

# ISB severity analysis

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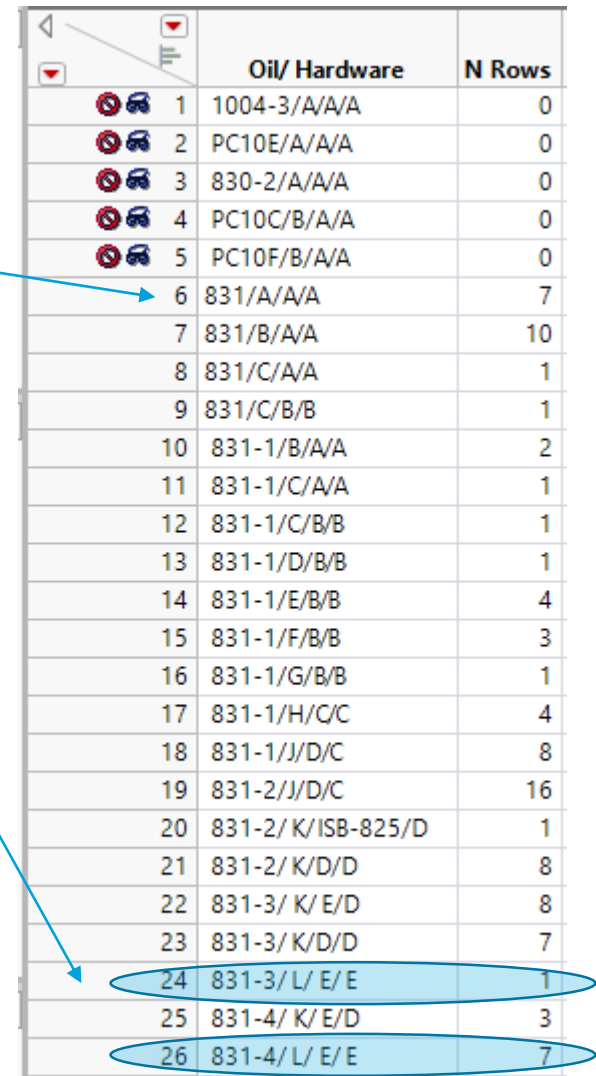
Performance you can rely on.



- Cam Wear Data
  - 95 tests – all chartable data plus three valid/ Non chartable tests
  - 92 tests – all chartable data
- Issues involved in updating the current CF
- Five Plots
  - Overall data: Standardized Cam wear over time highlighting latest hardware
  - Focus on stands behavior that have tested L/E/E hardware
  - Focus on comparing oil re-blends for fixed hardware type
- Models used
  - Lab/Stand, Oil/Hardware
  - Lab/Stand, Hardware – assuming that re-blends are the same
- Correction Factor Proposal varying model and data set
- Update or not standard deviation: Current 8.7 vs. updated (?)
- Questions

# Data: Cam wear

1. Data: reference oil 831 and re-blends; 95 tests including three valid/ Non chartable tests
2. Target: 14 tests (6 tests on 831/A/A/A and 8 tests on 831/B/A/A)
3. Most recent set of parts: L/E/E (8 tests)



|    | Oil/ Hardware       | N Rows |
|----|---------------------|--------|
| 1  | 1004-3/A/A/A        | 0      |
| 2  | PC10E/A/A/A         | 0      |
| 3  | 830-2/A/A/A         | 0      |
| 4  | PC10C/B/A/A         | 0      |
| 5  | PC10F/B/A/A         | 0      |
| 6  | 831/A/A/A           | 7      |
| 7  | 831/B/A/A           | 10     |
| 8  | 831/C/A/A           | 1      |
| 9  | 831/C/B/B           | 1      |
| 10 | 831-1/B/A/A         | 2      |
| 11 | 831-1/C/A/A         | 1      |
| 12 | 831-1/C/B/B         | 1      |
| 13 | 831-1/D/B/B         | 1      |
| 14 | 831-1/E/B/B         | 4      |
| 15 | 831-1/F/B/B         | 3      |
| 16 | 831-1/G/B/B         | 1      |
| 17 | 831-1/H/C/C         | 4      |
| 18 | 831-1/J/D/C         | 8      |
| 19 | 831-2/J/D/C         | 16     |
| 20 | 831-2/ K/ ISB-825/D | 1      |
| 21 | 831-2/ K/D/D        | 8      |
| 22 | 831-3/ K/ E/D       | 8      |
| 23 | 831-3/ K/D/D        | 7      |
| 24 | 831-3/ L/ E/ E      | 1      |
| 25 | 831-4/ K/ E/D       | 3      |
| 26 | 831-4/ L/ E/ E      | 7      |

# Some of the issues we need to discuss in order to update the current CF



1. In general, ISB oil re-blend and parts are changing at the same time
  - a) Sean has confirmed that 831-4 used the exact same base oil and components as 831-3, maybe allowing oil to be ignored when comparing batches of parts
2. Some Lab/Stands have more data over time than others.
  - a) In particular D1 tested for the first time twice (Cam wear=72  $\mu\text{m}$ ) with the latest oil re-blend and also the most recent set of parts. New Lab/Stand is then confounded with oil re-blend and L/E/E parts. Because D1 generated the highest cam values in L/E/E, we should keep this in mind, as we generate a potential CF.
  - b) G7 is also a new stand with relatively high cam value in L/E/E (62  $\mu\text{m}$ ).
3. Variability – should Standard deviation be updated?
4. If we assume that oil re-blend dash 4 did not change, there are 8 tests on L/E/E parts, only one test on the previous oil re-blend 831-3 – we will talk more about it
5. By itself, none of these issues are unusual, but combined they create unique challenges in establishing a sensible CF

# Possible Oil re-blend comparisons (dash 3 vs. dash 4) keeping parts fixed \*



a) based on the latest set of parts (L/E/E):

831-3 L/E/E => 1 test vs.  
831-4 L/E/E => 7 tests



Difference = 12.5  
P-value = 0.26

Mention transformation and testing for statistically significant differences

b) based on previous set of parts K/D/D and K/E/D assuming that crosshead batch can be ignored (or not)

831-3 K/D/D => 7 tests

831-3 K/E/D => 8 tests

vs.

831-4 K/E/D => 3 tests



Difference = 7.4  
P-value = 0.23

**K/E/D only**  
Difference = 8.1  
P-value = 0.24

None of the comparisons are statistically significant at 5% level  
p-values are greater than 0.23. Differences range from 7.4 to 12.5  $\mu\text{m}$

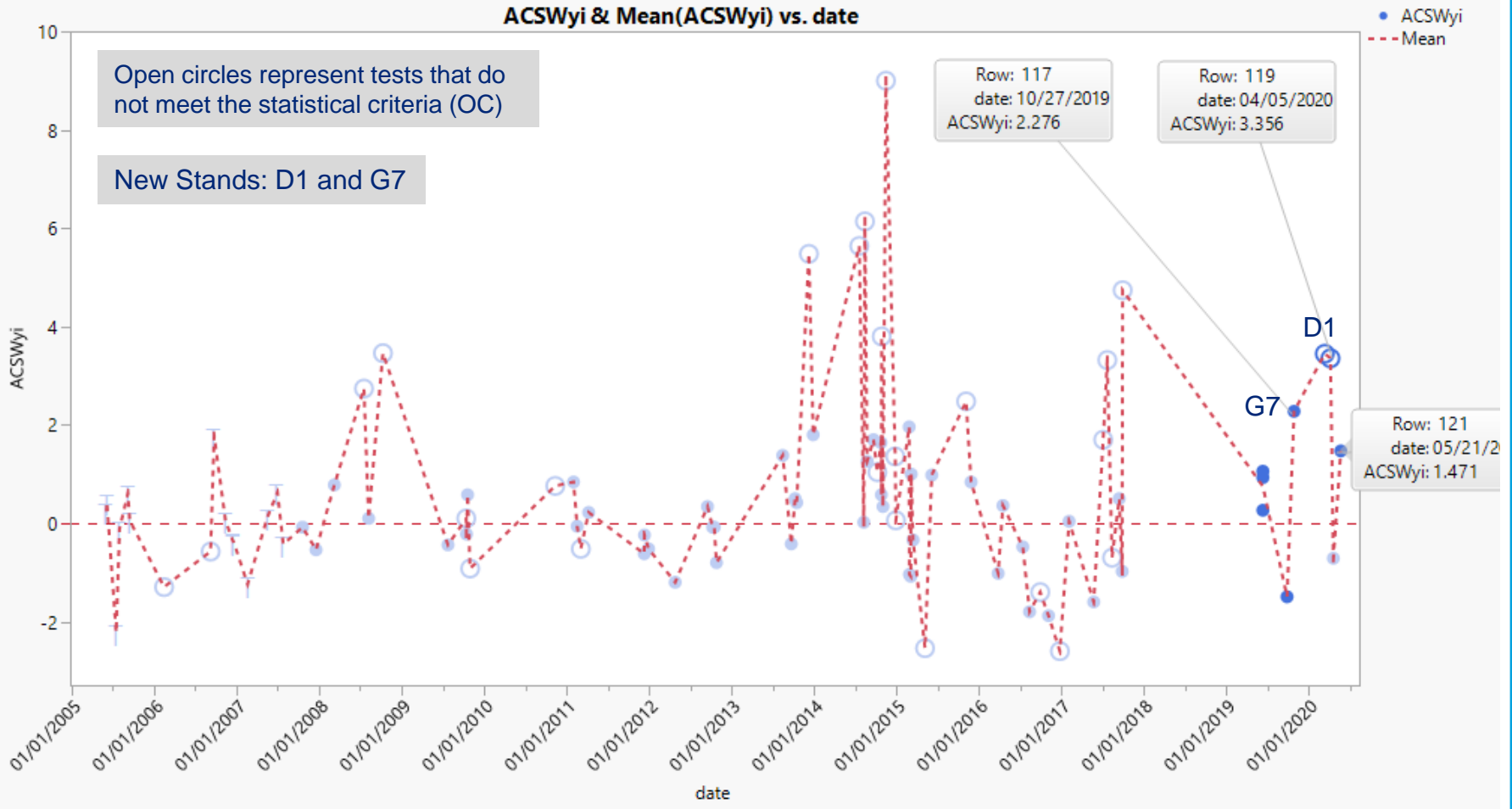
\*model used: all chartable data (92 tests); Lab/Stand and Oil/Hardware with Target RMSE of the model equal to 9.08

# Plots

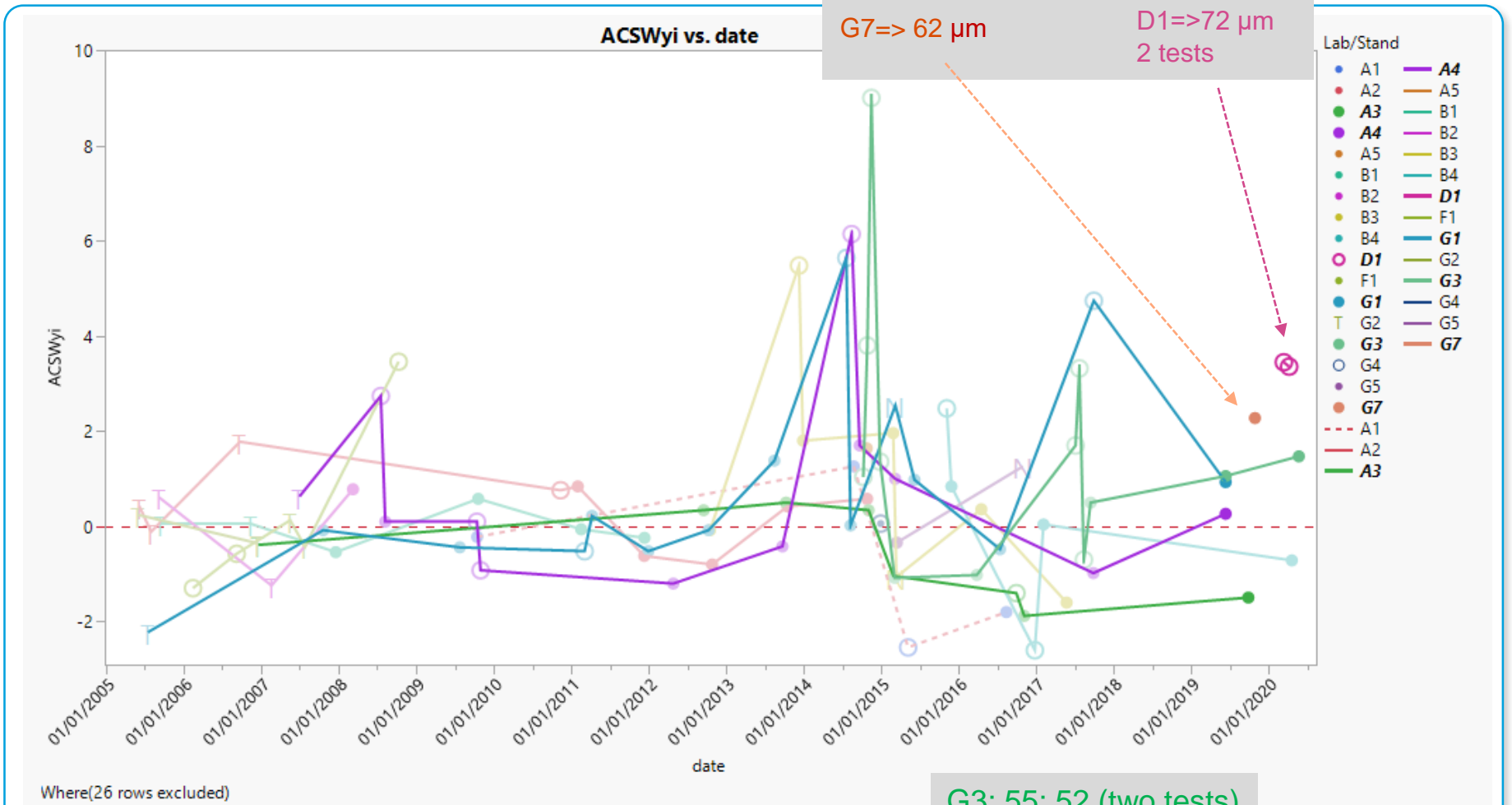
# Standardized Cam wear over time: *L/E/E tests* are highlighted



ACSWyi & Mean(ACSWyi) vs. date



# Highlighting stands that have tested L/E/E hardware, so that we can see their behavior over time:

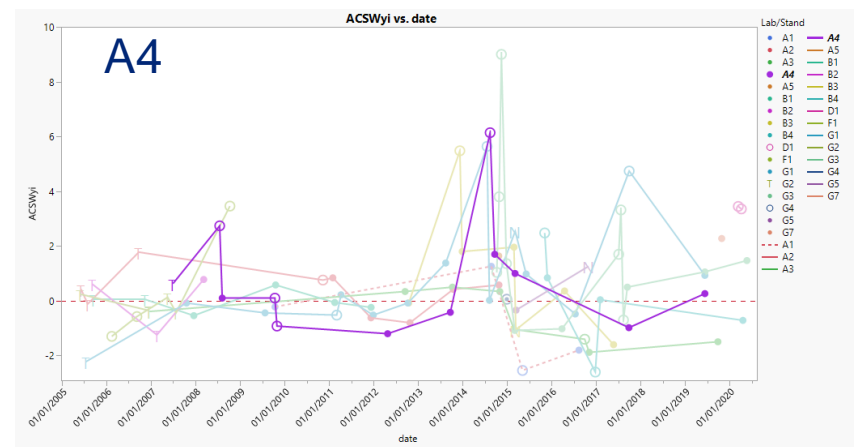
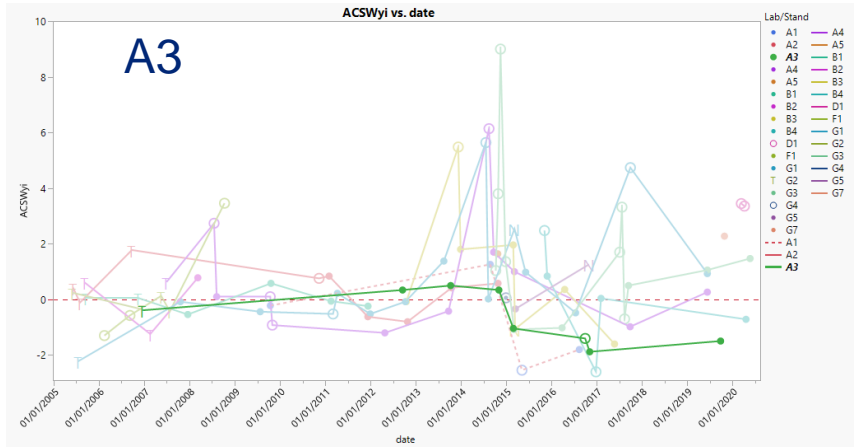


Other L/E/E cam wear test results

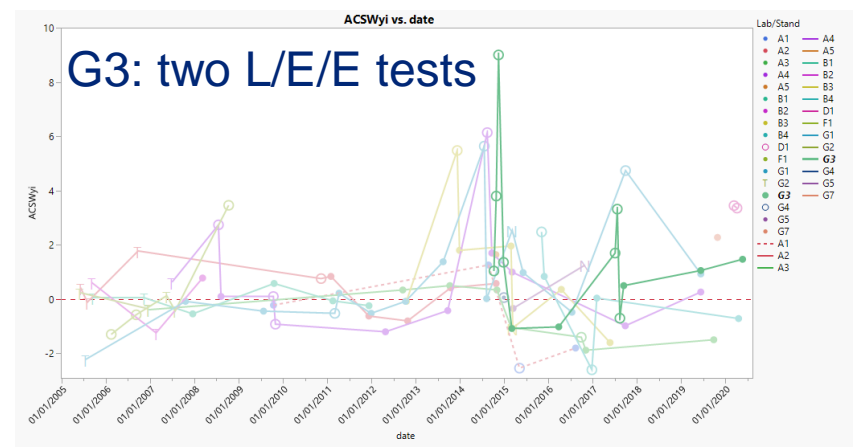
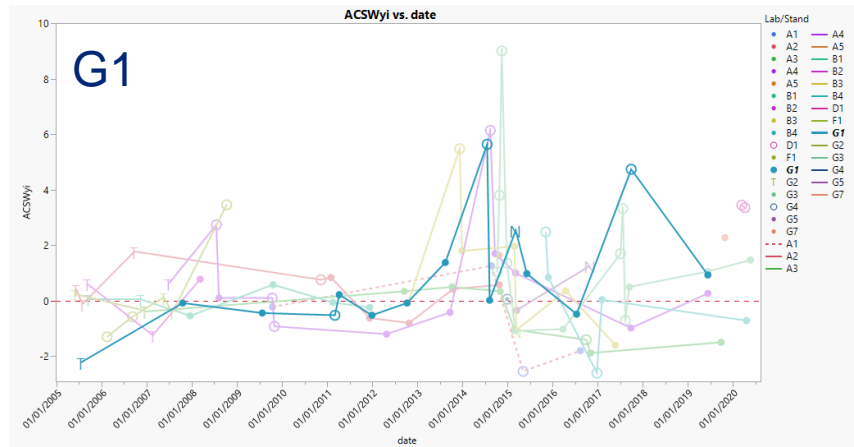
G3: 55; 52 (two tests)  
 A4: 45  
 A3: 29.5  
 G1: 51



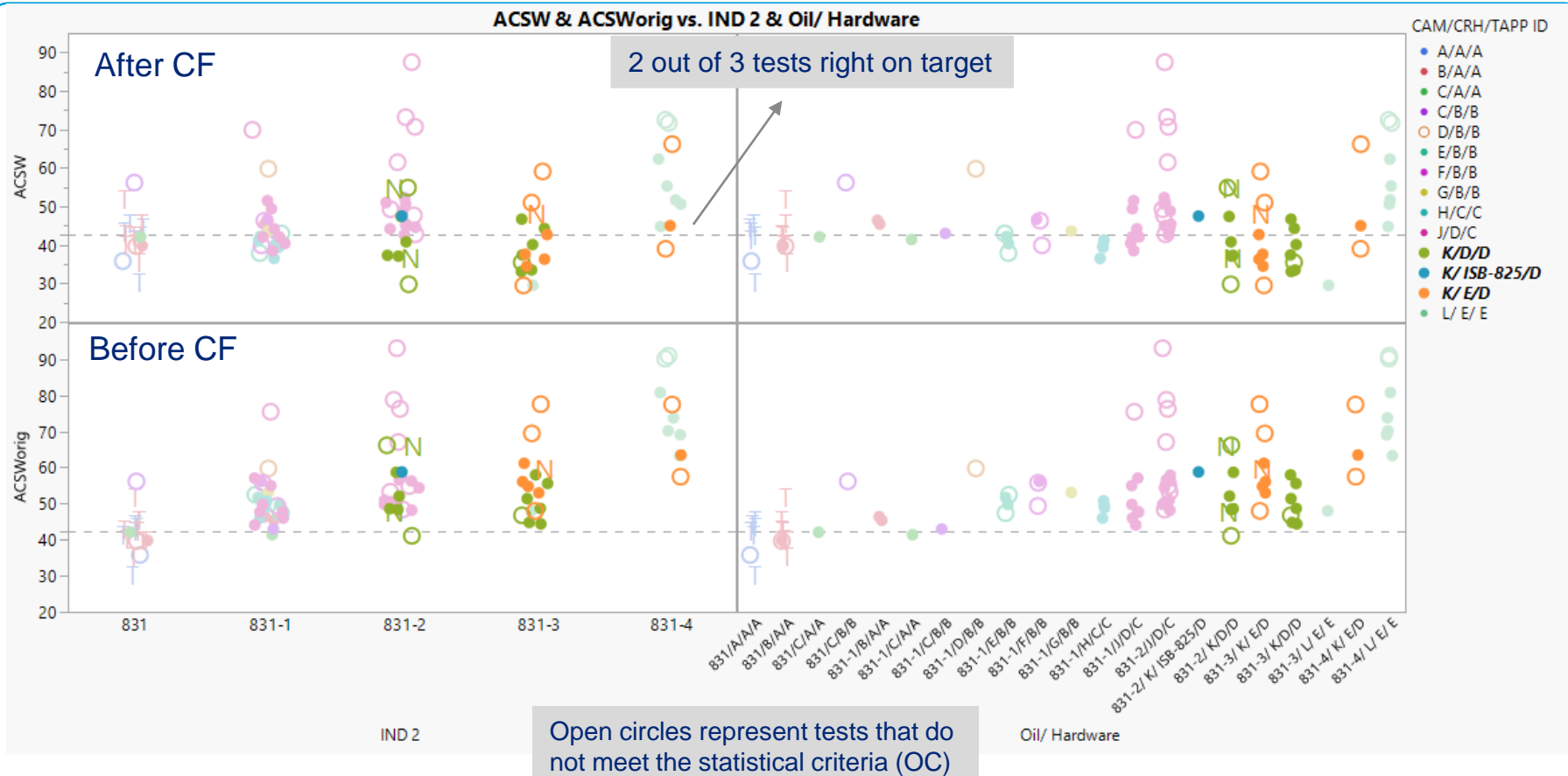
# Highlighting stands that have tested L/E/E hardware, so that we can see their behavior over time:



After seeing these plots, I started to question the need to update CF...

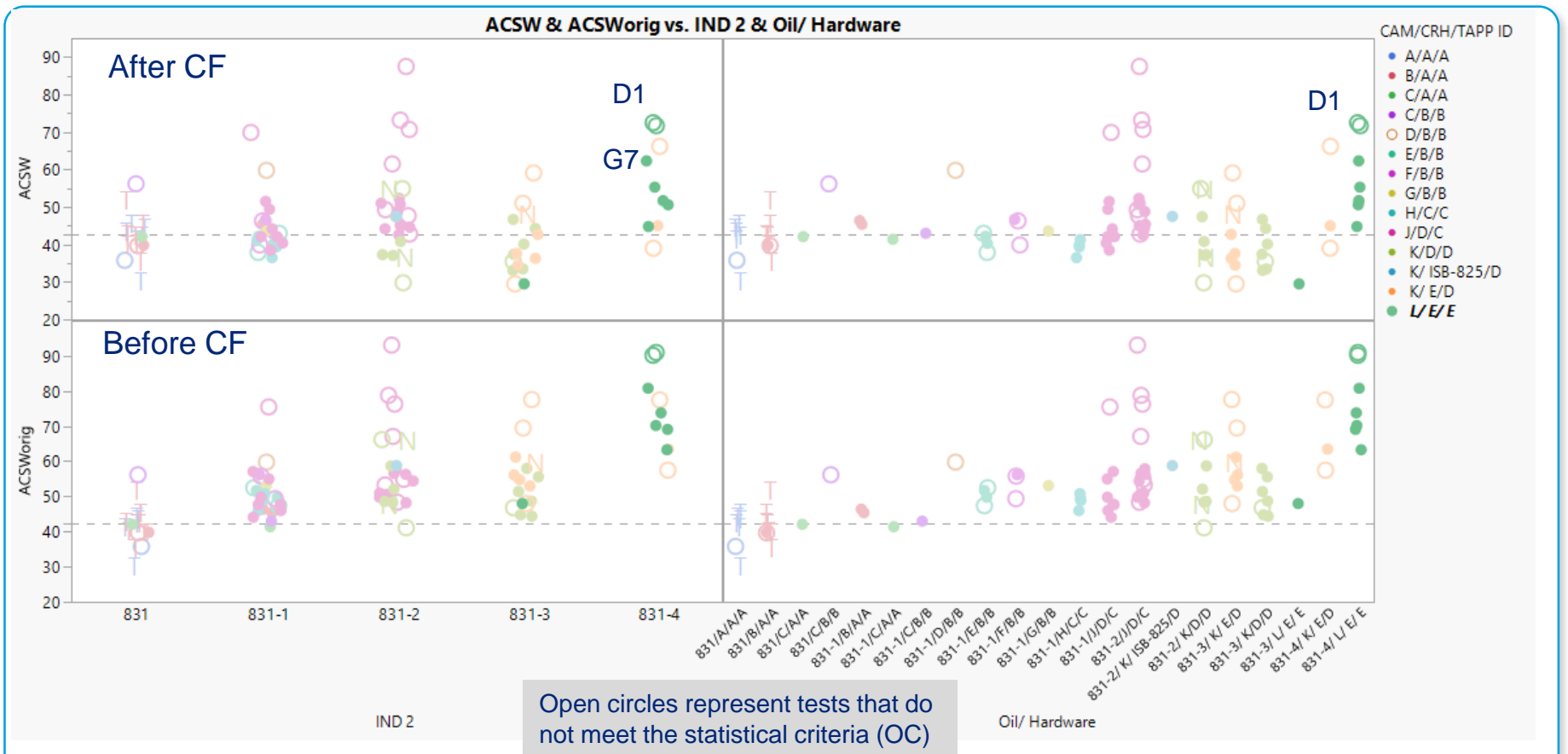


# Cam Wear before CF and after current CF: highlighting batch K cam/crosshead D or E/D tappet



I also highlighted 831-2 ...Based on the graph, it seems that the change is due to parts and not oil. I left three valid/ Non chartable (N markers) tests in the file for now. I may remove them later, before modeling. Their corresponding ACSW values are 55.2,37.2 and 48.8.

# Cam Wear before CF and after current CF: highlighting batch L cam/crosshead E/E tappet



With just one test for 831-3, it is risky to assume that 831-4 is different, especially after seeing the previous plot. The overall evidence seems to be pointing to, if there are differences, they would be likely due to parts and not oil re-blend. D1 and G7 are new stands – Stand confounded with new parts and dash 4 re-blend.

# Model: ACSW by Lab/Stand and Oil/Hardware

## 95 tests; including three valid/ Non chartable (N markers) tests



### Response ACSW

#### Whole Model

##### Summary of Fit

|                            |          |
|----------------------------|----------|
| RSquare                    | 0.533339 |
| RSquare Adj                | 0.230419 |
| Root Mean Square Error     | 9.084221 |
| Mean of Response           | 45.92316 |
| Observations (or Sum Wgts) | 95       |

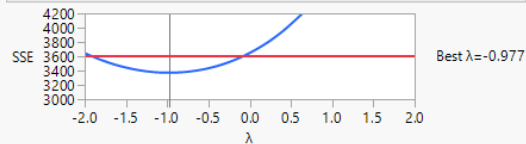
##### Analysis of Variance

| Source   | DF | Sum of Squares | Mean Square | F Ratio  |
|----------|----|----------------|-------------|----------|
| Model    | 37 | 5375.914       | 145.295     | 1.7607   |
| Error    | 57 | 4703.815       | 82.523      | Prob > F |
| C. Total | 94 | 10079.729      |             | 0.0267*  |

##### Effect Tests

| Source                    | Nparm | DF | Sum of Squares | F Ratio | Prob > F |
|---------------------------|-------|----|----------------|---------|----------|
| Lab/Stand                 | 16    | 16 | 1465.7780      | 1.1101  | 0.3681   |
| Oil/ Hardware with TARGET | 21    | 21 | 2374.9440      | 1.3704  | 0.1730   |

##### Box-Cox Transformations

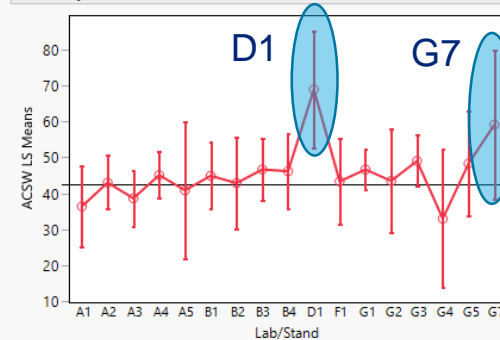


#### Lab/Stand

##### Least Squares Means Table

| Level | Least Sq Mean | Std Error | Mean    |
|-------|---------------|-----------|---------|
| A1    | 36.398659     | 5.652468  | 38.3750 |
| A2    | 43.040873     | 3.731644  | 44.5111 |
| A3    | 38.658033     | 3.912433  | 38.6875 |
| A4    | 45.137534     | 3.200707  | 46.4417 |
| A5    | 40.883841     | 9.577941  | 50.7000 |
| B1    | 44.942485     | 4.621035  | 42.4833 |
| B2    | 42.882151     | 6.452153  | 42.8667 |
| B3    | 46.698566     | 4.248842  | 47.4000 |
| B4    | 46.208711     | 5.217436  | 42.0200 |
| D1    | 68.984843     | 8.090074  | 72.1000 |
| F1    | 43.382151     | 5.968970  | 43.8600 |
| G1    | 46.673055     | 2.878341  | 46.7267 |
| G2    | 43.517068     | 7.263360  | 42.5000 |
| G3    | 49.064391     | 3.563410  | 51.8000 |
| G4    | 32.983841     | 9.577941  | 42.8000 |
| G5    | 48.326106     | 7.241039  | 44.8000 |
| G7    | 59.184843     | 10.330094 | 62.3000 |

##### Least Squares Means Plot

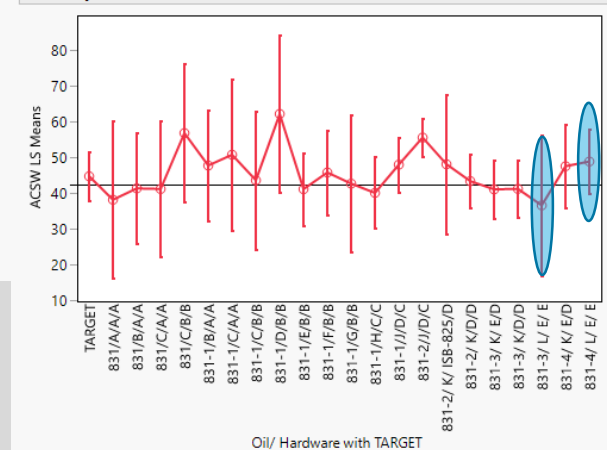


#### Oil/ Hardware with TARGET

##### Least Squares Means Table

| Level             | Least Sq Mean | Std Error | Mean    |
|-------------------|---------------|-----------|---------|
| TARGET            | 44.686882     | 3.393647  | 42.4857 |
| 831-A/A/A         | 38.121799     | 11.042224 | 35.8000 |
| 831-B/A/A         | 41.291632     | 7.771860  | 39.7500 |
| 831-C/A/A         | 41.130895     | 9.540938  | 42.1000 |
| 831-C/B/B         | 56.766416     | 9.695756  | 56.2000 |
| 831-1/B/A/A       | 47.691632     | 7.771860  | 45.9000 |
| 831-1/C/A/A       | 50.705291     | 10.606094 | 41.4000 |
| 831-1/C/B/B       | 43.566416     | 9.695756  | 43.0000 |
| 831-1/D/B/B       | 62.121799     | 11.042224 | 59.8000 |
| 831-1/E/B/B       | 41.081298     | 5.104571  | 40.8500 |
| 831-1/F/B/B       | 45.752350     | 5.914004  | 44.3000 |
| 831-1/G/B/B       | 42.630895     | 9.540938  | 43.6000 |
| 831-1/H/C/C       | 40.030463     | 4.999582  | 39.2750 |
| 831-1/J/D/C       | 47.931669     | 3.834754  | 47.2625 |
| 831-2/J/D/C       | 55.520109     | 2.705005  | 53.5813 |
| 831-2/K/ISB-825/D | 48.066416     | 9.695756  | 47.5000 |
| 831-2/K/D/D       | 43.328878     | 3.764495  | 42.4625 |
| 831-3/K/E/D       | 41.026810     | 4.111227  | 42.4375 |
| 831-3/K/D/D       | 41.166886     | 4.005503  | 38.6571 |
| 831-3/L/E/E       | 36.545917     | 9.830163  | 29.5000 |
| 831-4/K/E/D       | 47.503338     | 5.808455  | 50.0667 |
| 831-4/L/E/E       | 48.819107     | 4.515422  | 58.4143 |

##### Least Squares Means Plot



##### Contrast: Target vs. L/E/E

| SS    | NumDF | DenDF | F Ratio | Prob > F |
|-------|-------|-------|---------|----------|
| 7.712 | 1     | 57    | 0.0935  | 0.7609   |

New Stand D1 very high when compared to other stands  
G7 is also highlighted  
Model with 92 tests gives similar results

Nominal factors expanded to all levels



| Term  | Estimate  | Std Error | t Ratio | Prob> t | Estimate             |
|---|-----------|-----------|---------|---------|----------------------|
| Intercept                                       | 45.70395  | 1.951496  | 23.42   | <.0001  | 1 45.70395           |
| Lab/Stand[ A1]                                  | -9.305291 | 5.474136  | -1.7    | 0.0946  | 0.058823529 -0.54737 |
| Lab/Stand[ A2]                                  | -2.663077 | 3.62589   | -0.73   | 0.4657  | 0.058823529 -0.15665 |
| Lab/Stand[ A3]                                  | -7.045917 | 3.756201  | -1.88   | 0.0658  | 0.058823529 -0.41447 |
| Lab/Stand[ A4]                                  | -0.566416 | 3.388895  | -0.17   | 0.8679  | 0.058823529 -0.03332 |
| Lab/Stand[ A5]                                  | -4.820109 | 8.951621  | -0.54   | 0.5924  | 0.058823529 -0.28354 |
| Lab/Stand[ B1]                                  | -0.761465 | 4.697656  | -0.16   | 0.8718  | 0.058823529 -0.04479 |
| Lab/Stand[ B2]                                  | -2.821799 | 6.27755   | -0.45   | 0.6548  | 0.058823529 -0.16599 |
| Lab/Stand[ B3]                                  | 0.9946156 | 3.98851   | 0.25    | 0.804   | 0.058823529 0.058507 |
| Lab/Stand[ B4]                                  | 0.5047612 | 4.878696  | 0.1     | 0.918   | 0.058823529 0.029692 |
| Lab/Stand[ D1]                                  | 23.280893 | 7.53633   | 3.09    | 0.0031  | 0.058823529 1.369464 |
| Lab/Stand[ F1]                                  | -2.321799 | 6.27755   | -0.37   | 0.7129  | 0.058823529 -0.13658 |
| Lab/Stand[ G1]                                  | 0.9691048 | 2.916579  | 0.33    | 0.7409  | 0.058823529 0.057006 |
| Lab/Stand[ G2]                                  | -2.186882 | 6.922722  | -0.32   | 0.7532  | 0.058823529 -0.12864 |
| Lab/Stand[ G3]                                  | 3.3604408 | 3.213583  | 1.05    | 0.3001  | 0.058823529 0.197673 |
| Lab/Stand[ G4]                                  | -12.72011 | 8.951621  | -1.42   | 0.1608  | 0.058823529 -0.74824 |
| Lab/Stand[ G5]                                  | 2.622156  | 6.786606  | 0.39    | 0.7007  | 0.058823529 0.154244 |
| Lab/Stand[ G7]                                  | 13.480893 | 9.654196  | 1.4     | 0.168   | 0.058823529 0.792994 |
| Oil/ Hardware with TARGET[TARGET]               | -1.017068 | 3.390409  | -0.3    | 0.7653  | 0 0                  |
| Oil/ Hardware with TARGET[831/A/A/A]            | -7.582151 | 10.51901  | -0.72   | 0.474   | 0 0                  |
| Oil/ Hardware with TARGET[831/B/A/A]            | -4.412318 | 7.375923  | -0.6    | 0.5521  | 0 0                  |
| Oil/ Hardware with TARGET[831/C/A/A]            | -4.573055 | 9.127202  | -0.5    | 0.6183  | 0 0                  |
| Oil/ Hardware with TARGET[831/C/B/B]            | 11.062466 | 9.233932  | 1.2     | 0.2359  | 0 0                  |
| Oil/ Hardware with TARGET[ 831-1/B/A/A]         | 1.9876818 | 7.576614  | 0.26    | 0.794   | 0 0                  |
| Oil/ Hardware with TARGET[ 831-1/C/A/A]         | 5.0013411 | 10.3427   | 0.48    | 0.6305  | 0 0                  |
| Oil/ Hardware with TARGET[ 831-1/C/B/B]         | -2.137534 | 9.233932  | -0.23   | 0.8178  | 0 0                  |
| Oil/ Hardware with TARGET[ 831-1/D/B/B]         | 16.417849 | 10.51901  | 1.56    | 0.1241  | 0 0                  |
| Oil/ Hardware with TARGET[ 831-1/E/B/B]         | -4.622652 | 4.829822  | -0.96   | 0.3426  | 0 0                  |
| Oil/ Hardware with TARGET[ 831-1/F/B/B]         | 0.0484    | 5.737561  | 0.01    | 0.9933  | 0 0                  |
| Oil/ Hardware with TARGET[ 831-1/G/B/B]         | -3.073055 | 9.127202  | -0.34   | 0.7376  | 0 0                  |
| Oil/ Hardware with TARGET[ 831-1/H/C/C]         | -5.673487 | 4.771886  | -1.19   | 0.2394  | 0 0                  |
| Oil/ Hardware with TARGET[ 831-1/J/D/C]         | 2.2277193 | 3.822088  | 0.58    | 0.5623  | 0 0                  |
| Oil/ Hardware with TARGET[ 831-2/J/D/C]         | 9.8161589 | 3.03544   | 3.23    | 0.002   | 0 0                  |
| Oil/ Hardware with TARGET[ 831-2/ K/ ISB-825/D] | 2.3624663 | 9.233932  | 0.26    | 0.799   | 0 0                  |
| Oil/ Hardware with TARGET[ 831-2/ K/D/D]        | -2.375072 | 3.919792  | -0.61   | 0.547   | 0 0                  |
| Oil/ Hardware with TARGET[ 831-3/ K/ E/D]       | -4.67714  | 4.330066  | -1.08   | 0.2846  | 0 0                  |
| Oil/ Hardware with TARGET[ 831-3/ K/D/D]        | -4.537064 | 4.086568  | -1.11   | 0.2716  | 0 0                  |
| Oil/ Hardware with TARGET[ 831-3/ L/ E/ E]      | -9.158033 | 9.504109  | -0.96   | 0.3393  | 0.5 -4.57902         |
| Oil/ Hardware with TARGET[ 831-4/ K/ E/D]       | 1.7993879 | 5.722246  | 0.31    | 0.7543  | 0 0                  |
| Oil/ Hardware with TARGET[ 831-4/ L/ E/ E]      | 3.1151575 | 4.918107  | 0.63    | 0.529   | 0.5 1.557579         |

Option1: assuming that there is no difference in oil re-blend

- Subtract 0.18 to current L/E/E estimate, in practice, DO NOTHING

→ One test

→ Seven tests

# 92 chartable tests: option 1 DO NOTHING



| n=92  |           |           |         |   |             |          |
|---|-----------|-----------|---------|---|-------------|----------|
| Expanded Estimates                              |           |           |         |   |             |          |
| Nominal factors expanded to all levels          |           |           |         |   |             |          |
| Term  | Estimate  | Std Error | t Ratio | Prob> t   | Estimate    |          |
| Intercept                                       | 45.528027 | 1.951496  | 23.42   | <.0001  | 1           | 45.52803 |
| Lab/Stand[ A1]                                  | -9.000579 | 5.474136  | -1.7    | 0.0946  | 0.058823529 | -0.52945 |
| Lab/Stand[ A2]                                  | -2.539718 | 3.62589   | -0.73   | 0.4657  | 0.058823529 | -0.1494  |
| Lab/Stand[ A3]                                  | -6.688891 | 3.756201  | -1.88   | 0.0658  | 0.058823529 | -0.39346 |
| Lab/Stand[ A4]                                  | -0.215561 | 3.388895  | -0.17   | 0.8679  | 0.058823529 | -0.01268 |
| Lab/Stand[ A5]                                  | -4.502561 | 8.951621  | -0.54   | 0.5924  | 0.058823529 | -0.26486 |
| Lab/Stand[ B1]                                  | -0.739369 | 4.697656  | -0.16   | 0.8718  | 0.058823529 | -0.04349 |
| Lab/Stand[ B2]                                  | -2.776163 | 6.27755   | -0.45   | 0.6548  | 0.058823529 | -0.1633  |
| Lab/Stand[ B3]                                  | 2.9385656 | 3.98851   | 0.25    | 0.804   | 0.058823529 | 0.172857 |
| Lab/Stand[ B4]                                  | 1.6345606 | 4.878696  | 0.1     | 0.918   | 0.058823529 | 0.096151 |
| Lab/Stand[ D1]                                  | 23.435422 | 7.53633   | 3.09    | 0.0031  | 0.058823529 | 1.378554 |
| Lab/Stand[ F1]                                  | -2.276163 | 6.27755   | -0.37   | 0.7129  | 0.058823529 | -0.13389 |
| Lab/Stand[ G1]                                  | 0.2826529 | 2.916579  | 0.33    | 0.7409  | 0.058823529 | 0.016627 |
| Lab/Stand[ G2]                                  | -2.135362 | 6.922722  | -0.32   | 0.7532  | 0.058823529 | -0.12561 |
| Lab/Stand[ G3]                                  | 3.8372979 | 3.213583  | 1.05    | 0.3001  | 0.058823529 | 0.225723 |
| Lab/Stand[ G4]                                  | -12.40256 | 8.951621  | -1.42   | 0.1608  | 0.058823529 | -0.72956 |
| Lab/Stand[ G5]                                  | -2.486992 | 6.786606  | 0.39    | 0.7007  | 0.058823529 | -0.14629 |
| Lab/Stand[ G7]                                  | 13.635422 | 9.654196  | 1.4     | 0.168   | 0.058823529 | 0.802084 |
| Oil/ Hardware with TARGET[TARGET]               | -0.892665 | 3.390409  | -0.3    | 0.7653  | 0           | 0        |
| Oil/ Hardware with TARGET[831/A/A/A]            | -7.451863 | 10.51901  | -0.72   | 0.474   | 0           | 0        |
| Oil/ Hardware with TARGET[831/B/A/A]            | -4.27026  | 7.375923  | -0.6    | 0.5521  | 0           | 0        |
| Oil/ Hardware with TARGET[831/C/A/A]            | -3.71068  | 9.127202  | -0.5    | 0.6183  | 0           | 0        |
| Oil/ Hardware with TARGET[831/C/B/B]            | 10.887534 | 9.233932  | 1.2     | 0.2359  | 0           | 0        |
| Oil/ Hardware with TARGET[ 831-1/B/A/A]         | 2.1297395 | 7.576614  | 0.26    | 0.794   | 0           | 0        |
| Oil/ Hardware with TARGET[ 831-1/C/A/A]         | 4.872552  | 10.3427   | 0.48    | 0.6305  | 0           | 0        |
| Oil/ Hardware with TARGET[ 831-1/C/B/B]         | -2.312466 | 9.233932  | -0.23   | 0.8178  | 0           | 0        |
| Oil/ Hardware with TARGET[ 831-1/D/B/B]         | 16.548137 | 10.51901  | 1.56    | 0.1241  | 0           | 0        |
| Oil/ Hardware with TARGET[ 831-1/E/B/B]         | -4.456067 | 4.829822  | -0.96   | 0.3426  | 0           | 0        |
| Oil/ Hardware with TARGET[ 831-1/F/B/B]         | 0.3709006 | 5.737561  | 0.01    | 0.9933  | 0           | 0        |
| Oil/ Hardware with TARGET[ 831-1/G/B/B]         | -2.21068  | 9.127202  | -0.34   | 0.7376  | 0           | 0        |
| Oil/ Hardware with TARGET[ 831-1/H/C/C]         | -5.450028 | 4.771886  | -1.19   | 0.2394  | 0           | 0        |
| Oil/ Hardware with TARGET[ 831-1/J/D/C]         | 1.7423691 | 3.822088  | 0.58    | 0.5623  | 0           | 0        |
| Oil/ Hardware with TARGET[ 831-2/J/D/C]         | 9.6745343 | 3.03544   | 3.23    | 0.002   | 0           | 0        |
| Oil/ Hardware with TARGET[ 831-2/ K/ ISB-825/D] | 2.1875343 | 9.233932  | 0.26    | 0.799   | 0           | 0        |
| Oil/ Hardware with TARGET[ 831-2/ K/D/D]        | -2.241035 | 3.919792  | -0.61   | 0.547   | 0           | 0        |
| Oil/ Hardware with TARGET[ 831-3/ K/ E/D]       | -6.185353 | 4.330066  | -1.08   | 0.2846  | 0           | 0        |
| Oil/ Hardware with TARGET[ 831-3/ K/D/D]        | -4.915843 | 4.086568  | -1.11   | 0.2716  | 0           | 0        |
| Oil/ Hardware with TARGET[ 831-3/ L/ E/ E]      | -9.339136 | 9.504109  | -0.96   | 0.3393  | 0.5         | -4.66957 |
| Oil/ Hardware with TARGET[ 831-4/ K/ E/D]       | 1.8862236 | 5.722246  | 0.31    | 0.7543  | 0           | 0        |
| Oil/ Hardware with TARGET[ 831-4/ L/ E/ E]      | 3.1365513 | 4.918107  | 0.63    | 0.529   | 0.5         | 1.568276 |
|   |           |           |         | estimate  | 42.42673    |          |
|   |           |           |         | Target  | 42.5        |          |
|   |           |           |         | difference                                      | -0.07327    |          |
|   |           |           |         | add 0.073 to bring L/E/E results back to Target |             |          |

# Why not use the simple average of Cam Wear for L/E/E?

- My opinion is that we should always use models/LSMEANS estimates for targets and standard deviations, especially for larger data sets
- The simple average of Cam wear does not take into account the imbalance across Lab/Stand
- The LSMEANS estimates compared to the target, employ an average lab effect

|    | Lab/Stand | N Rows |
|----|-----------|--------|
| 1  | A1        | 4      |
| 2  | A2        | 9      |
| 3  | A3        | 8      |
| 4  | A4        | 12     |
| 5  | A5        | 1      |
| 6  | B1        | 6      |
| 7  | B2        | 3      |
| 8  | B3        | 7      |
| 9  | B4        | 5      |
| 10 | D1        | 2      |
| 11 | F1        | 5      |
| 12 | G1        | 15     |
| 13 | G2        | 2      |
| 14 | G3        | 12     |
| 15 | G4        | 1      |
| 16 | G5        | 2      |
| 17 | G6        | 0      |
| 18 | G7        | 1      |

Highlighted the labs that have batch L/E/E cam wear data, beyond the two new stands D1 and G7. All the data is used to estimate an average lab effect

# Model: ACSW by Lab/Stand and Hardware

## 92 chartable tests



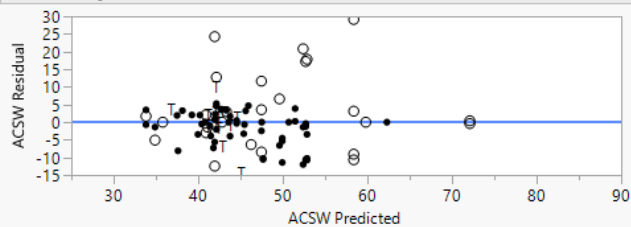
### Response ACSW

#### Whole Model

##### Lack Of Fit

| Source      | DF | Sum of Squares | Mean Square | F Ratio            |
|-------------|----|----------------|-------------|--------------------|
| Lack Of Fit | 23 | 1913.1257      | 83.1794     | 0.9970             |
| Pure Error  | 38 | 3170.1908      | 83.4261     | <b>Prob &gt; F</b> |
| Total Error | 61 | 5083.3165      |             | 0.4909             |
|             |    |                |             | <b>Max RSq</b>     |
|             |    |                |             | 0.6801             |

#### Residual by Predicted Plot



#### Summary of Fit

|                            |          |
|----------------------------|----------|
| RSquare                    | 0.487009 |
| RSquare Adj                | 0.234718 |
| Root Mean Square Error     | 9.128694 |
| Mean of Response           | 45.88587 |
| Observations (or Sum Wgts) | 92       |

#### Analysis of Variance

| Source   | DF | Sum of Squares | Mean Square | F Ratio            |
|----------|----|----------------|-------------|--------------------|
| Model    | 30 | 4825.8551      | 160.862     | 1.9303             |
| Error    | 61 | 5083.3165      | 83.333      | <b>Prob &gt; F</b> |
| C. Total | 91 | 9909.1716      |             | 0.0150*            |

#### Effect Tests

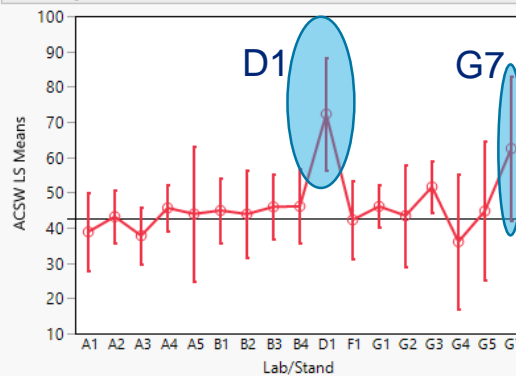
| Source                 | Nparm | DF | Sum of Squares | F Ratio | Prob > F |
|------------------------|-------|----|----------------|---------|----------|
| Lab/Stand              | 16    | 16 | 2084.6754      | 1.5635  | 0.1073   |
| TARGET CAM/CRH/TAPP ID | 14    | 14 | 1765.1363      | 1.5130  | 0.1337   |

#### Lab/Stand

##### Least Squares Means Table

| Level | Least Sq Mean | Std Error | Mean    |
|-------|---------------|-----------|---------|
| A1    | 38.831606     | 5.479832  | 38.3750 |
| A2    | 43.158509     | 3.746320  | 44.5111 |
| A3    | 37.764493     | 3.999592  | 38.6875 |
| A4    | 45.623615     | 3.279239  | 46.4417 |
| A5    | 43.930366     | 9.576453  | 50.7000 |
| B1    | 44.911029     | 4.600647  | 42.4833 |
| B2    | 43.875800     | 6.191813  | 42.8667 |
| B3    | 45.934701     | 4.557784  | 49.1000 |
| B4    | 46.083105     | 5.238658  | 42.0200 |
| D1    | 72.257063     | 7.882960  | 72.1000 |
| F1    | 42.242467     | 5.561579  | 43.8600 |
| G1    | 46.081683     | 3.018466  | 46.1214 |
| G2    | 43.433659     | 7.255297  | 42.5000 |
| G3    | 51.607763     | 3.723293  | 51.8000 |
| G4    | 36.030366     | 9.576453  | 42.8000 |
| G5    | 44.744708     | 9.843729  | 40.8000 |
| G7    | 62.457063     | 10.188601 | 62.3000 |

#### Least Squares Means Plot

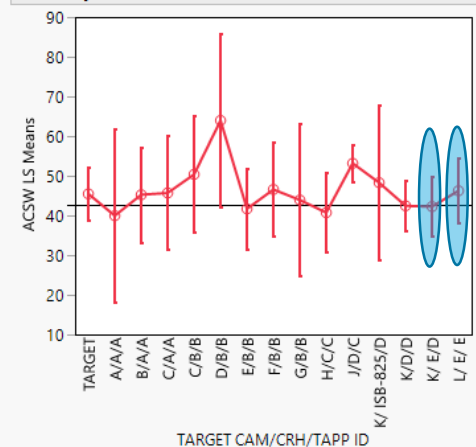


#### TARGET CAM/CRH/TAPP ID

##### Least Squares Means Table

| Level        | Least Sq Mean | Std Error | Mean    |
|--------------|---------------|-----------|---------|
| TARGET       | 45.476223     | 3.403918  | 42.4857 |
| A/A/A        | 39.967416     | 10.969164 | 35.8000 |
| B/A/A        | 45.249801     | 5.999780  | 42.8250 |
| C/A/A        | 45.703237     | 7.153897  | 41.7500 |
| C/B/B        | 50.386267     | 7.311184  | 49.6000 |
| D/B/B        | 63.967416     | 10.969164 | 59.8000 |
| E/B/B        | 41.699897     | 5.141388  | 40.8500 |
| F/B/B        | 46.576982     | 5.941708  | 44.3000 |
| G/B/B        | 43.928199     | 9.582212  | 43.6000 |
| H/C/C        | 40.741173     | 5.031006  | 39.2750 |
| J/D/C        | 53.179516     | 2.408394  | 51.4750 |
| K/ ISB-825/D | 48.286267     | 9.752945  | 47.5000 |
| K/D/D        | 42.465174     | 3.204123  | 39.8385 |
| K/ E/D       | 42.267846     | 3.743163  | 44.0900 |
| L/ E/E       | 46.252819     | 4.083678  | 54.8000 |

#### Least Squares Means Plot





# Ignoring oil re-blend (data: 92 tests)



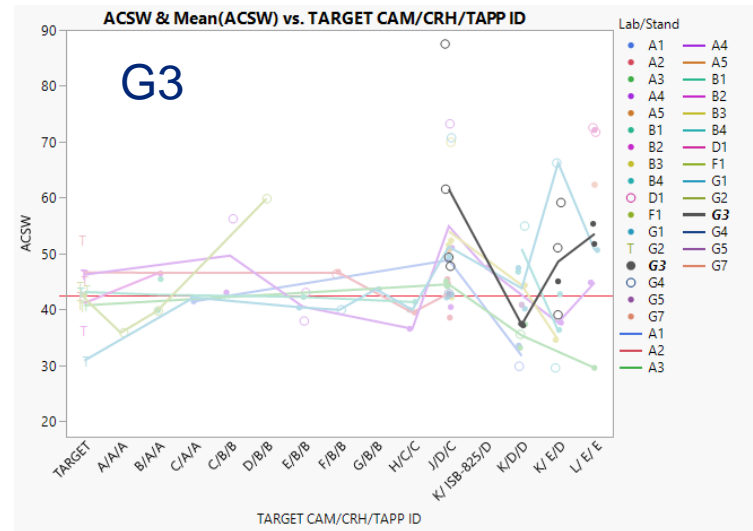
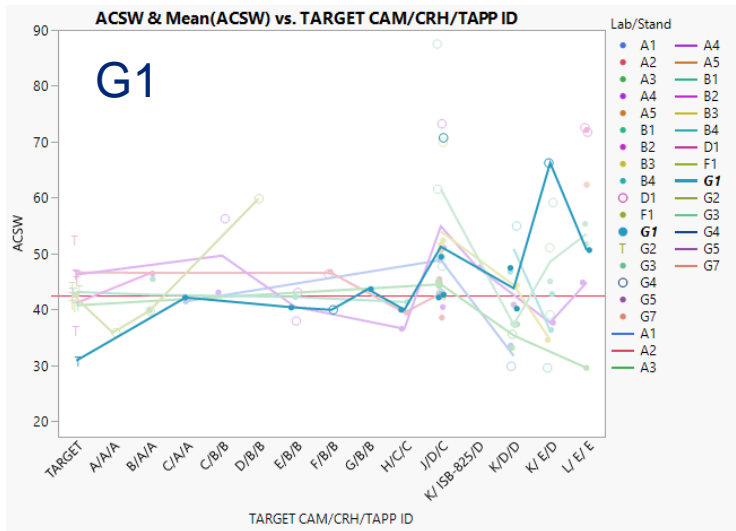
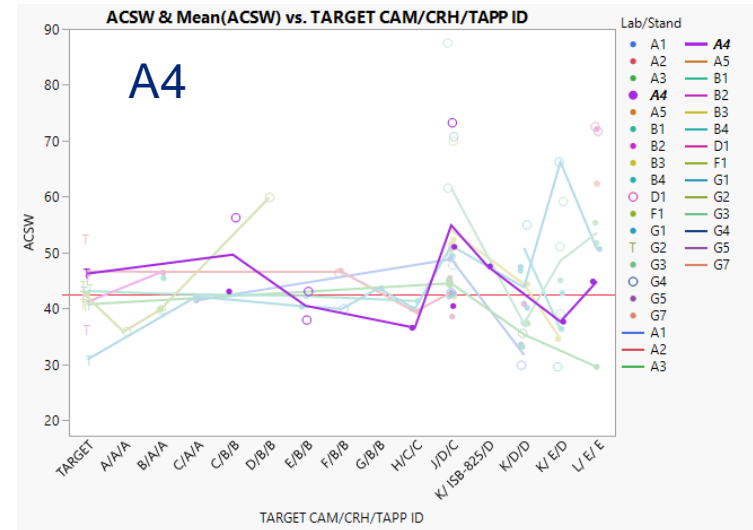
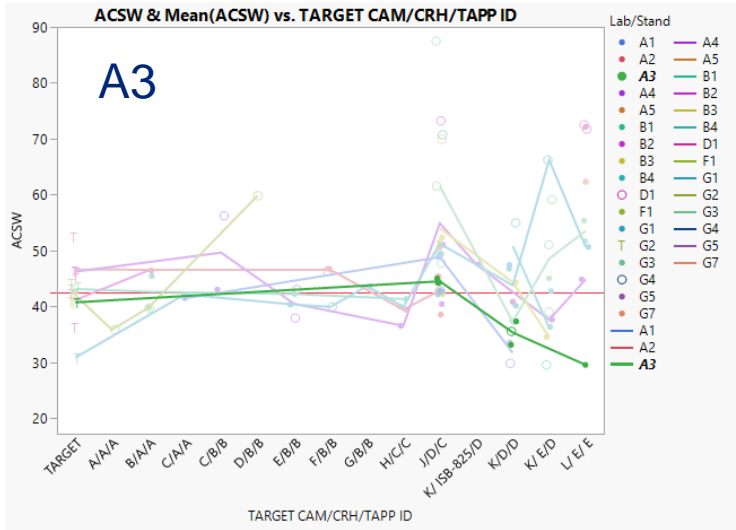
| Term                                  | Estimate  | Std Error | t Ratio | Prob> t    | estimate             |
|---------------------------------------|-----------|-----------|---------|------------|----------------------|
| Intercept                             | 46.409882 | 2.155215  | 21.53   | <.0001     | 1 46.40988           |
| Lab/Stand[ A1]                        | -7.578276 | 5.109229  | -1.48   | 0.1432     | 0.058823529 -0.44578 |
| Lab/Stand[ A2]                        | -3.251373 | 3.645444  | -0.89   | 0.376      | 0.058823529 -0.19126 |
| Lab/Stand[ A3]                        | -8.645389 | 3.488589  | -2.48   | 0.016      | 0.058823529 -0.50855 |
| Lab/Stand[ A4]                        | -0.786267 | 3.433203  | -0.23   | 0.8196     | 0.058823529 -0.04625 |
| Lab/Stand[ A5]                        | -2.479516 | 8.906713  | -0.28   | 0.7817     | 0.058823529 -0.14585 |
| Lab/Stand[ B1]                        | -1.498853 | 4.723753  | -0.32   | 0.7521     | 0.058823529 -0.08817 |
| Lab/Stand[ B2]                        | -2.534082 | 6.081899  | -0.42   | 0.6784     | 0.058823529 -0.14906 |
| Lab/Stand[ B3]                        | -0.475181 | 4.066091  | -0.12   | 0.9074     | 0.058823529 -0.02795 |
| Lab/Stand[ B4]                        | -0.326777 | 4.789571  | -0.07   | 0.9458     | 0.058823529 -0.01922 |
| Lab/Stand[ D1]                        | 25.847181 | 7.310336  | 3.54    | 0.0008     | 0.058823529 1.520422 |
| Lab/Stand[ F1]                        | -4.167416 | 6.081899  | -0.69   | 0.4958     | 0.058823529 -0.24514 |
| Lab/Stand[ G1]                        | -0.328199 | 2.913029  | -0.11   | 0.9107     | 0.058823529 -0.01931 |
| Lab/Stand[ G2]                        | -2.976223 | 6.953506  | -0.43   | 0.6701     | 0.058823529 -0.17507 |
| Lab/Stand[ G3]                        | 5.1978804 | 3.213288  | 1.62    | 0.1109     | 0.058823529 0.305758 |
| Lab/Stand[ G4]                        | -10.37952 | 8.906713  | -1.17   | 0.2484     | 0.058823529 -0.61056 |
| Lab/Stand[ G5]                        | -1.665174 | 9.153992  | -0.18   | 0.8563     | 0.058823529 -0.09795 |
| Lab/Stand[ G7]                        | 16.047181 | 9.497663  | 1.69    | 0.0962     | 0.058823529 0.943952 |
| TARGET CAM/CRH/TAPP ID[TARGET]        | -0.933659 | 3.312523  | -0.28   | 0.779      | 0 0                  |
| TARGET CAM/CRH/TAPP ID[A/A/A]         | -6.442467 | 10.15643  | -0.63   | 0.5282     | 0 0                  |
| TARGET CAM/CRH/TAPP ID[B/A/A]         | -1.160081 | 5.609663  | -0.21   | 0.8369     | 0 0                  |
| TARGET CAM/CRH/TAPP ID[C/A/A]         | -0.706645 | 6.920808  | -0.1    | 0.919      | 0 0                  |
| TARGET CAM/CRH/TAPP ID[C/B/B]         | 3.9763849 | 6.845758  | 0.58    | 0.5635     | 0 0                  |
| TARGET CAM/CRH/TAPP ID[D/B/B]         | 17.557533 | 10.15643  | 1.73    | 0.0889     | 0 0                  |
| TARGET CAM/CRH/TAPP ID[E/B/B]         | -4.709986 | 4.796743  | -0.98   | 0.33       | 0 0                  |
| TARGET CAM/CRH/TAPP ID[F/B/B]         | 0.1670994 | 5.683816  | 0.03    | 0.9766     | 0 0                  |
| TARGET CAM/CRH/TAPP ID[G/B/B]         | -2.481683 | 9.018488  | -0.28   | 0.7841     | 0 0                  |
| TARGET CAM/CRH/TAPP ID[H/C/C]         | -5.668709 | 4.725534  | -1.2    | 0.2349     | 0 0                  |
| TARGET CAM/CRH/TAPP ID[I/D/C]         | 6.7696343 | 2.894026  | 2.34    | 0.0226     | 0 0                  |
| TARGET CAM/CRH/TAPP ID[ K/ ISB-825/D] | 1.8763849 | 9.109083  | 0.21    | 0.8375     | 0 0                  |
| TARGET CAM/CRH/TAPP ID[ K/D/D]        | -3.944708 | 3.683198  | -1.07   | 0.2884     | 0 0                  |
| TARGET CAM/CRH/TAPP ID[ K/ E/D]       | -4.142036 | 4.006186  | -1.03   | 0.3053     | 0 0                  |
| TARGET CAM/CRH/TAPP ID[ L/ E/ E]      | -0.157063 | 4.524878  | -0.03   | 0.9724     | 1 -0.15706           |
|                                       |           |           |         | estimate   | 46.25282             |
|                                       |           |           |         | Target     | 42.5                 |
|                                       |           |           |         | difference | 3.752819             |

Model: Lab/Stand and Hardware

Option2: ignore oil and look at hardware ONLY

- Subtract 3.75 to current cam wear (after the current -18.5 CF)

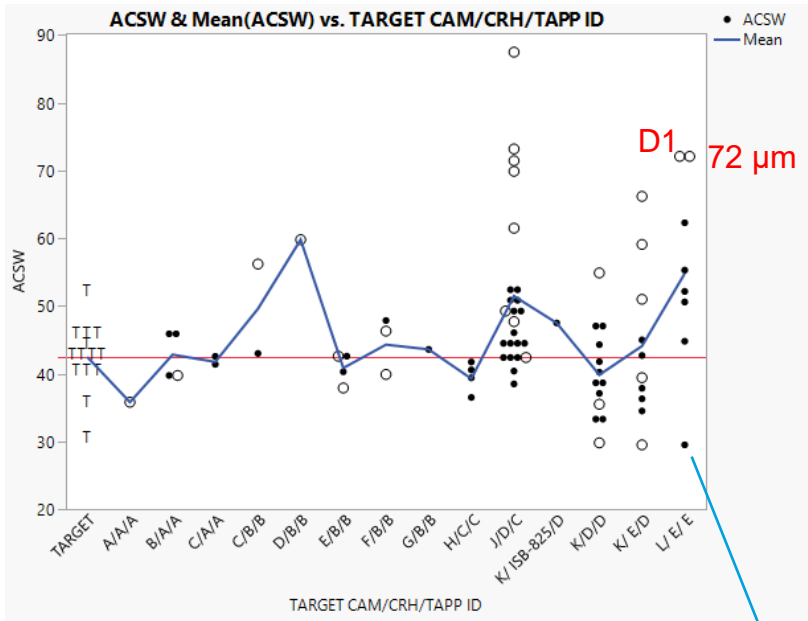
# Highlighting stands that have tested L/E/E hardware, so that we can see their behavior over batches of parts – ignoring oil re-blend



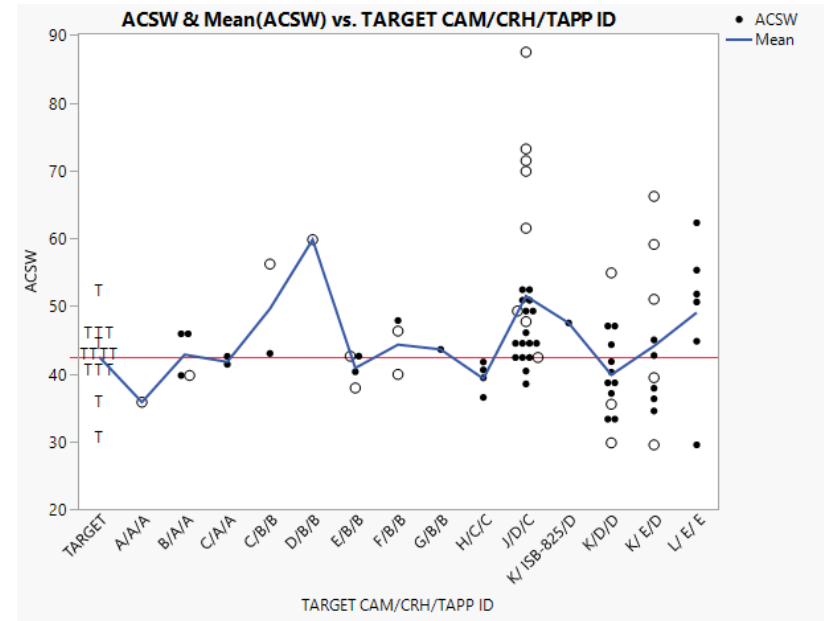
# Average Cam wear across batches of parts



## With two D1 tests



## Without D1 tests



13 micrometers below target – only one test 831-3 L/E/E, the other tests are on 831-4

What else can I do to help the SP move forward?

# Appendices

# Testing for oil differences between 831- 3 and 831- 4 assuming that batches of parts are the same

# Testing for oil differences between 831- 3 and 831- 4, ignoring parts, *assuming that CF should not be updated for the most recent parts*

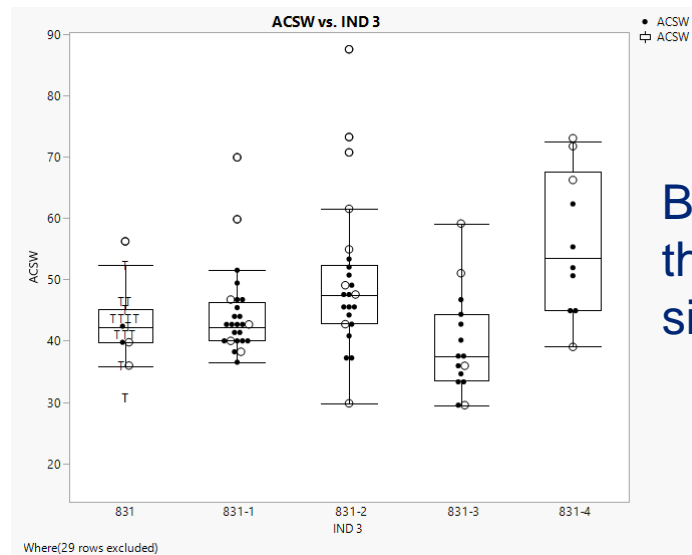


|                     |        |
|---------------------|--------|
| TARGET              | 0      |
| 831/A/A/A           | 0      |
| 831/B/A/A           | 0      |
| 831/C/A/A           | 0      |
| 831/C/B/B           | 0      |
| 831-1/B/A/A         | 0      |
| 831-1/C/A/A         | 0      |
| 831-1/C/B/B         | 0      |
| 831-1/D/B/B         | 0      |
| 831-1/E/B/B         | 0      |
| 831-1/F/B/B         | 0      |
| 831-1/G/B/B         | 0      |
| 831-1/H/C/C         | 0      |
| 831-1/J/D/C         | 0      |
| 831-2/J/D/C         | 0      |
| 831-2/ K/ ISB-825/L | 0      |
| 831-2/ K/D/D        | 0      |
| 831-3/ K/ E/D       | 0.3333 |
| 831-3/ K/D/D        | 0.3333 |
| 831-3/ L/ E/ E      | 0.3333 |
| 831-4/ K/ E/D       | -0.5   |
| 831-4/ L/ E/ E      | -0.5   |
| Estimate            | -9.325 |
| Std Error           | 5.449  |
| t Ratio             | -1.711 |
| Prob> t             | 0.0928 |
| SS                  | 241.39 |

92 chartable tests: no exclusions  
Model: Lab/Stand and Hardware

The difference between dash 3 and dash 4 is 9.3  $\mu\text{m}$ .  
This difference is not statistically significant at 5% level.  
P-value is 0.0928

Sean has confirmed that 831-4 used the exact same base oil and components as 831-3.

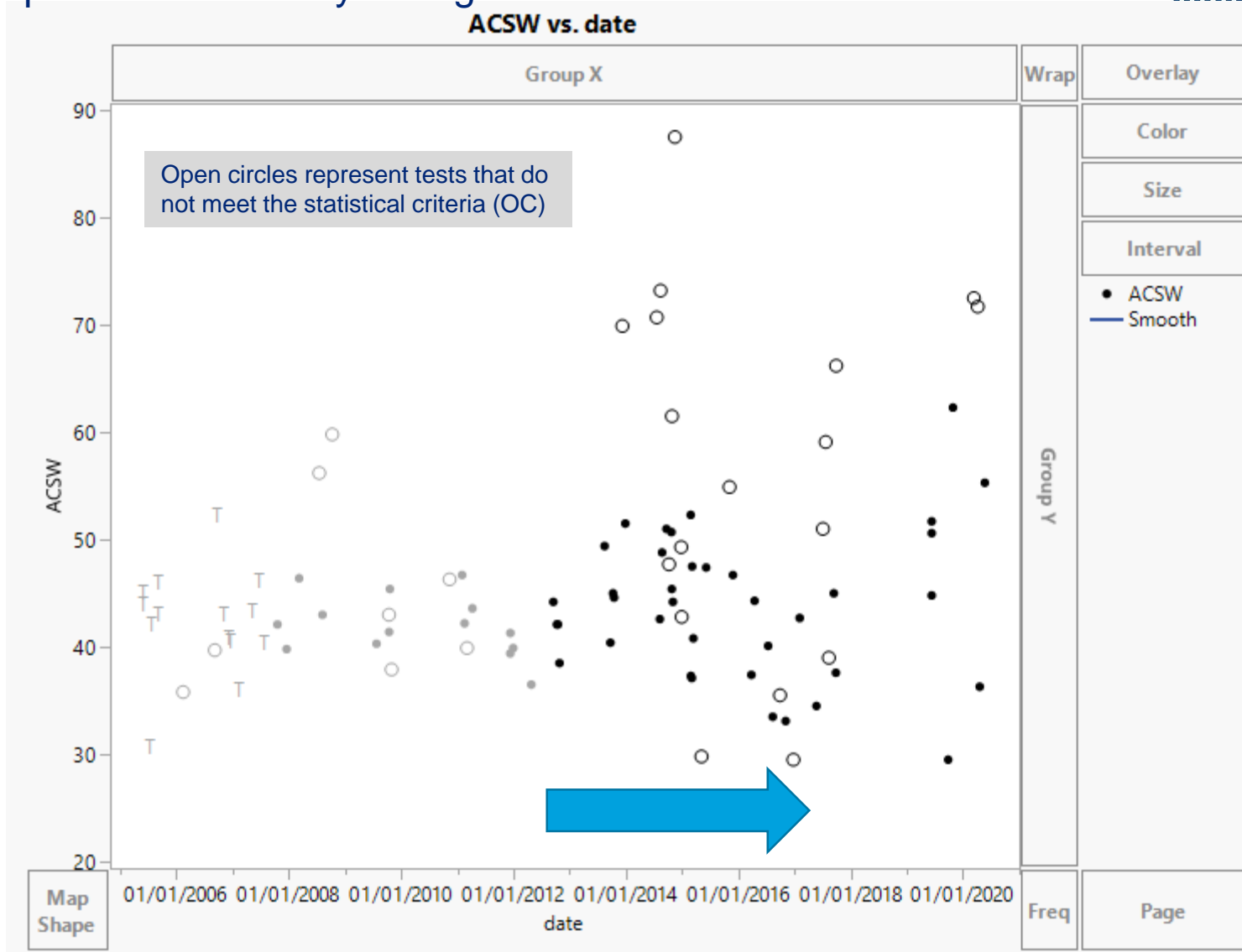


But on the transformed scale the difference is statistically significant at 5% level

# Data subset: JDC parts forward... 56 tests



# Data subset: JDC parts forward... 56 tests --- Travis suggestion to deal with potential variability change



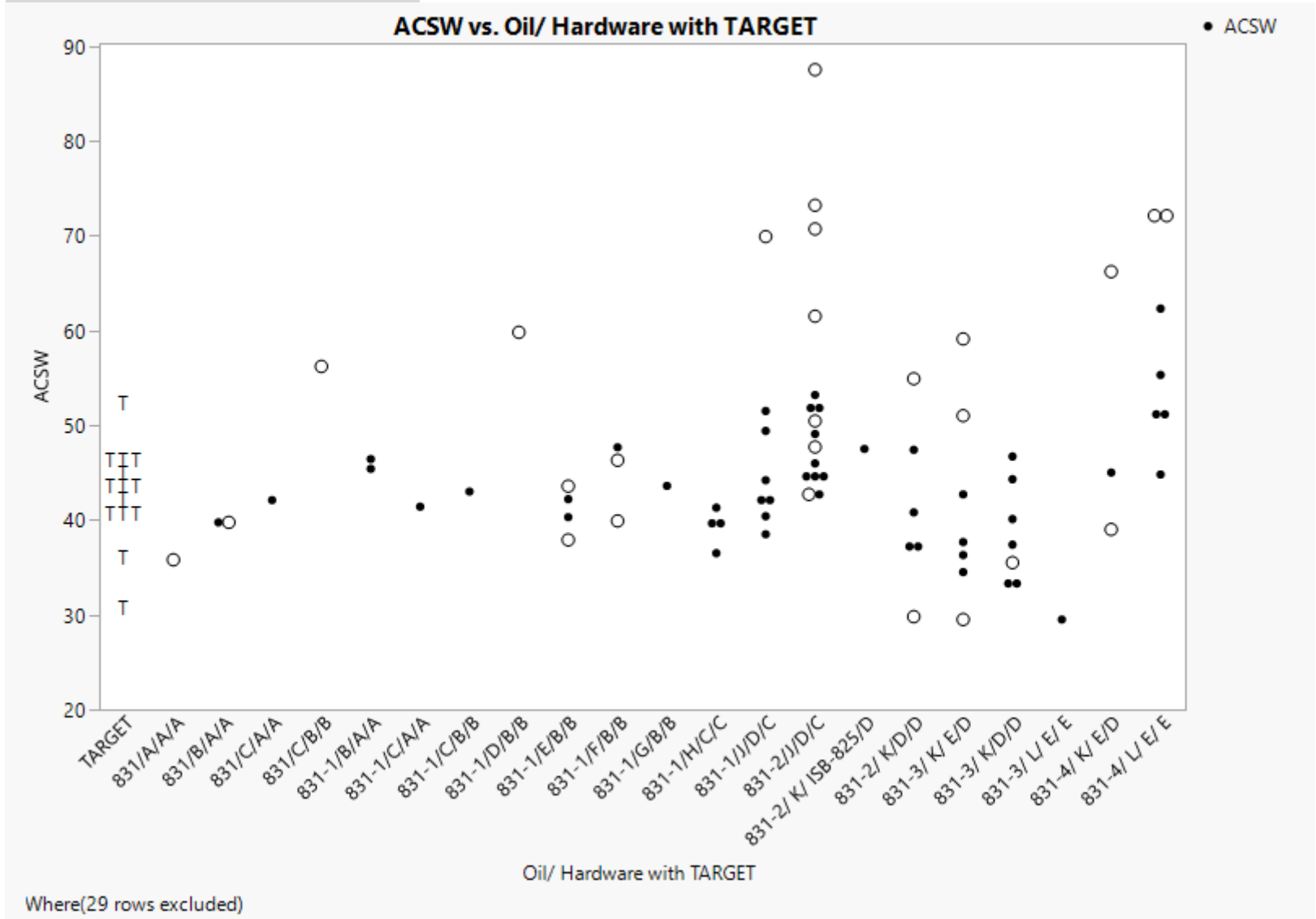
# Additional calculations based on the subset: subtract 3.6 $\mu\text{m}$ from current CF corrected ACSW



| RMSE = 10.36                           |           |           |            |         |             |
|--|-----------|-----------|------------|---------|-------------|
| reduced set J/D/C forward              |           |           |            |         |             |
| Expanded Estimates                     |           |           |            |         |             |
| Nominal factors expanded to all levels |           |           |            |         |             |
| Term                                   | Estimate  | Std Error | t Ratio    | Prob> t |             |
| Intercept                              | 46.697433 | 2.957817  | 15.79      | <.0001  | 1           |
| Lab/Stand[ A1]                         | -9.158542 | 6.110807  | -1.5       | 0.142   | 0.076923077 |
| Lab/Stand[ A2]                         | -11.38312 | 6.142339  | -1.85      | 0.0714  | 0.076923077 |
| Lab/Stand[ A3]                         | -9.708528 | 4.180673  | -2.32      | 0.0255  | 0.076923077 |
| Lab/Stand[ A4]                         | -0.790082 | 4.781713  | -0.17      | 0.8696  | 0.076923077 |
| Lab/Stand[ A5]                         | -3.516455 | 9.914725  | -0.35      | 0.7247  | 0.076923077 |
| Lab/Stand[ B3]                         | -1.195813 | 4.504151  | -0.27      | 0.792   | 0.076923077 |
| Lab/Stand[ B4]                         | -0.389516 | 5.292154  | -0.07      | 0.9417  | 0.076923077 |
| Lab/Stand[ D1]                         | 26.028427 | 8.103447  | 3.21       | 0.0026  | 0.076923077 |
| Lab/Stand[ G1]                         | 2.3217457 | 3.921567  | 0.59       | 0.5572  | 0.076923077 |
| Lab/Stand[ G3]                         | 4.8594984 | 3.504617  | 1.39       | 0.1734  | 0.076923077 |
| Lab/Stand[ G4]                         | -11.41645 | 9.914725  | -1.15      | 0.2566  | 0.076923077 |
| Lab/Stand[ G5]                         | -1.879585 | 10.16872  | -0.18      | 0.8543  | 0.076923077 |
| Lab/Stand[ G7]                         | 16.228427 | 10.54021  | 1.54       | 0.1317  | 0.076923077 |
| CAM/CRH/TAPP ID[J/D/C]                 | 7.5190218 | 3.25936   | 2.31       | 0.0265  | 0           |
| CAM/CRH/TAPP ID[ K/D/D]                | -4.017848 | 3.837133  | -1.05      | 0.3015  | 0           |
| CAM/CRH/TAPP ID[ K/ ISB-825/D]         | 1.5926486 | 9.13525   | 0.17       | 0.8625  | 0           |
| CAM/CRH/TAPP ID[ K/ E/D]               | -4.467963 | 3.910686  | -1.14      | 0.2602  | 0           |
| CAM/CRH/TAPP ID[ L/ E/ E]              | -0.62586  | 4.474306  | -0.14      | 0.8895  | 1           |
|  |           |           |            |         | 46.07157355 |
|  |           |           |            |         | 42.5        |
|  |           |           | difference |         | 3.571573546 |

Model: Lab/Stand; Hardware  
RMSE: 10.36  $\mu\text{m}$

Open circles represent tests that do not meet the statistical criteria (OC)



# ISB reference oil targets



| ISB Reference Oil Targets |    |                 |                 |                       |     |                            |      |
|---------------------------|----|-----------------|-----------------|-----------------------|-----|----------------------------|------|
| Oil                       | n  | Effective Dates |                 | Average Camshaft Wear |     | Average Tappet Weight Loss |      |
|                           |    | From            | To <sup>1</sup> | $\bar{X}$             | 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 <sup>2</sup>        | -- | 8-7-07          | 10-18-17        | 42.5                  | 5.0 | 97.2                       | 14.8 |
| 831-1 <sup>2</sup>        | -- | 10-19-17        | ***             | 42.5                  | 8.7 | 97.2                       | 14.8 |
| 831-2 <sup>2</sup>        | -- | 8-6-13          | 10-18-17        | 42.5                  | 5.0 | 97.2                       | 14.8 |
| 831-2 <sup>2</sup>        | -- | 10-19-17        | ***             | 42.5                  | 8.7 | 97.2                       | 14.8 |
| 831-3 <sup>2</sup>        | -- | 8-11-15         | 10-18-17        | 42.5                  | 5.0 | 97.2                       | 14.8 |
| 831-3 <sup>2</sup>        | -- | 10-19-17        | ***             | 42.5                  | 8.7 | 97.2                       | 14.8 |
| 831-4 <sup>2</sup>        | -- | 6-14-17         | 10-18-17        | 42.5                  | 5.0 | 97.2                       | 14.8 |
| 831-4 <sup>2</sup>        | -- | 10-19-17        | ***             | 42.5                  | 8.7 | 97.2                       | 14.8 |

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