ISB Tappet Correction Factor and RO Blend Target Review

Statistics Group

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Executive Summary

ISB Correction Factor and RO Blend Target Review

- Executive Summary:
  - Options:
    1. "Do Nothing" – use existing targets and correction factor for Tappet Wear
    2. Get direction from Surveillance Panel on alternate approach
       - *Other "unknown" sources of variance may be co-linear with hardware changes / reference oil re-blends.*
    3. Use proposed correction factors and targets for Tappet Wear
   - *Analysis provided in the following presentation slides*

ISB Correction Factor and RO Blend Target Review

- Executive Summary *(continued — Option 3)*:

    - Use reference oil test data that corresponds with AA_BA, JC, KD, and LE hardware Camshaft-Tappet hardware batches & Ref Oils 831X to generate targets and CFs

    - Recommended Correction Factor is Multiplicative with a value of 0.85 for "LE" Camshaft-Tappet Hardware

    - Revised reference oil target for 831-3|4 is 118.5

    - Revised Standard Deviation Target for Reference Oil 831-3|4 is 21.1
        - Currently it is 14.8

    - Revised Severity Adjustment Standard deviation is 16.5
        - Currently it is 14.8

ISB Tappet Analysis

ISB Correction Factor and RO Blend Target Review

- ATWL Parameter chart indicates that the test is currently on target
- CUSUM chart suggests a trend in severe direction
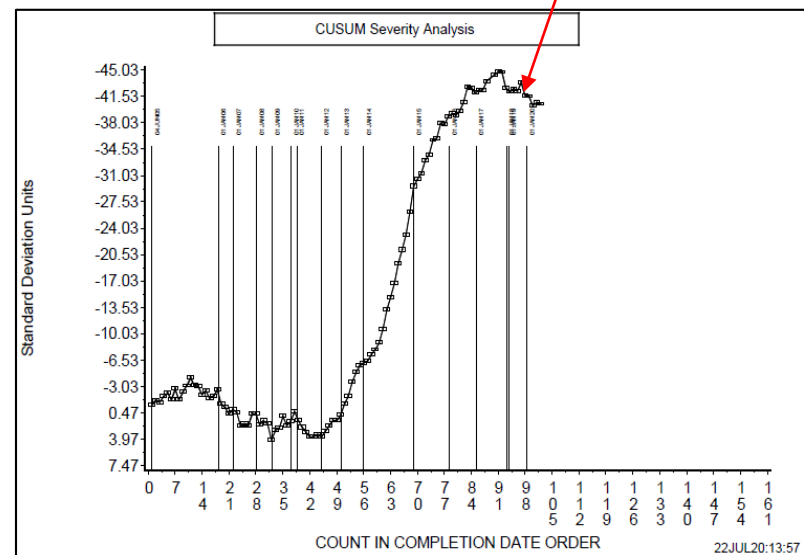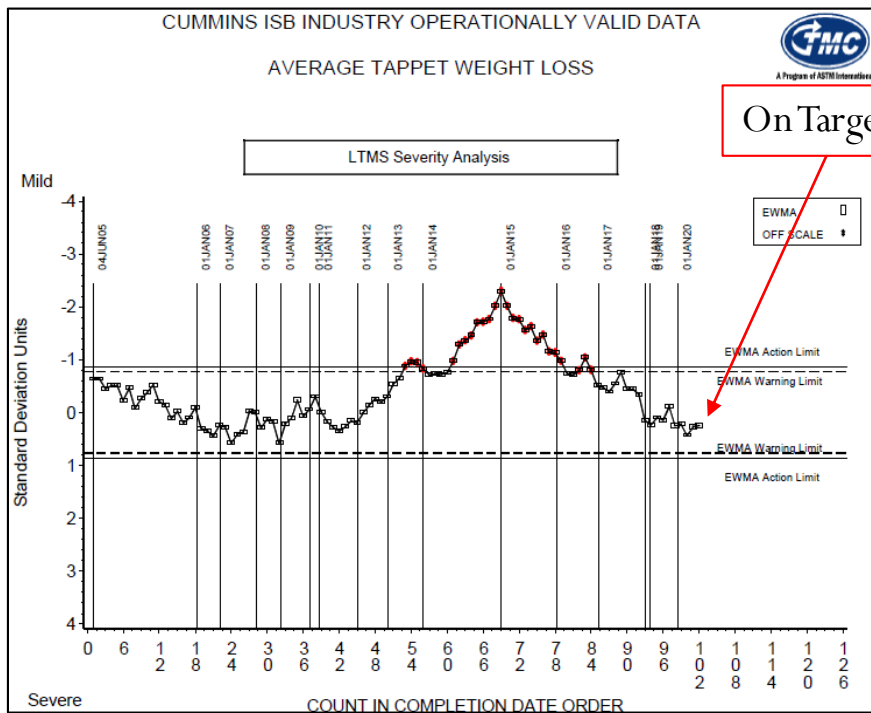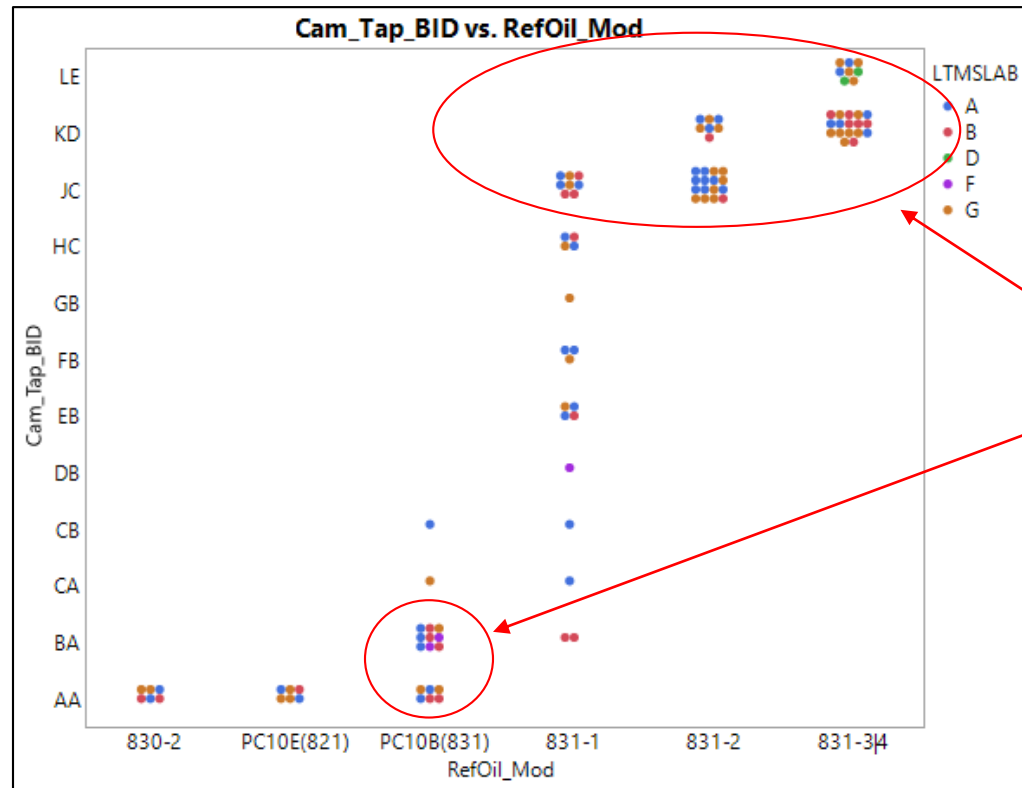
ISB Correction Factor and RO Blend Target Review

- Issues related to reference oil 831X re-blends:
  - Data suggests a ~1.0 cSt difference between 831(PC10B) & 831-4
  - Feedback from Supplier/TMC indicates RO831-3|4 can be combined
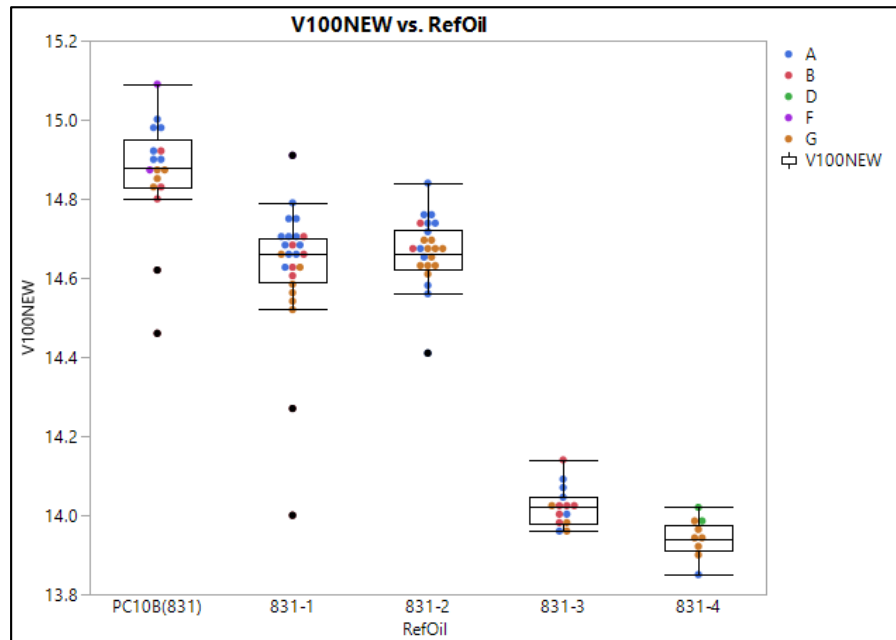
V100 New			
RefOil	Mean	Stdev	N
PC10B(831)	14.865	0.145	17
831-1	14.625	0.173	25
831-2	14.660	0.082	23
831-3	14.021	0.050	15
831-4	13.941	0.049	9

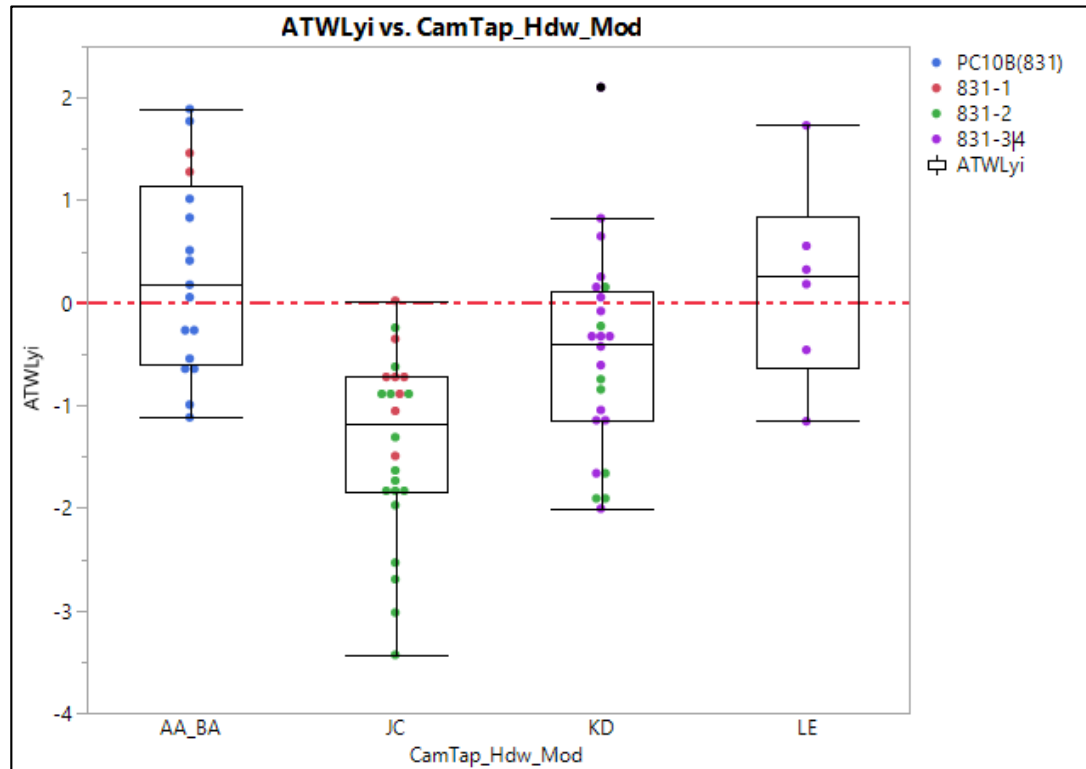# ISB Correction Factor and RO Blend Target Review

- What are the tested hardware & reference oil blend combinations?
  - Plot of Camshaft and Tappet Hardware by Reference Oil batch is shown below
  - Initial Cam/Tap batch (PM phase) AA hardware tested with Reference oils 830-2, PC10B, and PC10E
  - Recent hardware batches JC, KD, and LE tested with RO 831-1, 831-2, & 831-3|4
  - Correction Factor Proposal corresponds to hardware & Ref Oil data shown below

Tappet Analysis Data

ISB Correction Factor and RO Blend Target Review

- Are current hardware Correction Factors (CFs) resulting in "*on target performance?*"
  - Plot of ATWLYi (w/o Lab D) is plotted below.
  - Plot suggests that means of corrected data by hardware batch may not equal zero *(not "on target performance")*
  - Advantageous to analyze with ATWLOrig data in lieu of using the corrected ATWL data

ISB Correction Factor and RO Blend Target Review

- Correction Factor history:
  - Both Linear vs. Multiplicative CFs have been applied to the ISB

|				
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

- Camshaft wear may be better represented as being proportional to the reference oil/candidate wear - in lieu of a linear constant
- Analysis will evaluate multiplicative correction factor approach for the ATWL parameter

ISB Correction Factor and RO Blend Target Review

- Analysis Method Steps:

  1. Analyze the data to predict the severity by hardware batch as compared to original "targets" hardware *(CamTap batch AA & BA)* with RO PC10B(831) to quantify severity shift by hardware batch

     - Use ATWLOrig *(vs. Corrected ATWL)* as the key dependent variable for the analyses

  2. Use fitted ATWLOrig model to predict hardware and reference oil blend combinations - to estimate CFs

  3. Apply CFs to the data & then re-analyze to generate new targets for RO 831-3|4

ISB Correction Factor and RO Blend Target Review

- Predicted LSMeans for (PM) PC10B(831) and Camshaft-Tappet hardware combinations are summarized below:

  - Predictions are generated to predict ATWL for the "AA_BA" *(Target hardware)*, "JC", "KD", and "LE" hardware with reference oil PC10B(831) *(Target RO blend)*
  - LSMeans are used to establish multiplicative CFs (by hardware batch)
   - Correction Factor calculated from original target of 97.2 (n=14)
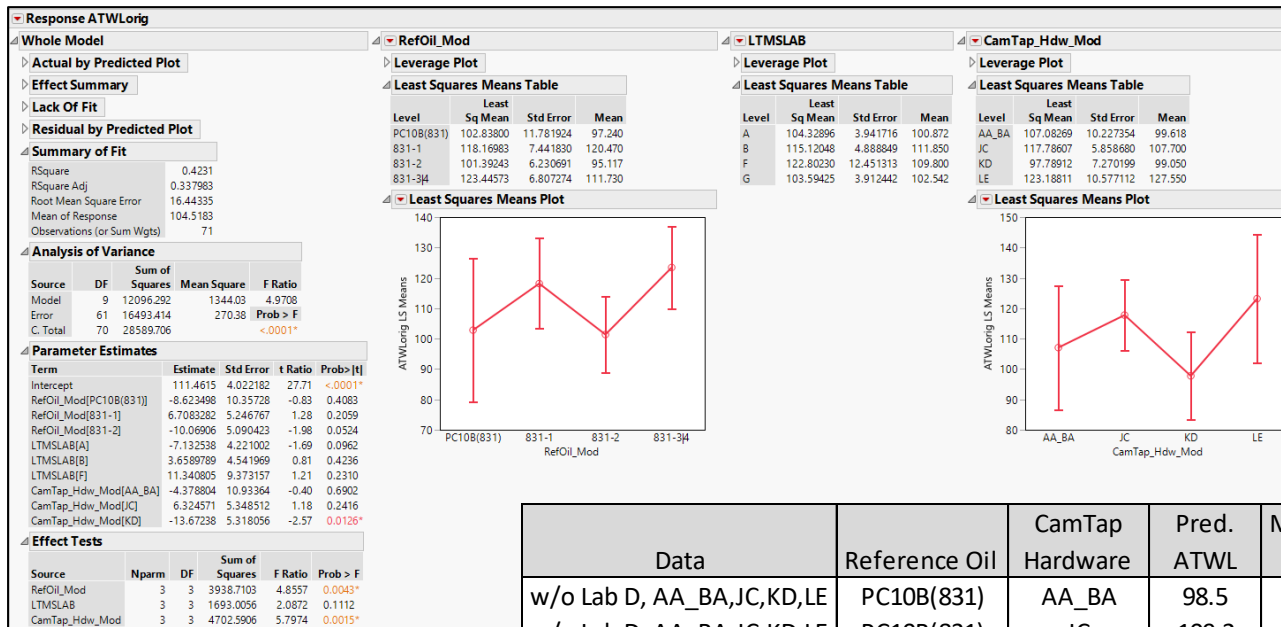
Correction Factor Example
$$0.85 = 114.6 / 97.2$$

Data	Reference Oil	CamTap Hardware	Pred. ATWL	Multiplicative CF	Updated Target
w/o Lab D, AA_BA,JC,KD,LE	PC10B(831)	AA_BA	98.5	0.99	97.2
w/o Lab D, AA_BA,JC,KD,LE	PC10B(831)	JC	109.2	0.89	
w/o Lab D, AA_BA,JC,KD,LE	PC10B(831)	KD	89.2	1.09	
w/o Lab D, AA_BA,JC,KD,LE	PC10B(831)	LE	114.6	0.85	

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ISB Correction Factor and RO Blend Target Review

- Analysis of ATWLOrig using (*multiplicative*) *corrected* data

- Overall model summary:
  - Reference oil is significant and lab is marginally significant
  - RMSE = 16.0, RO LSMeans Target for 831-3|4 = 118.5
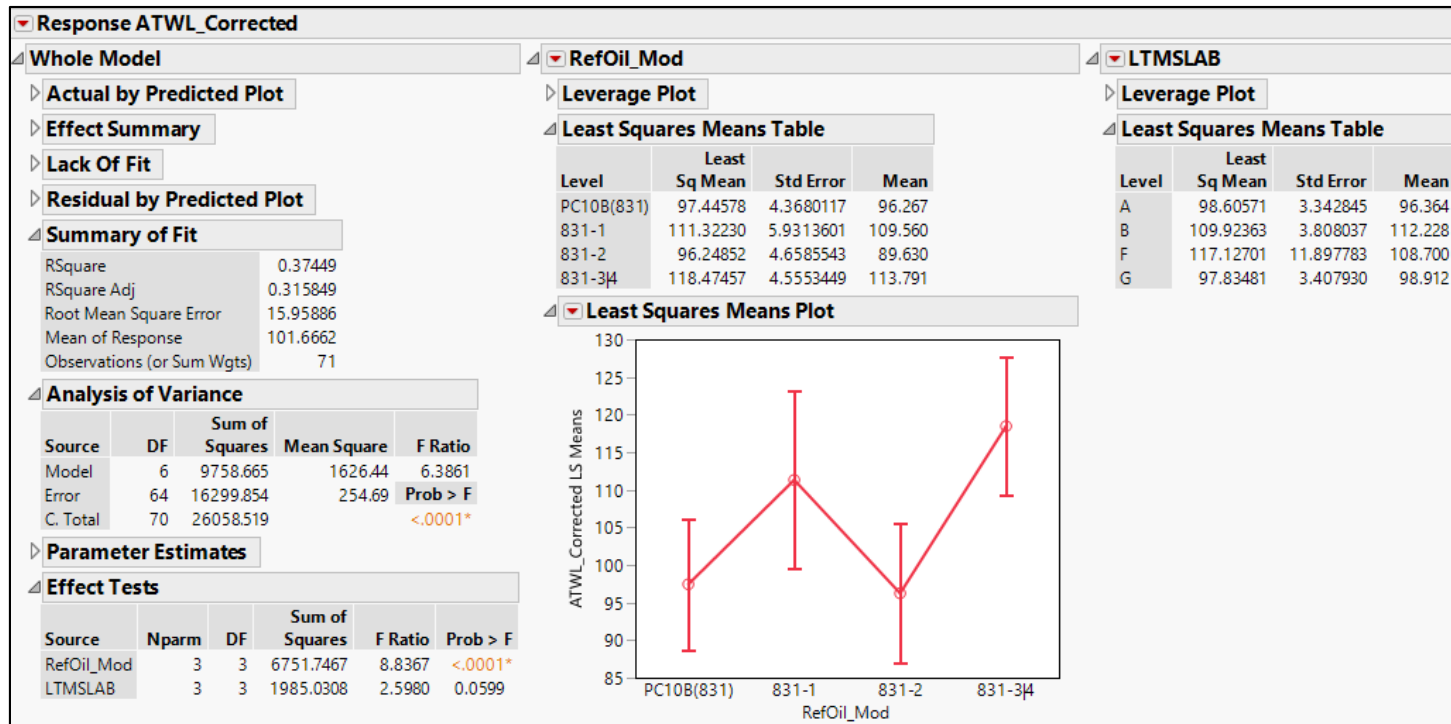
ISB Correction Factor and RO Blend Target Review

- Plot of model fit residuals without Lab D - using multiplicative corrected data
 - No apparent severity trend by Reference Oil – using corrected data
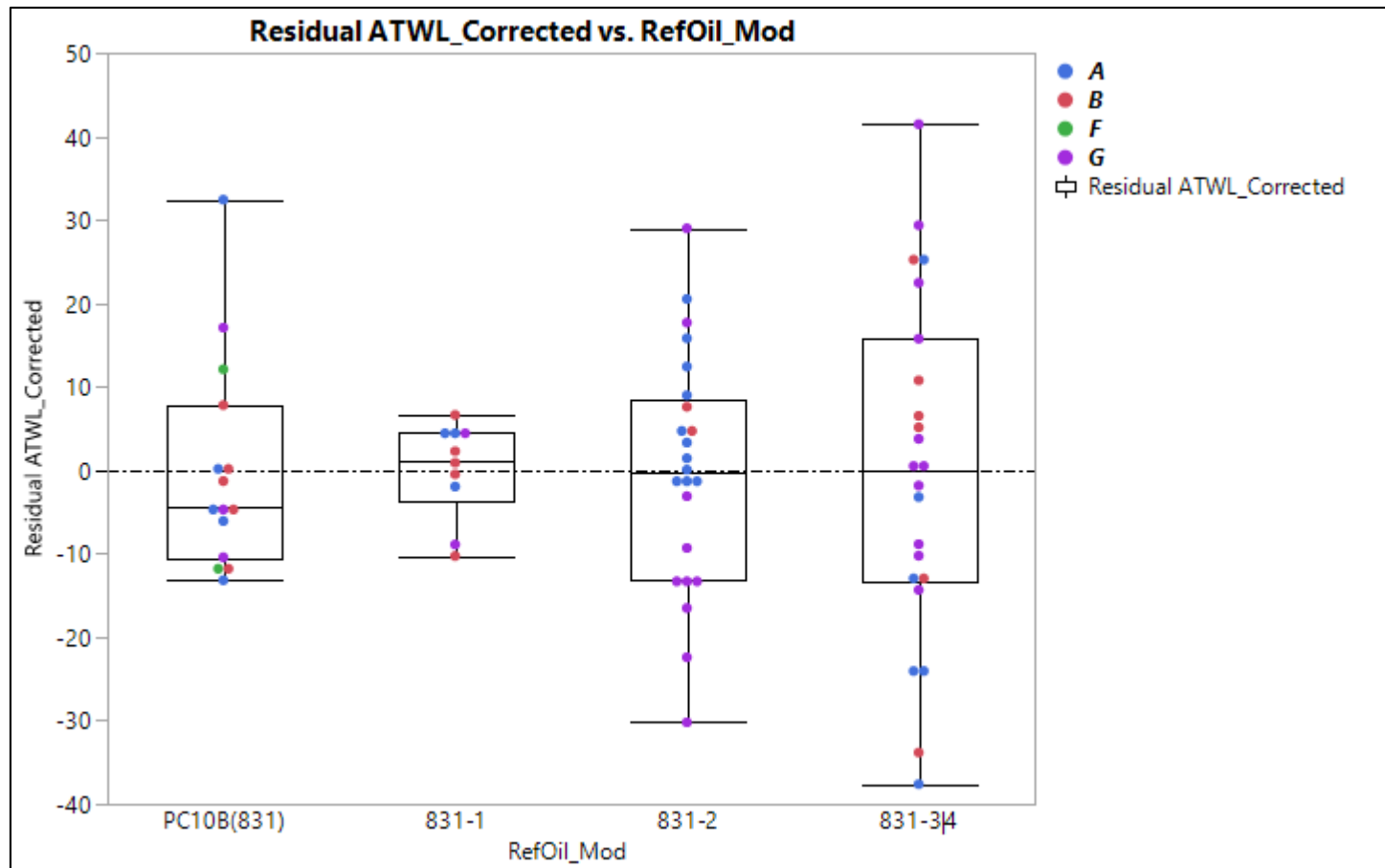
ISB Correction Factor and RO Blend Target Review

- Analysis of multiplicative corrected data for severity adjustment calculation
  - Based on reference oil model only (no laboratory factor)
  - RMSE for Severity Adjustment = 16.5

Response ATWL_Corrected

Whole Model

▷ **Actual by Predicted Plot**

▷ **Effect Summary**

▷ **Residual by Predicted Plot**

Summary of Fit

RSquare	0.298315
RSquare Adj	0.266896
Root Mean Square Error	16.51995
Mean of Response	101.6662
Observations (or Sum Wgts)	71

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	3	7773.635	2591.21	9.4948
Error	67	18284.884	272.91	Prob > F
C. Total	70	26058.519		<.0001*

▷ **Parameter Estimates**

Effect Tests

Source	Nparm	DF	Sum of Squares	F Ratio	Prob > F
RefOil_Mod	3	3	7773.6346	9.4948	<.0001*

RefOil_Mod

▷ **Leverage Plot**

Least Squares Means Table

Level	Least Sq Mean	Std Error	Mean
PC10B(831)	96.26667	4.2654325	96.267
831-1	109.56000	5.2240666	109.560
831-2	89.63043	3.4446475	89.630
831-3 4	113.79130	3.4446475	113.791

ISB Correction Factor and RO Blend Target Review

- Recommended Correction Factor & Target Updates:

  - Use ATWLOrig to generate Hardware CFs and Targets

    - Include Camshaft-Tappet hardware batches "AA_BA", "JC", "KD", "LE" with RO 831X blends

    - Select Multiplicative method to hardware correct data

  - Multiplicative Correction Factor for "LE" Cam-Tap Hardware (w/RO 831-3|4) = 0.85
    - If using "KD" Cam-Tap Hardware, multiplicative correction factor = 1.09

  - Reference Oil Target (831-3|4) with hardware corrected data = 118.5

  - Standard Deviation Update for Reference Oil Y_i calculations:

    - Raw Standard Deviation for (831-3|4) = 21.1
    - Currently it is 14.8

  - Severity Adjustment Pooled S = 16.5 *(reference slide 15)*
    - Currently it is 14.8

Appendix
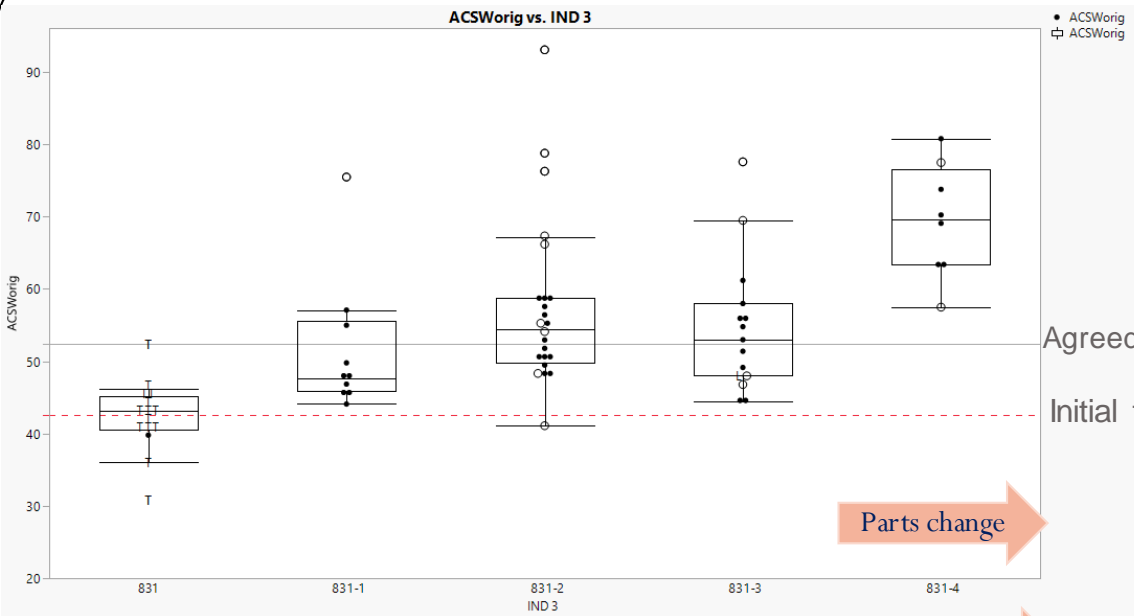
The original cam data shown to the left has been above the target since the first oil re-blend has been introduced. The target was updated to 52.4 (08/2020)
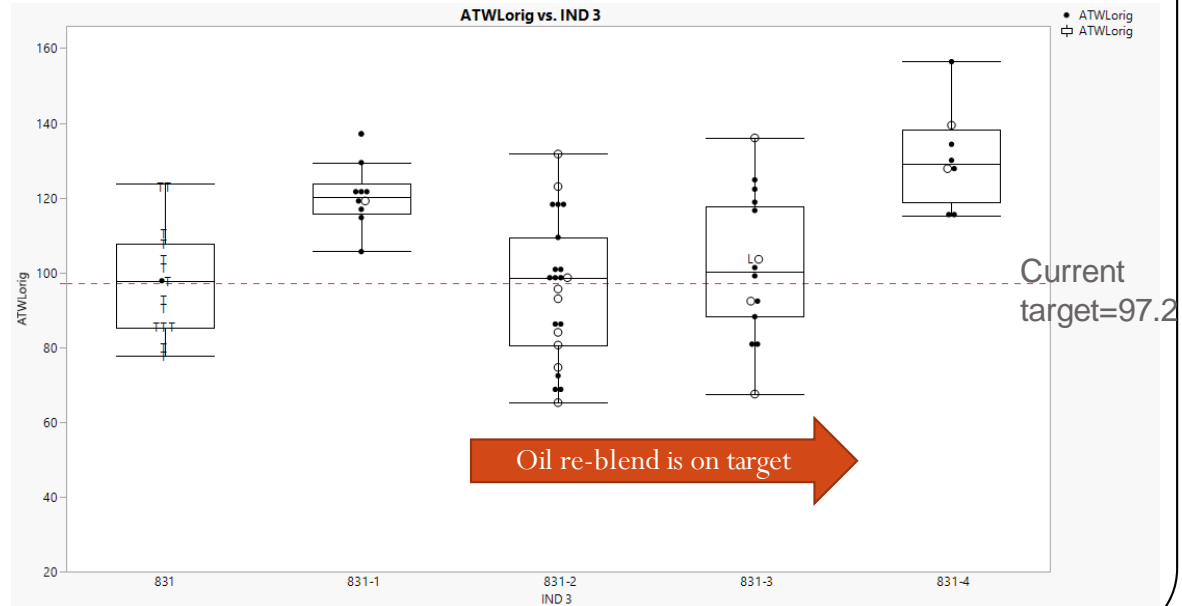
Agreed target= 52.4

Initial target=42.4

Parts change

Likely impact of changes in oil re-blends

The original tappet data shown to the right illustrates the tappet test results on target for 831-2 and 831-3, not supporting a target update
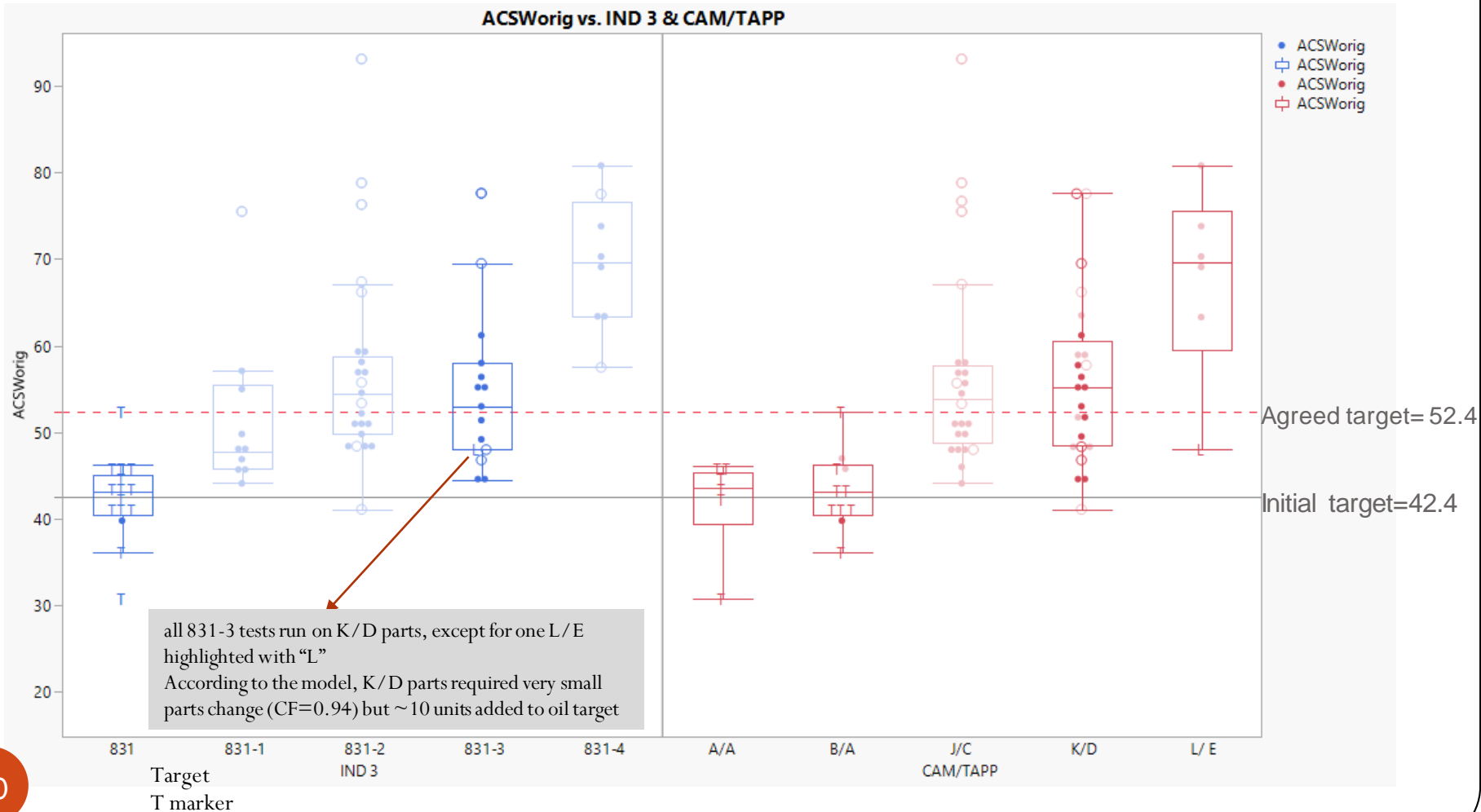
Current target=97.2

Oil re-blend is on target

Fact: oil supplier reported <mark>no</mark> oil changes between dash 3 & 4 re-blends

Highlighted below are tests run on 831 (target) and 831-3

- Look at the plot (ACSWorig) at the left to see the agreed camshaft target change
- Look at the plot at the right to visualize the agreed camshaft correction factor changes: small CF for K/D (0.94) and larger CF for L/E (0.77)

all 831-3 tests run on K/D parts, except for one L/E highlighted with "L"

According to the model, K/D parts required very small parts change (CF=0.94) but ~10 units added to oil target

Fact: oil supplier reported <mark>no</mark> oil changes between dash 3 & 4 re-blends

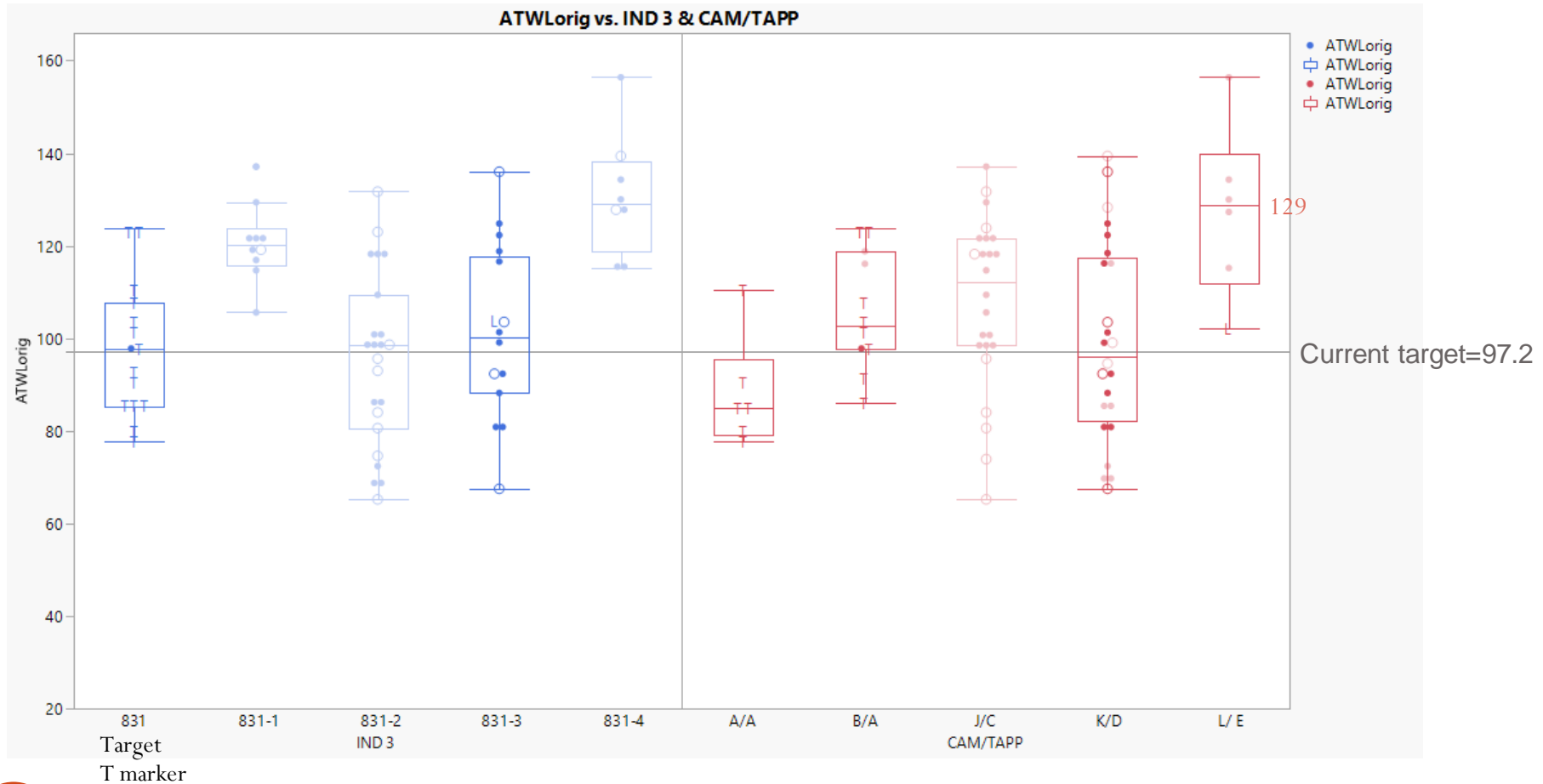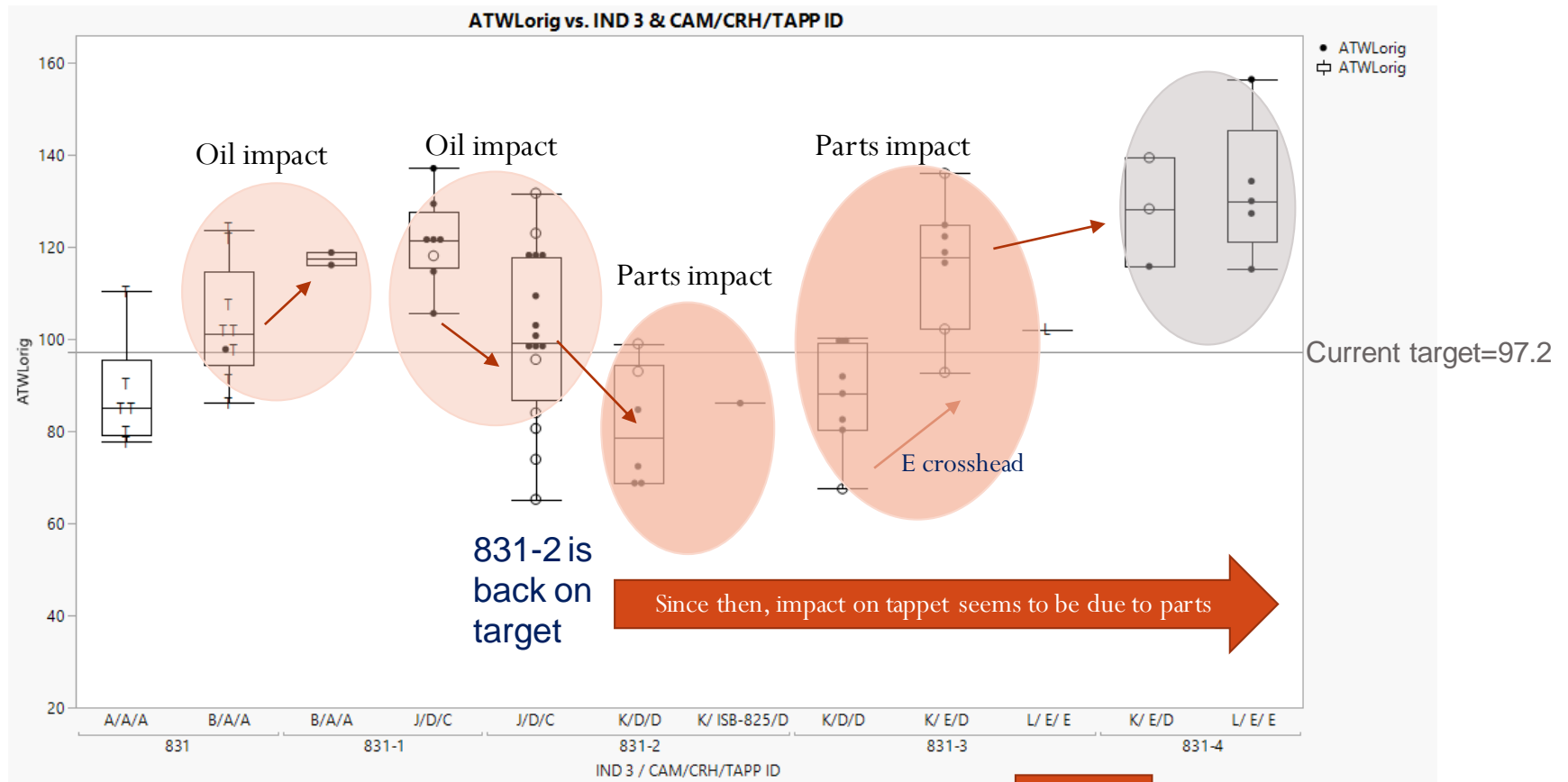Highlighted below are tests run on 831 (target) and 831-3

- Look at the plot (ATWLorig) at the left to see the 831-3 data pretty much on target
- Look at the plot at the right to visualize a quick L/E tappet correction factor $=97.2/129=0.75$ that can be compared to the current CF $= 0.785$

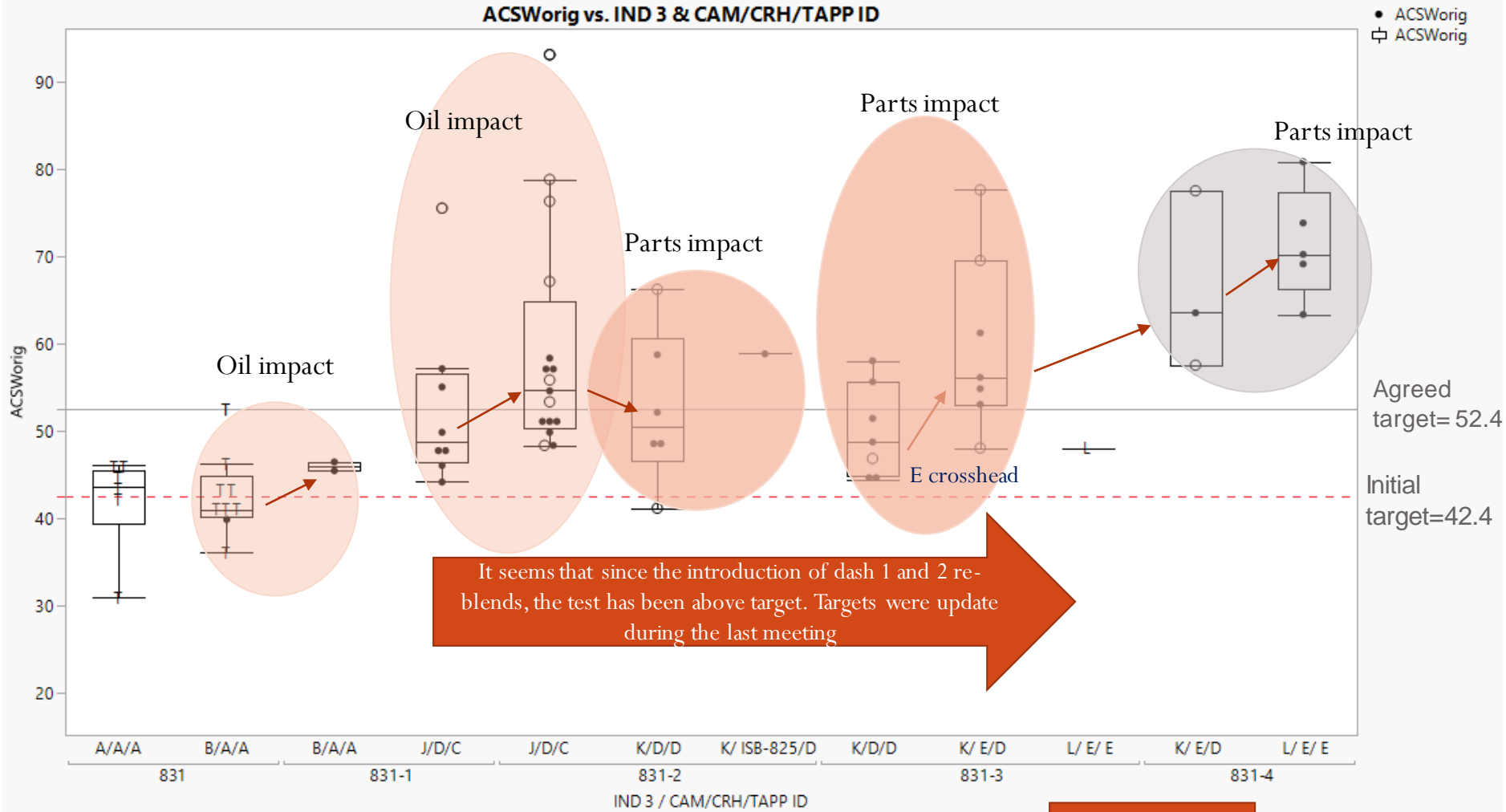# In support of *not changing oil target* for tappet weight loss

Tappet values have been above and below throughout the life of the test

ATWLorig vs. IND 3 & CAM/CRH/TAPP ID

Oil impact
Oil impact
Parts impact
Parts impact
Current target=97.2
E crosshead
831-2 is back on target
Since then, impact on tappet seems to be due to parts

Supplier has reported no change from dash 3 to 4

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ACSWorig vs. IND 3 & CAM/CRH/TAPP ID

Oil impact

Parts impact

Parts impact

Parts impact

Oil impact

Parts impact

E crosshead

Agreed target= 52.4

Initial target=42.4

It seems that since the introduction of dash 1 and 2 re-blends, the test has been above target. Targets were update during the last meeting

Supplier has reported no change from dash 3 to 4

Cam and Tappet side by side showing that the impact of changes over time on Cam and Tappet are different
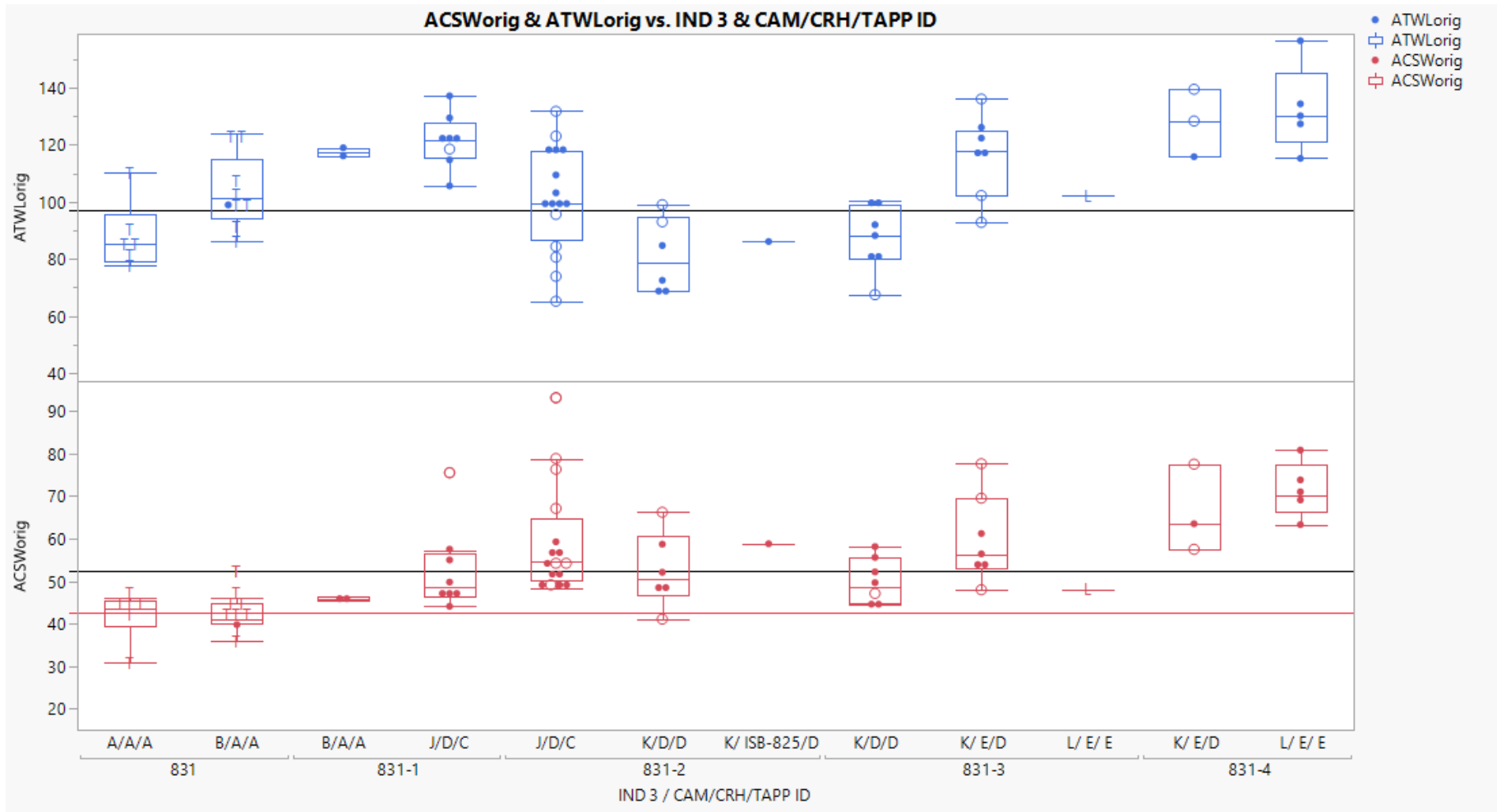
Highlighting K/E/D data forward: that's what the CF =0.785 corresponds to
From this plot it becomes clear that for tappet, K/E/D forward corresponds to a clear change from the previous batch of parts

ATWLorig & ATWL vs. IND 3 & 2 more