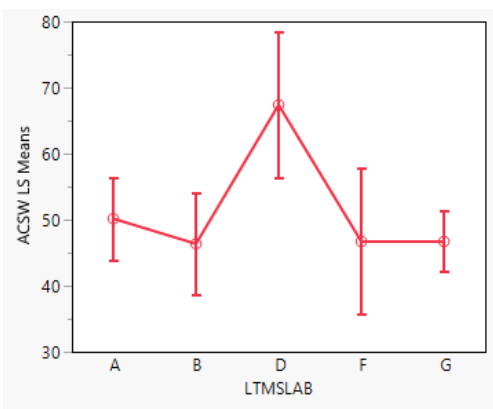
Camshaft Wear vs Lab and Oil

A model of ACSW (corrected results)



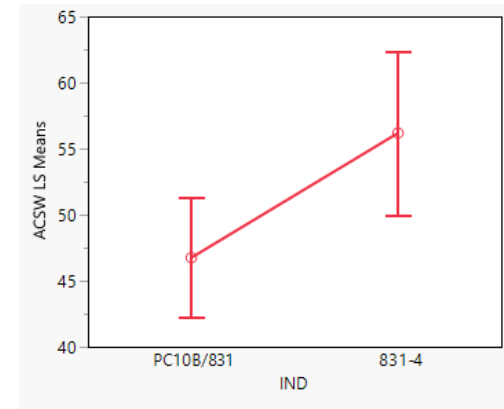
Least Squares Means Table

| Level | Least Sq Mean | Std Error | Mean |
|-------|---------------|-----------|---------|
| A | 50.169275 | 2.9903972 | 46.8000 |
| B | 46.356985 | 3.6824433 | 41.6400 |
| D | 67.383015 | 5.3325534 | 72.1000 |
| F | 46.716985 | 5.3325534 | 42.0000 |
| G | 46.713550 | 2.1860428 | 48.0000 |



Least Squares Means Table

| Level | Least Sq Mean | Std Error | Mean |
|-----------|---------------|-----------|---------|
| PC10B/831 | 46.750977 | 2.1654271 | 43.1118 |
| 831-4 | 56.184947 | 2.9817140 | 55.9100 |



| Level | Least Sq Mean |
|-------|---------------|
| D A | 67.383015 |
| A B | 50.169275 |
| F B | 46.716985 |
| G B | 46.713550 |
| B B | 46.356985 |

Levels not connected by same letter are significantly different.

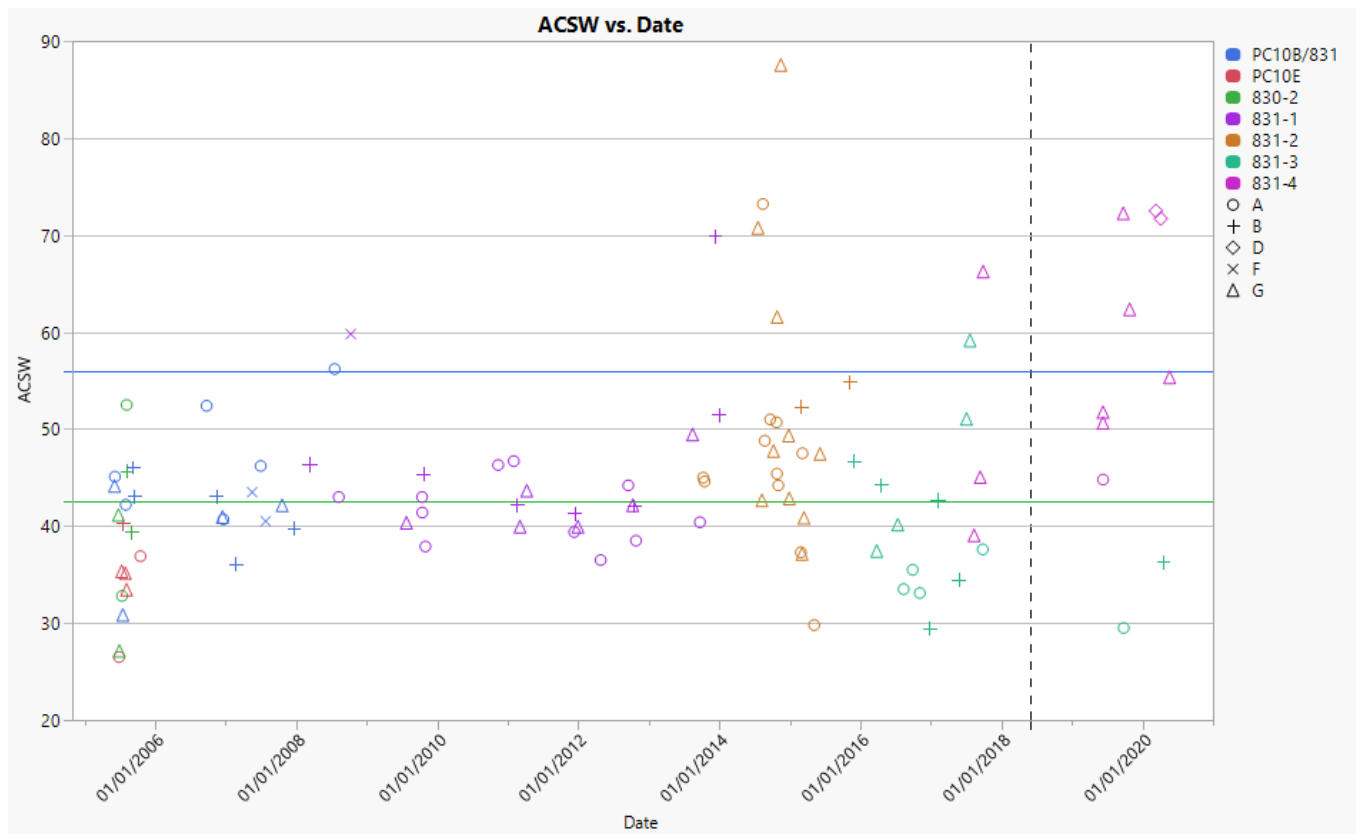
| Level | Least Sq Mean |
|-------------|---------------|
| 831-4 A | 56.184947 |
| PC10B/831 B | 46.750977 |

Update Oil Targets (arithmetic mean, sd)

ACSW target (corrected results) – Only Chartable Runs

▲ 831-4 Average ACSW = 55.9

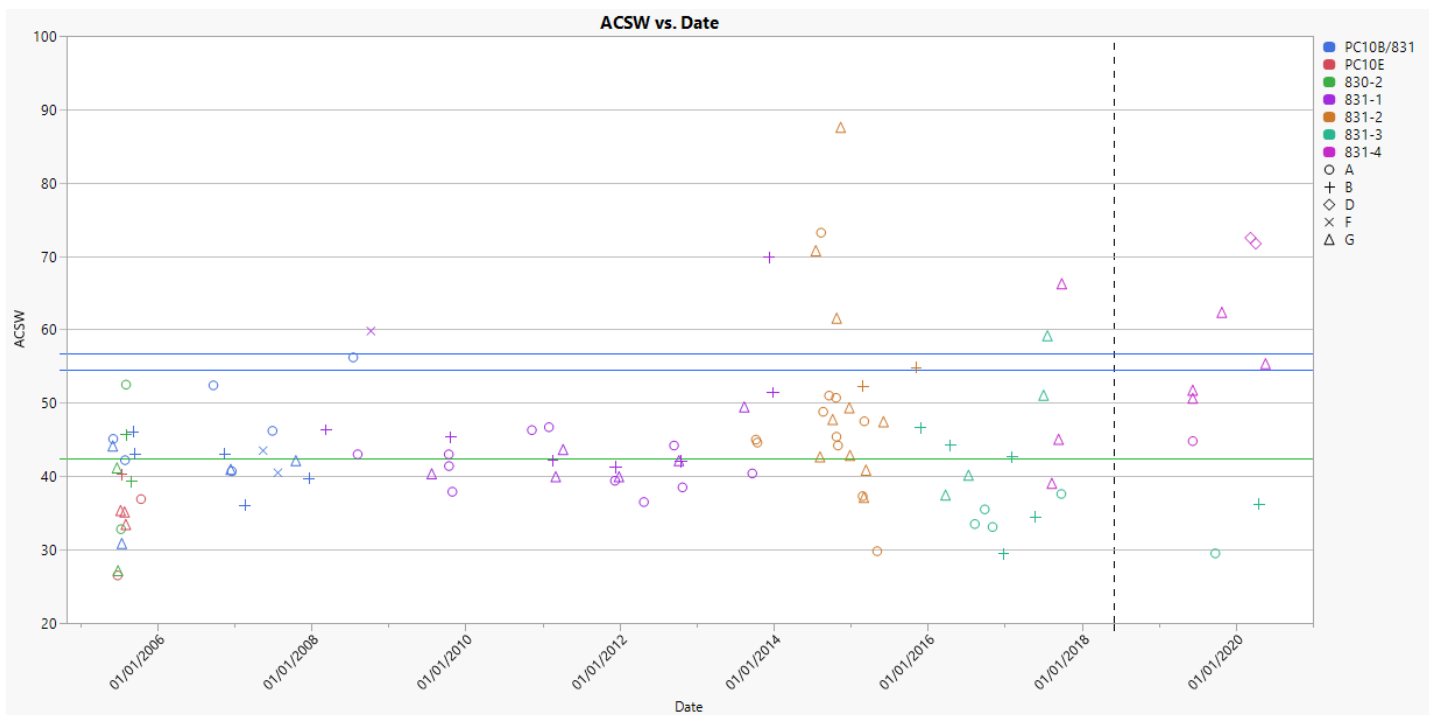
▲ 831-4 Standard Deviation ACSW = 11.8



Update Hardware Correction Factors

ACSW – Only Chartable Runs using CAM/TAP = L/E Oil 831-4 in [model](#)

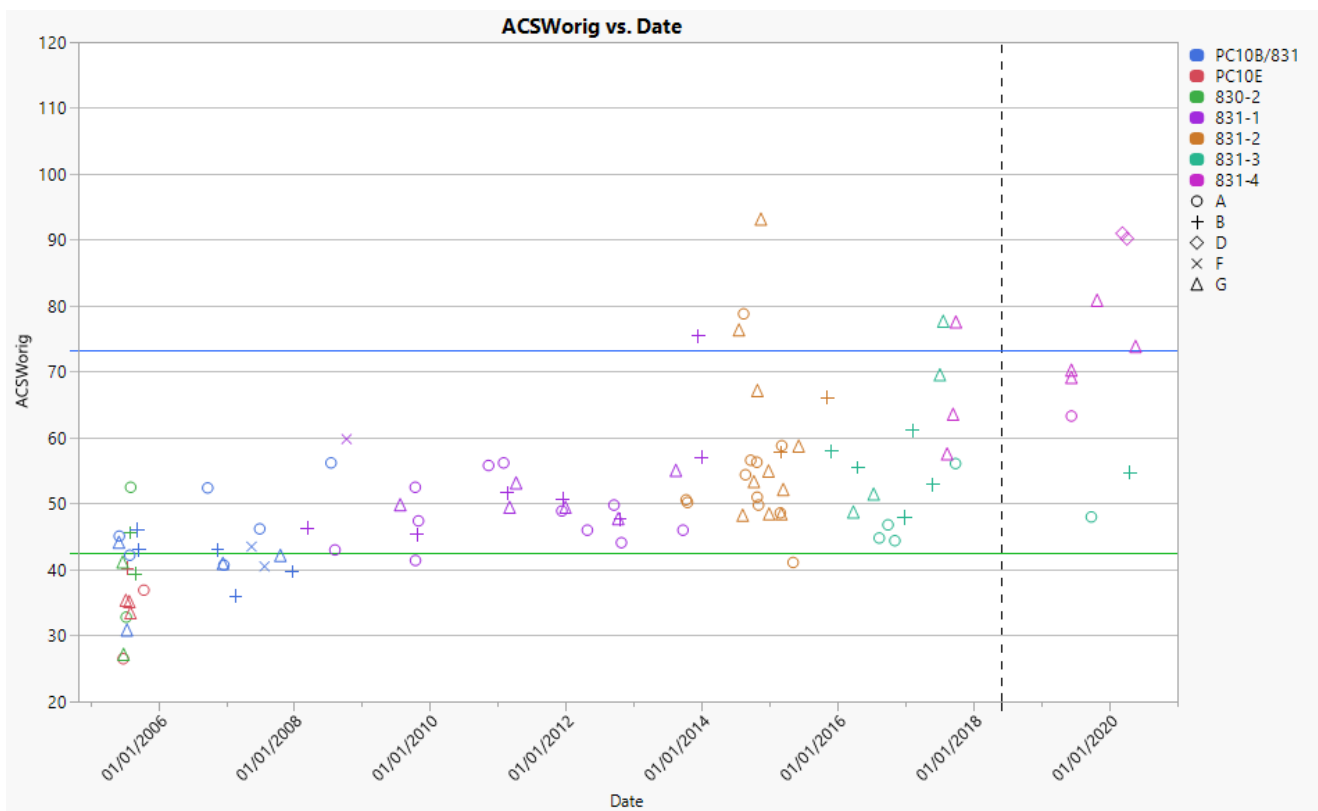
- ▲ L/E LS Mean = 56.8
- ▲ K/D LS Mean = 54.5



Update Hardware Correction Factors

🏠 ACSWorig – Only Chartable Runs using CAM/TAP = L/E

▲ L/E Average ACSWorig = $73.3 - 30.8 = 42.5$



Summary of Options

- Option 1: Update 831-4 Target and Sigma for Average Camshaft Wear using raw mean and standard deviation

| | Oil | n | Average Camshaft Wear | |
|----------|-------|----|-----------------------|------|
| | | | Target | s |
| Current | 831-4 | | 42.5 | 8.7 |
| Proposed | 831-4 | 10 | 55.9 | 11.8 |

- Option 2: Consider Modifying Industry Correction Factor with Minor Update

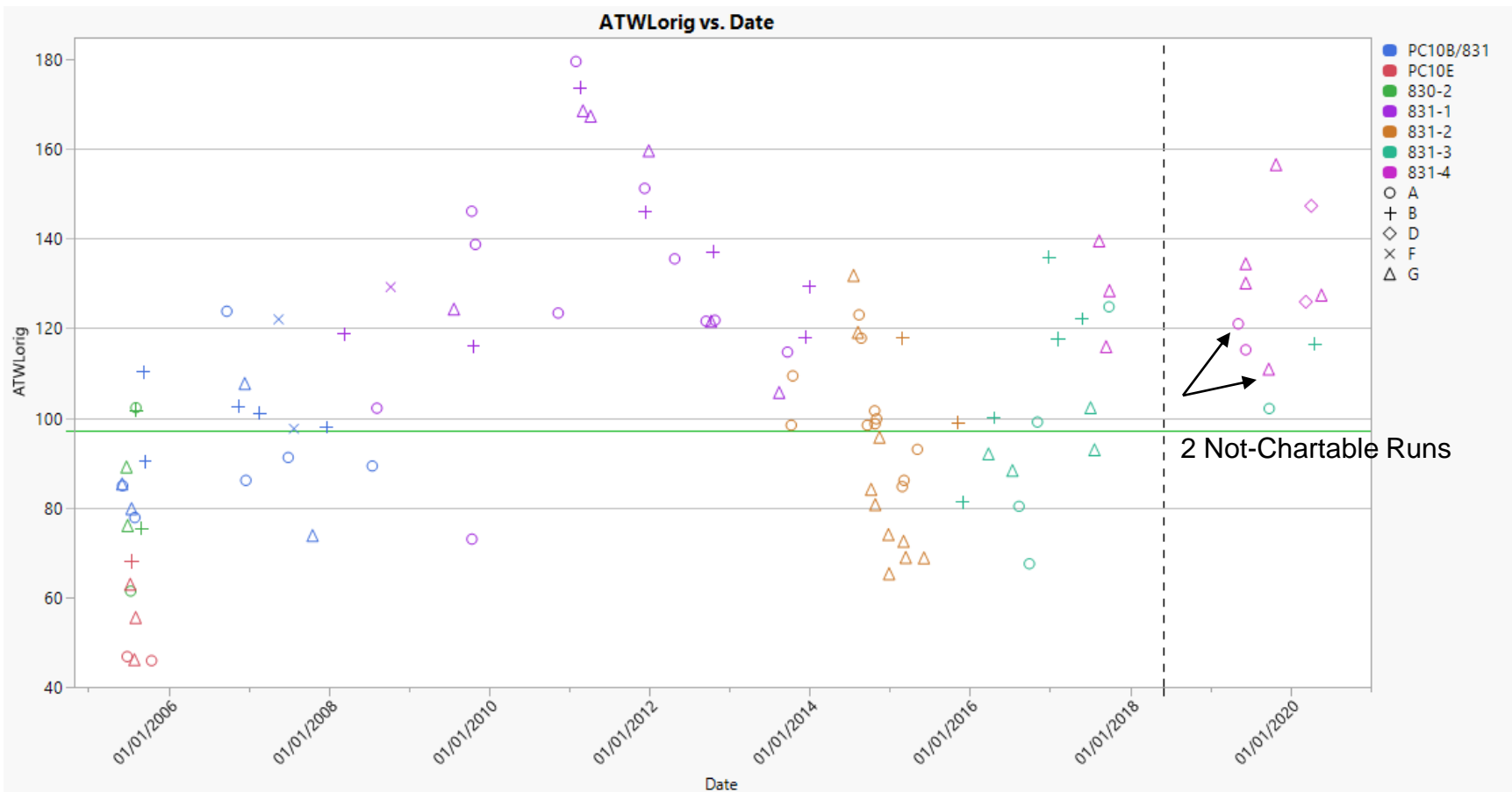
▲ Difference in Hardware LS Mean $(-18.5 + (54.5 - 56.8)) = -20.8$

- Option 3 : Modifying Industry Correction Factor for L/E cams and tappets

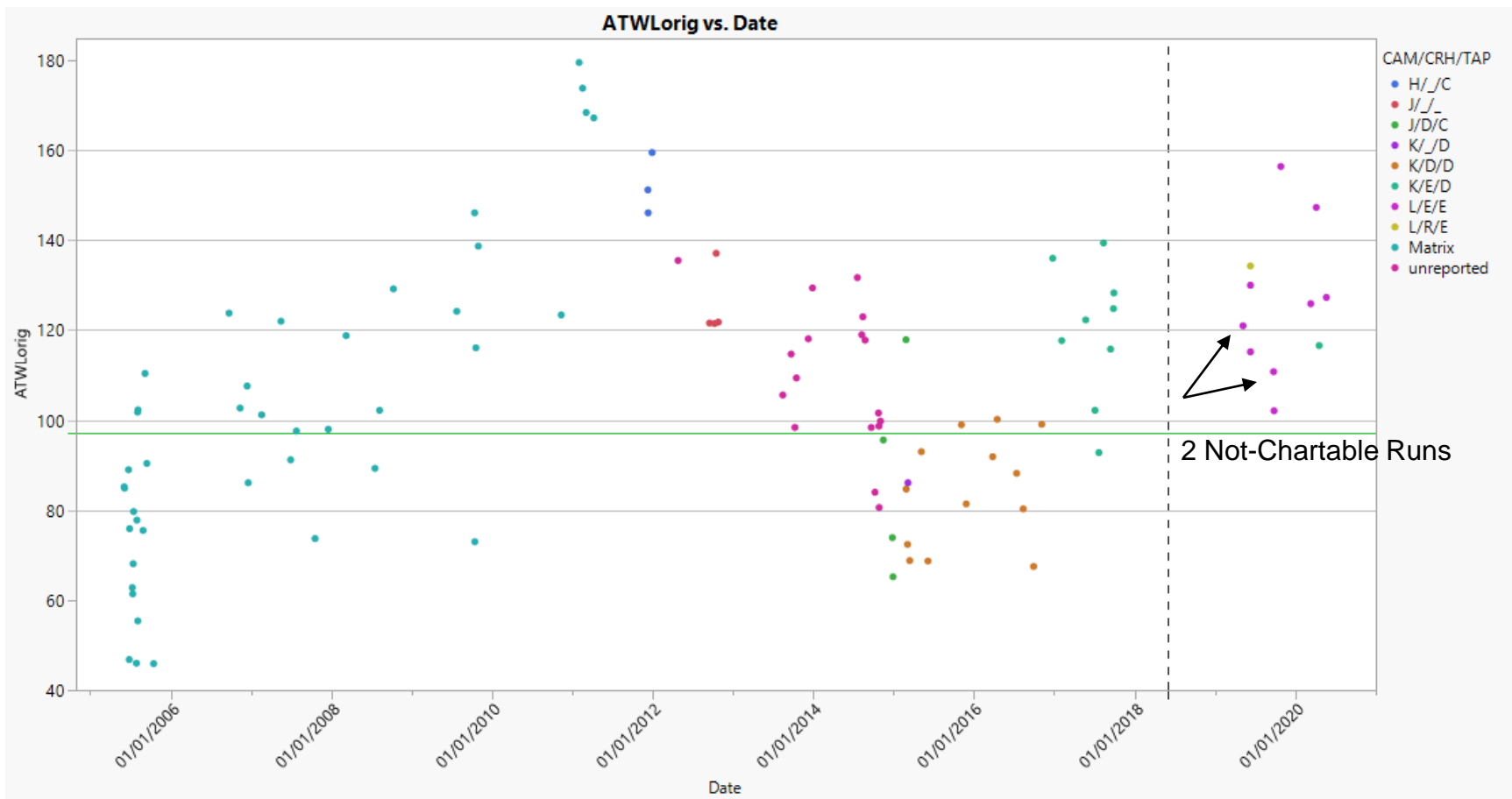
▲ L/E Average ACSWorig = $73.3 - 30.8 = 42.5$

AVERAGE TAPPET WEAR UNCORRECTED ORIGINAL RESULTS

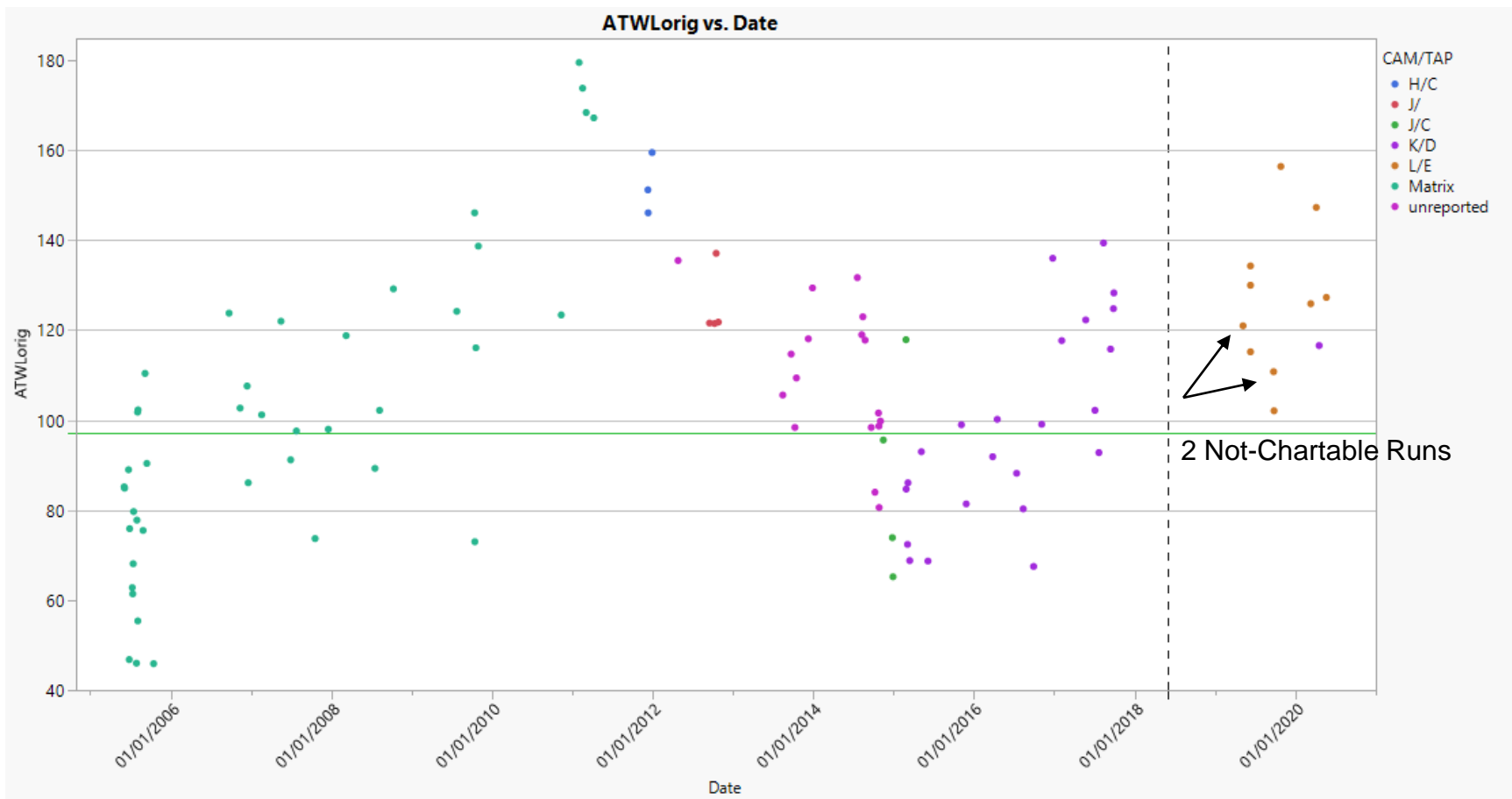
Average Tappet Wear (ATWOrig):



Average Tappet Wear (ATWLorig): CAM/CRH/TAP ID

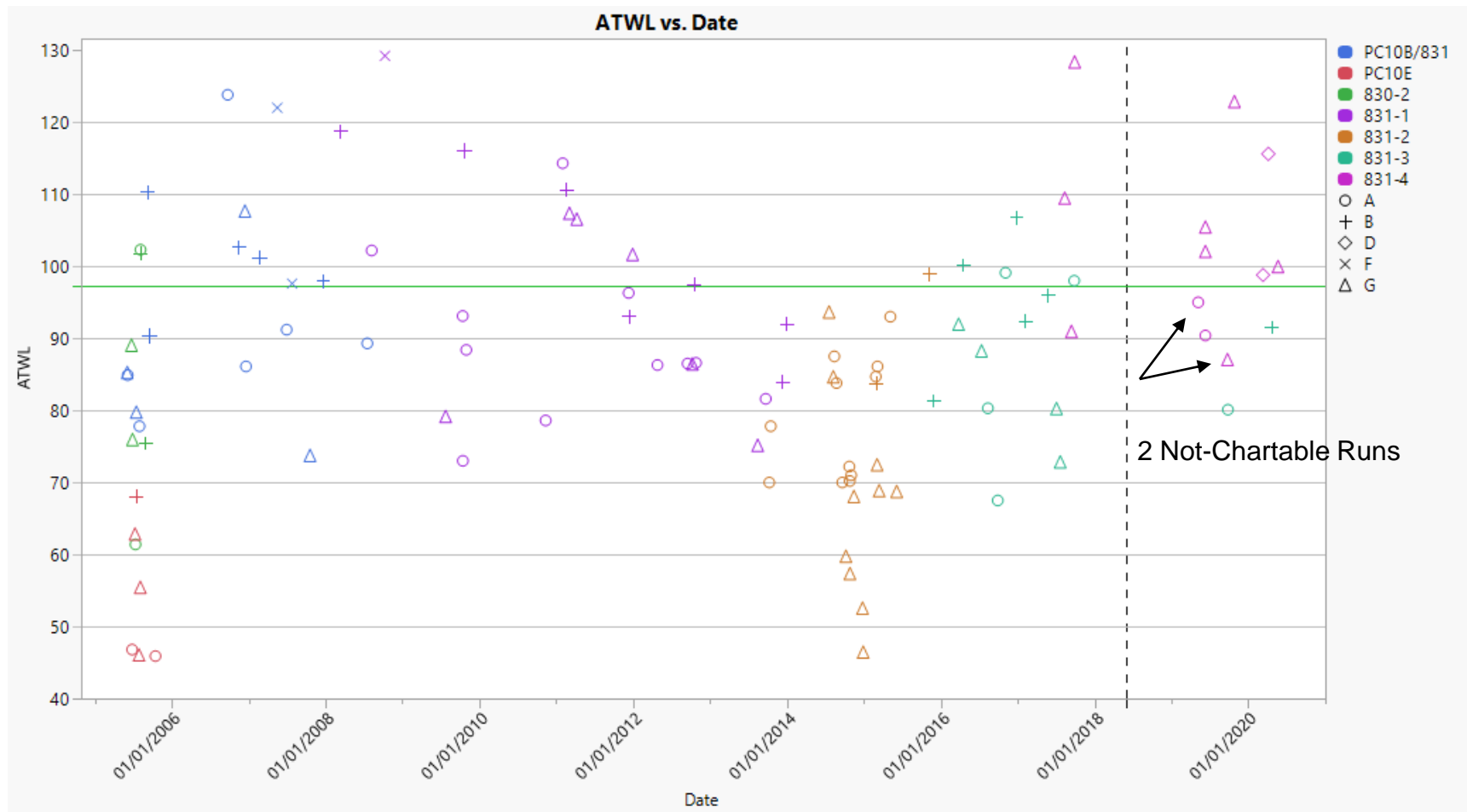


Average Tappet Wear (ATWLorig): CAM/TAP ID

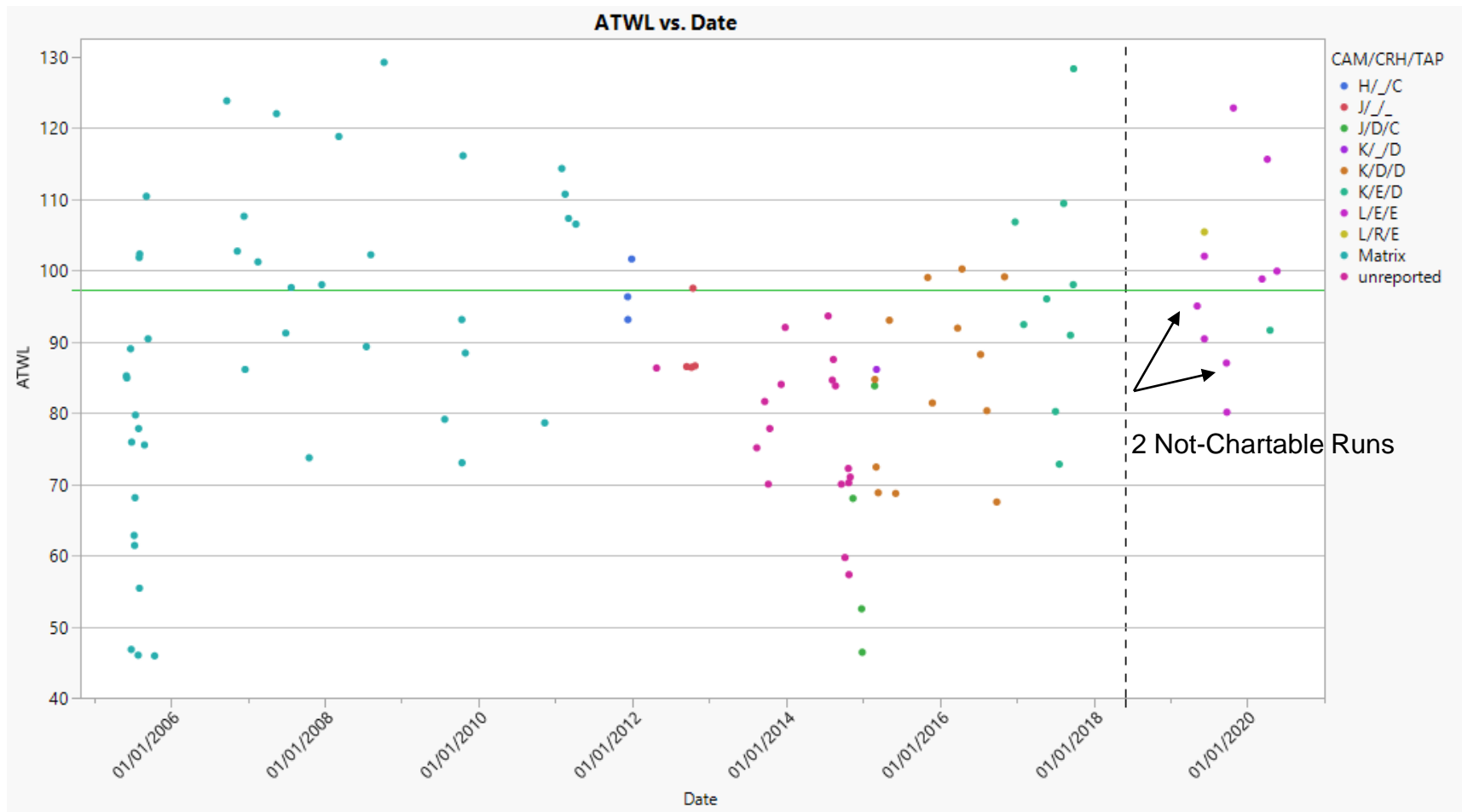


AVERAGE TAPPET WEAR CORRECTION FACTORS APPLIED

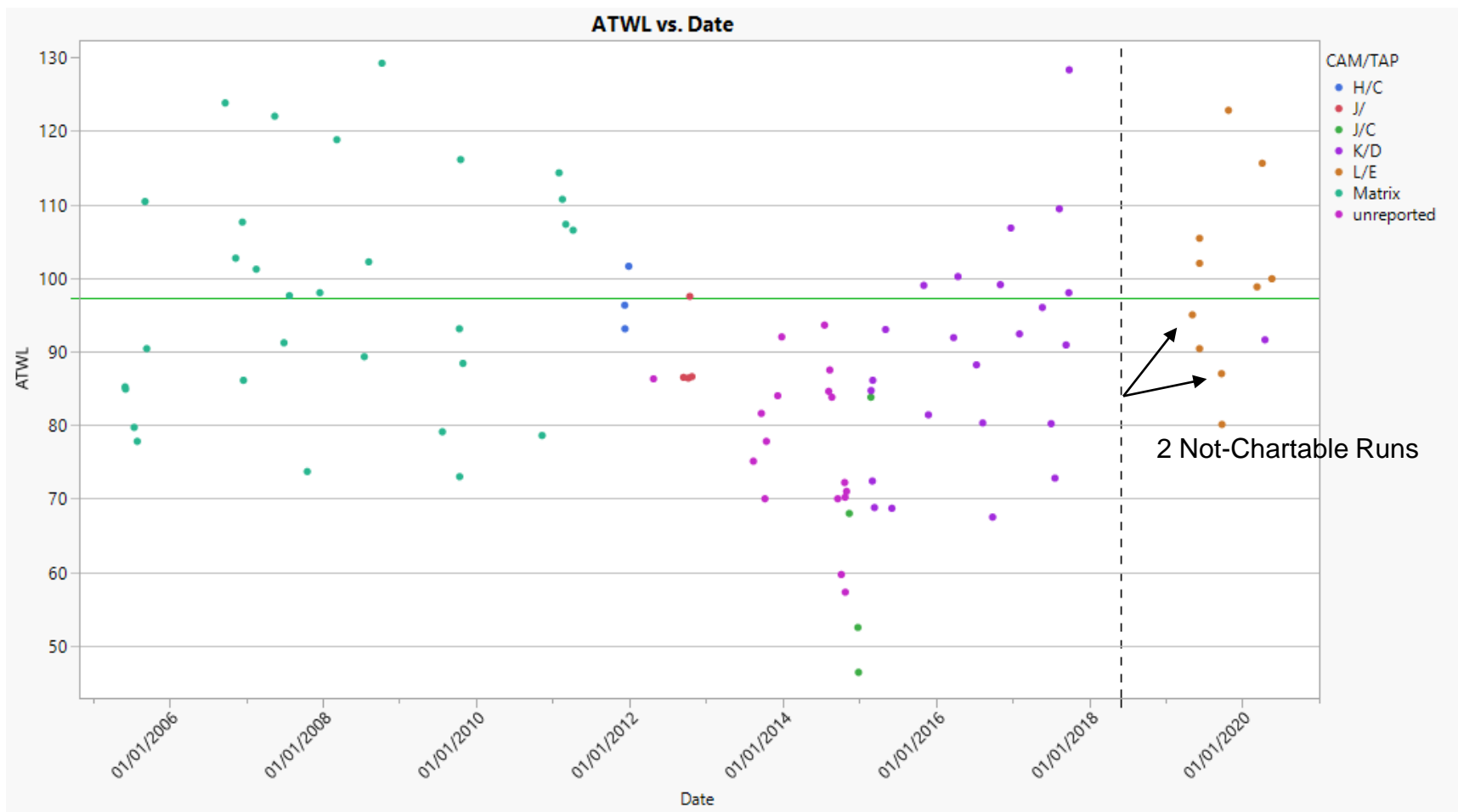
Average Tappet Wear Correction Factors Applied (ATWL):



Average Tappet Wear Correction Factors Applied (ATWL): CAM/CRH/TAP ID



Average Tappet Wear Correction Factors Applied (ATWL): CAM/TAP ID



Update Oil Targets Tappet Wear

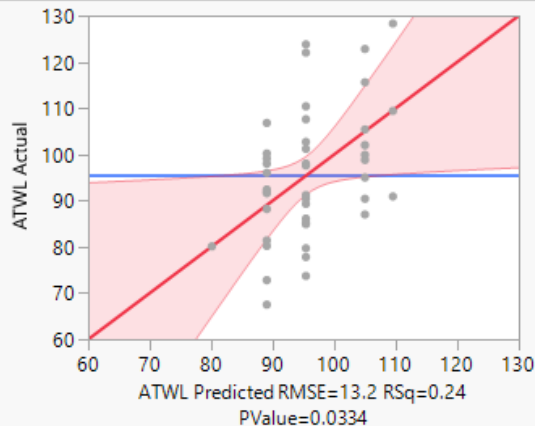
- ▲ A model of ATWL (corrected results) with Lab and Oil/CAMBID/TAPBID shows there is a significant difference in the Hardware Batch
- ▲ The model includes:
 - ▲ Not enough runs for both oil and hardware batches
 - 831-3 nested with KD and LE CAM/TAP hardware
 - 831-4 nested with KD and LE CAM/TAP hardware
 - ▲ Significant difference in 831-4_KD and 831-4_KD compared to 831-3_KD
 - ▲ Lab-Not a significant difference, removed from model

Update Oil Targets

A model of ATWL (corrected results)

Whole Model

Actual by Predicted Plot



Summary of Fit

| | |
|----------------------------|----------|
| RSquare | 0.240759 |
| RSquare Adj | 0.158679 |
| Root Mean Square Error | 13.19998 |
| Mean of Response | 95.51429 |
| Observations (or Sum Wgts) | 42 |

Analysis of Variance

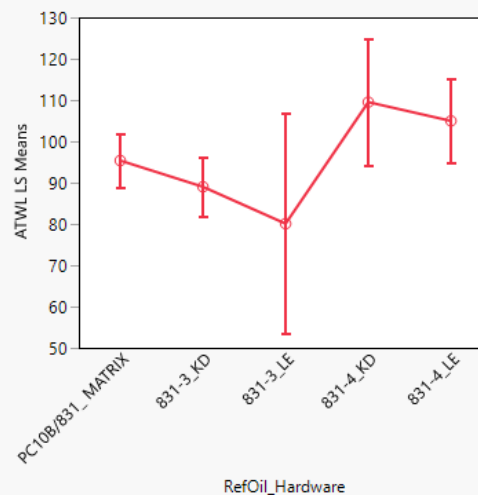
| Source | DF | Sum of Squares | Mean Square | F Ratio |
|----------|----|----------------|-------------|----------|
| Model | 4 | 2044.3300 | 511.082 | 2.9332 |
| Error | 37 | 6446.8615 | 174.239 | Prob > F |
| C. Total | 41 | 8491.1914 | | 0.0334* |

Effect Tests

| Source | Nparm | DF | Sum of Squares | F Ratio | Prob > F |
|-----------------|-------|----|----------------|---------|----------|
| RefOil_Hardware | 4 | 4 | 2044.3300 | 2.9332 | 0.0334* |

Least Squares Means Table

| Level | Least Sq Mean | Std Error | Mean |
|------------------|---------------|-----------|---------|
| PC10B/831_MATRIX | 95.38824 | 3.201466 | 95.388 |
| 831-3_KD | 89.02857 | 3.527843 | 89.029 |
| 831-3_LE | 80.10000 | 13.199981 | 80.100 |
| 831-4_KD | 109.53333 | 7.621013 | 109.533 |
| 831-4_LE | 104.98571 | 4.989124 | 104.986 |



| Level | | Least Sq Mean |
|------------------|-----|---------------|
| 831-4_KD | A | 109.53333 |
| 831-4_LE | A | 104.98571 |
| PC10B/831_MATRIX | A B | 95.38824 |
| 831-3_KD | B | 89.02857 |
| 831-3_LE | A B | 80.10000 |

Count

| |
|----|
| 14 |
| 7 |
| 17 |
| 14 |
| 1 |

Levels not connected by same letter are significantly different.

Update Oil Targets Tappet Wear

▲ A model of ATWL (corrected results) with Lab and Oil show there is a significant difference in both Oil and Lab

▲ The model includes:

▲ Lab

- Labs A and G are significantly different than Labs B and F

▲ Oils PC10B/831, 831-1, 831-2, 831-3, and 831-4 (target at 97.2)

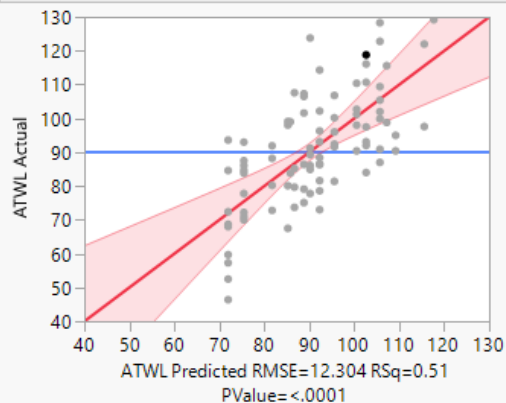
- Blend 831-4 is significantly higher than all other oils
- Blend 831-2 is significantly lower than all other oils
- There is no difference in blends PC10B/831, 831-1 and 831-3

Update Oil Targets

A model of ATWL (corrected results)

Whole Model

Actual by Predicted Plot



Summary of Fit

| | |
|----------------------------|----------|
| RSquare | 0.509382 |
| RSquare Adj | 0.460925 |
| Root Mean Square Error | 12.30392 |
| Mean of Response | 90.18889 |
| Observations (or Sum Wgts) | 90 |

Analysis of Variance

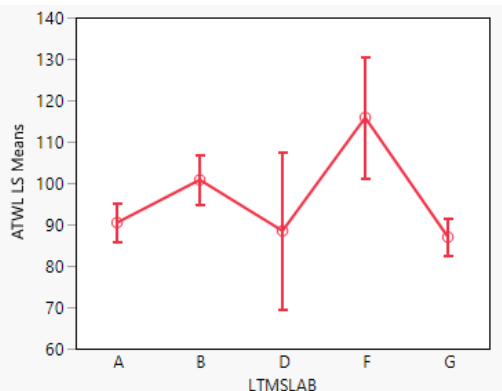
| Source | DF | Sum of Squares | Mean Square | F Ratio |
|----------|----|----------------|-------------|----------|
| Model | 8 | 12731.263 | 1591.41 | 10.5122 |
| Error | 81 | 12262.306 | 151.39 | Prob > F |
| C. Total | 89 | 24993.569 | | <.0001* |

Effect Tests

| Source | Nparm | DF | Sum of Squares | F Ratio | Prob > F |
|---------|-------|----|----------------|---------|----------|
| LTMSLAB | 4 | 4 | 3516.7493 | 5.8076 | 0.0004* |
| IND | 4 | 4 | 7634.9648 | 12.6084 | <.0001* |

Least Squares Means Table

| Level | Least Sq Mean | Std Error | Mean |
|-------|---------------|-----------|---------|
| A | 90.47167 | 2.3012068 | 85.932 |
| B | 100.81193 | 2.9771960 | 98.305 |
| D | 88.47669 | 9.5424341 | 107.200 |
| F | 115.84921 | 7.3744805 | 116.267 |
| G | 86.97741 | 2.2625788 | 86.000 |



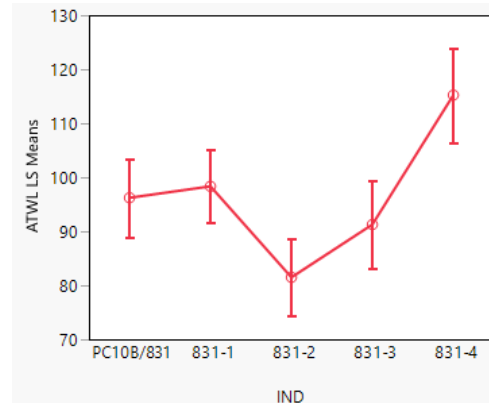
Least Squares Means Table

| Level | | Least Sq Mean |
|-------|-----|---------------|
| F | A | 115.84921 |
| B | A | 100.81193 |
| A | B | 90.47167 |
| D | A B | 88.47669 |
| G | B | 86.97741 |

Levels not connected by same letter are significantly different.

Least Squares Means Table

| Level | Least Sq Mean | Std Error | Mean |
|-----------|---------------|-----------|---------|
| PC10B/831 | 96.22928 | 3.6472173 | 95.388 |
| 831-1 | 98.34596 | 3.3989855 | 95.372 |
| 831-2 | 81.49624 | 3.6022459 | 74.830 |
| 831-3 | 91.27474 | 4.0520519 | 88.433 |
| 831-4 | 115.24069 | 4.3967226 | 106.350 |



Least Squares Means Table

| Level | | Least Sq Mean |
|-----------|-----|---------------|
| 831-4 | A | 115.24069 |
| 831-1 | B | 98.34596 |
| PC10B/831 | B | 96.22928 |
| 831-3 | B C | 91.27474 |
| 831-2 | C | 81.49624 |



| Appendix

Passion for Solutions®

Camshaft Wear vs Lab, Oil nested with Hardware (CAM/TAP)

 A model of ACSW (corrected results) with Lab and Oil/CAMBID/TAPBID The model includes:

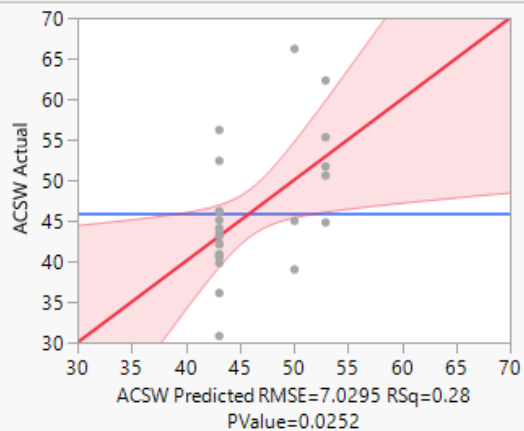
- ▶ Lab – Exclude Lab D, Lab no longer significant and removed from model
- ▶ Not enough runs for both oil and hardware batches
 - 831 Precision Matrix/original hardware
 - 831-4 nested with KD CAM/TAP hardware
 - 831-4 nested with LE CAM/TAP hardware
- ▶ Oil/Hardware Batch is significant
 - 831-4_LE is significantly different 831 Precision Matrix

Camshaft Wear vs Lab, Oil nested with Hardware (CAM/TAP)

A model of ACSW (corrected results)

Whole Model

Actual by Predicted Plot



Summary of Fit

| | |
|----------------------------|----------|
| RSquare | 0.284403 |
| RSquare Adj | 0.219349 |
| Root Mean Square Error | 7.029471 |
| Mean of Response | 45.912 |
| Observations (or Sum Wgts) | 25 |

Analysis of Variance

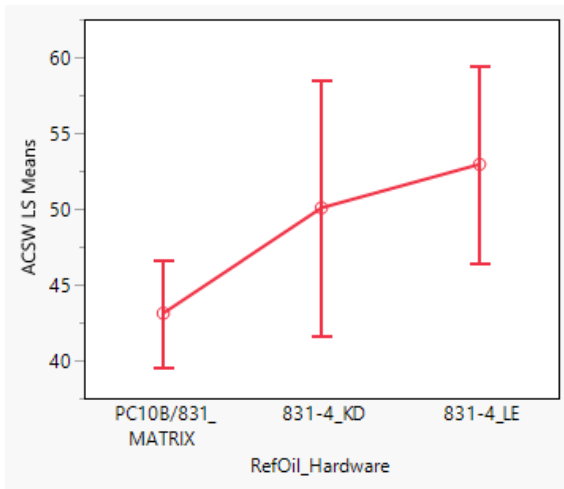
| Source | DF | Sum of Squares | Mean Square | F Ratio | Prob > F |
|----------|----|----------------|-------------|---------|----------|
| Model | 2 | 432.0501 | 216.025 | 4.3718 | |
| Error | 22 | 1087.0963 | 49.413 | | |
| C. Total | 24 | 1519.1464 | | | 0.0252* |

Effect Tests

| Source | Nparm | DF | Sum of Squares | F Ratio | Prob > F |
|-----------------|-------|----|----------------|---------|----------|
| RefOil_Hardware | 2 | 2 | 432.05009 | 4.3718 | 0.0252* |

Least Squares Means Table

| Level | Least Sq Mean | Std Error | Mean |
|------------------|---------------|-----------|---------|
| PC10B/831_MATRIX | 43.111765 | 1.7048973 | 43.1118 |
| 831-4_KD | 50.066667 | 4.0584672 | 50.0667 |
| 831-4_LE | 52.940000 | 3.1436752 | 52.9400 |



| Level | | Least Sq Mean |
|------------------|-----|---------------|
| 831-4_LE | A | 52.940000 |
| 831-4_KD | A B | 50.066667 |
| PC10B/831_MATRIX | B | 43.111765 |

Levels not connected by same letter are significantly different.

Camshaft Wear vs Lab and Oil

▲ A model of ACSW (corrected results) with Lab and Oil

▲ The model includes:

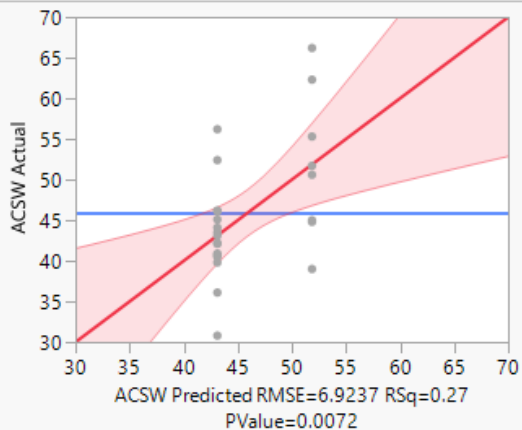
- ▲ Remove Lab D
 - Lab is no longer a significant factor and removed
- ▲ PC10B/831 and 831-4
 - 831-4 is significantly higher than PC10B/831
 - Difference in LS Mean is about 8

Camshaft Wear vs Lab and Oil

A model of ACSW (corrected results)

Whole Model

Actual by Predicted Plot



Summary of Fit

| | |
|----------------------------|----------|
| RSquare | 0.274213 |
| RSquare Adj | 0.242657 |
| Root Mean Square Error | 6.923735 |
| Mean of Response | 45.912 |
| Observations (or Sum Wgts) | 25 |

Analysis of Variance

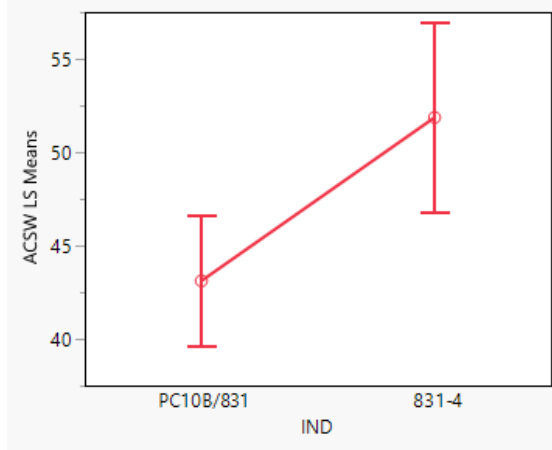
| Source | DF | Sum of Squares | Mean Square | F Ratio |
|----------|----|----------------|-------------|--------------------|
| Model | 1 | 416.5700 | 416.570 | 6.6897 |
| Error | 23 | 1102.5764 | 47.938 | Prob > F |
| C. Total | 24 | 1519.1464 | | 0.0072* |

Parameter Estimates

| Term | Estimate | Std Error | t Ratio | Prob> t |
|------------------|-----------|-----------|---------|----------|
| Intercept | 47.487132 | 1.484263 | 31.99 | <.0001* |
| IND[PC10B/831] | -4.375368 | 1.484263 | -2.95 | 0.0072* |

Least Squares Means Table

| Level | Least Sq Mean | Std Error | Mean |
|-----------|---------------|-----------|---------|
| PC10B/831 | 43.111765 | 1.6792524 | 43.1118 |
| 831-4 | 51.862500 | 2.4479099 | 51.8625 |



| Level | Least Sq Mean |
|-----------|---------------|
| 831-4 | A 51.862500 |
| PC10B/831 | B 43.111765 |

Levels not connected by same letter are significantly different.