

T-13 Liner Severity Analysis

Suggested Solutions for Current Severity Issues in the T-13 Due to Parts and Operations

October 15, 2025

ASTM Data Analysts

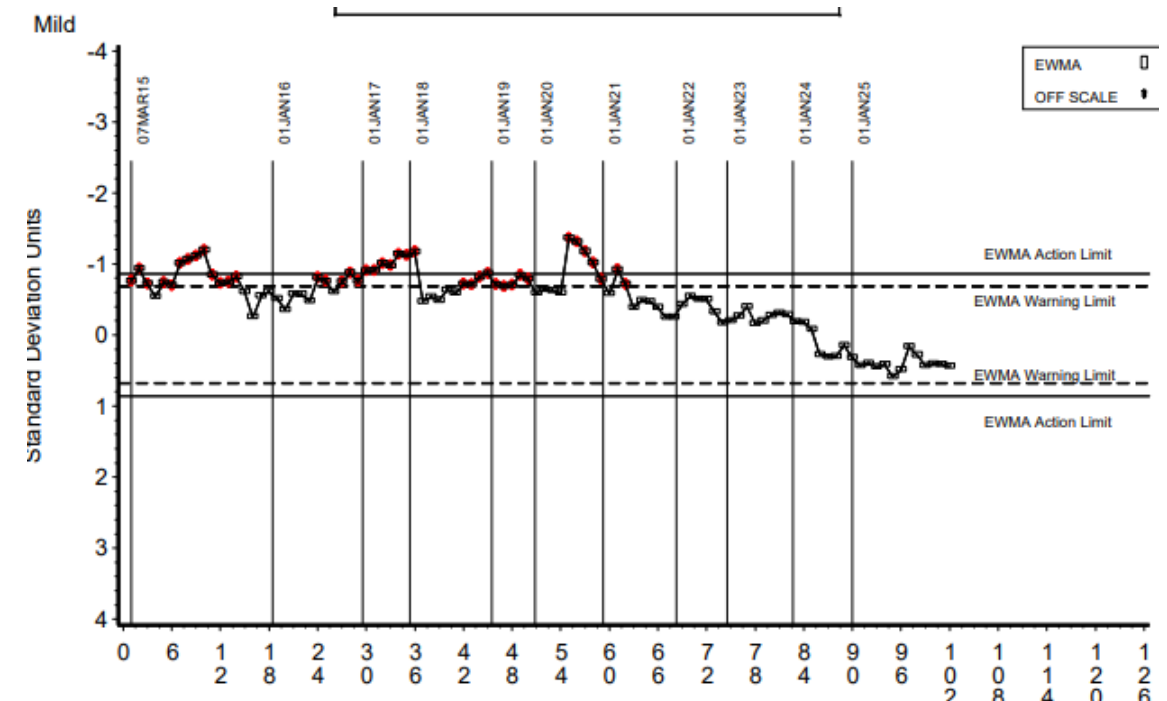
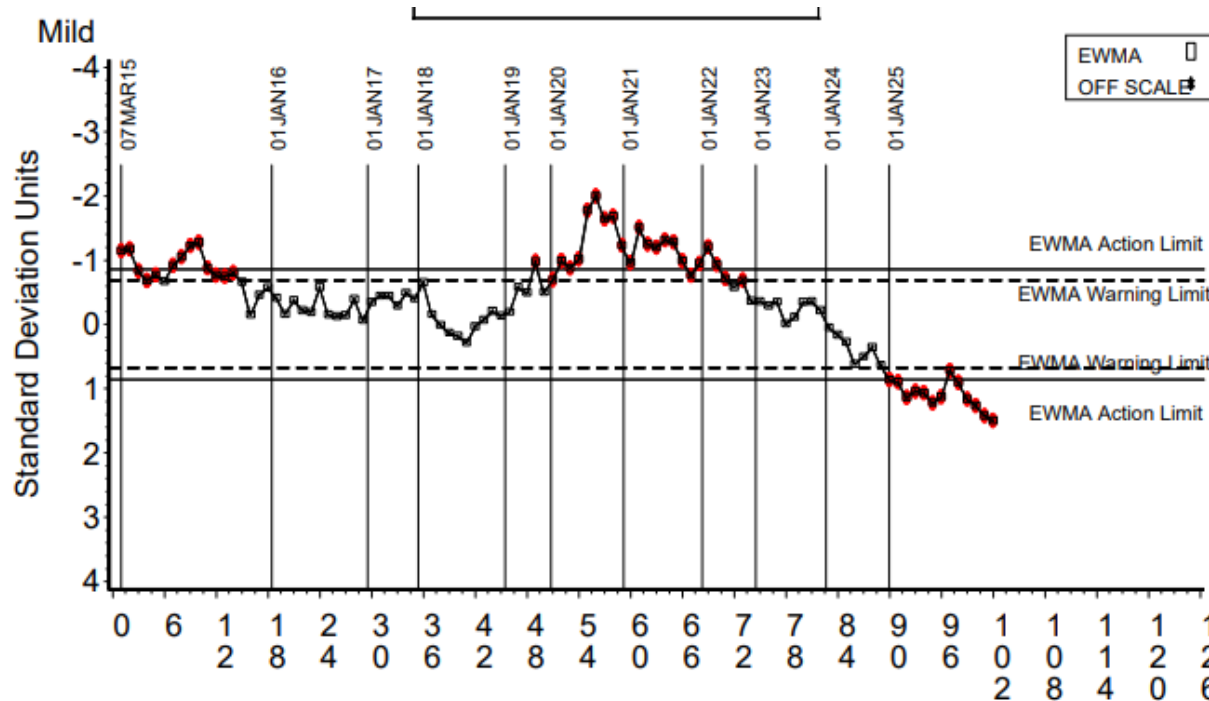
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Summary

- Both IRPH and KV40 Severity have increased since 2023
 - Possibly due to of new Liner Batches (D and E), Brazil Rings introduced with kit 1002, increases in OC and Soot, slight miscalculation of targets for RO 823-1 or a combination of all the above
- Evidence of Severity confirmed by numerous model iterations
 - Models in the Appendix
- Chose Median of Liner Batch E Results as 'Fairness' way to estimate ICF for IRPH and SQR(KV40C)
- Recommendations
 - Reset Control Charts starting with Liner E
 - Reduce the ICF for SQR(KV40) from +0.857 to **+0.361**
 - Implement an ICF for IRPH of **-19.9**
 - **Revisit ICFs and Targets in 2026**
 - **Consider Soot Correction Factors**

Motivation

- Potential Test Severity Issue in the T-13 Due to Recent Liner Batches D and E
- Industry Control Charts Indicate FTIR Peak Height Oxidation (IRPH) is Severe
- Industry Control Charts Indicate Percent Change in Kinematic Viscosity at 40C from 300 to 360 Hours (KV40) may be Severe with current ICF

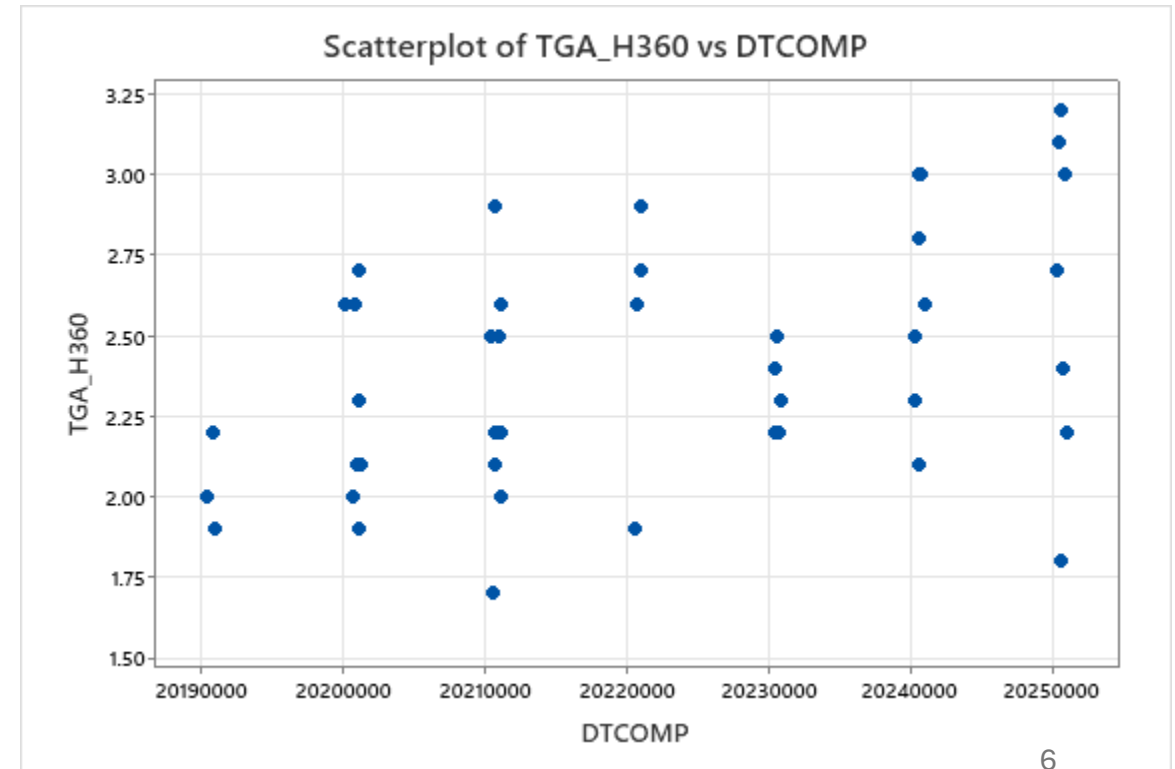
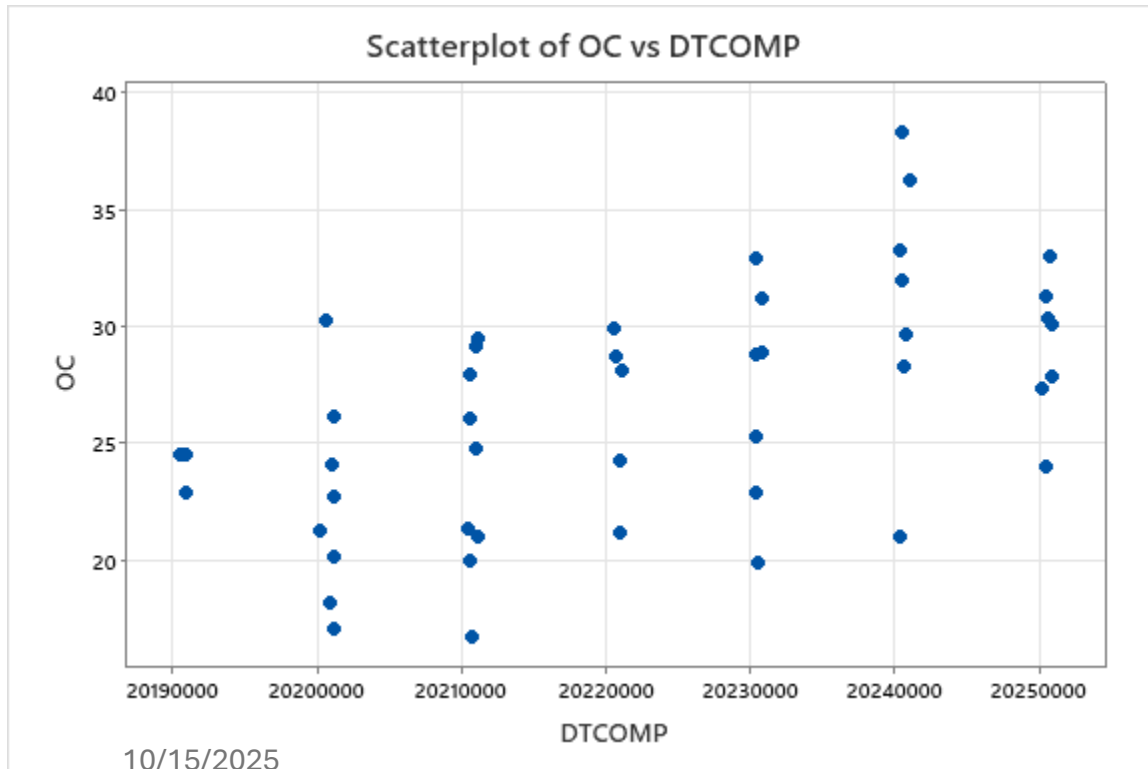


Recent History

- There were warning signs of possible Severity Issues
- ASTM Data Analysts Quorum from April 10, 2025, Meeting Summary
 - No change in ICF at the time, BUT
 - Liner D is directionally more severe than Liner C and may warrant a change in the KV40 ICF and/or development of an IRPH ICF
 - Plots at end show potential for better centering if ICF lowered from +0.857 for KV40 and a slightly negative ICF were applied to IRPH
 - This was even before introduction of Liner Batch E
- Last five (5) Reference Test runs were all on Liner Batch E and all were severe of 823-1 Reference Oil Target
 - ~ 1.9s severe in IRPH
 - ~ 0.6s severe in SQRT(KV40)

What is the Real Underlying Factor?

- Severity has Increased with Liner Batch, BUT is Liner the Root Cause?
 - Not enough credible data to test theory, but could be new Brazil Rings
- Oil Consumption and Soot have Increased Over Time
 - Is Severity Increase due to Increase in Oil Consumption and/or Soot



Models for IRPH and SQRT(KV40)

- See Appendix
- IRPH
 - Models suggest incorporating an ICF ranging from -16.9 to -32 for Liner E
 - Models suggest that severity correlated with Soot
 - What's right? What's fair?
- SQRT(KV40)
 - Models suggest reducing or eliminating the ICF of +0.857 for Liner E
 - Models suggest that severity correlated with Soot
 - What's right? What's fair?

Estimating the New ICFs

- Models provide evidence that IRPH and KV40 results are severe
- Why? Liner Batch, Rings, Soot, OC, Targets, Combination, Other?
 - We do not exactly know why
- ‘Fair’ ICF Calculations
 - Compare the MEDIAN of the five (5) test results on Liner E against Targets

TESTKEY	STAND	LAB	RO	DTCOMP	IRPH360	KV40PC	TKV40PC	Liner
197218-T13	2	D	823_1	20250523	127.5	63.4	7.9624	E
197308-T13	3	G	823_1	20250601	133.6	67.7	8.228	E
197307-T13	1	B	823_1	20250704	127.8	57.3	7.5697	E
199069-T13	1	G	823_1	20250816	132	59	7.6811	E
195078-T13	8	A	823_1	20250924	129.2	60.5	7.7782	E
AVG					130.02		7.84388	
MEDIAN					129.2		7.7782	
TARGET					109.3		8.139	
DIFF AVG					20.72		-0.29512	
DIFF MED					19.9		-0.3608	

Estimating the New ICFs

	FTIR Peak Height Oxidation		SQRT(PVIS 40C, 300-360 Hours)	
	Mean	s	Mean	s
T-13 Targets				
RO 823	127.4	11.1	8.61	0.929
RO 823-1	109.3	11.1	8.139	0.929
RO 824	48.03	11.8	3.699	0.97
Current ICF	0		0.857	
Proposed ICF	-19.9		0.361	

ICF Impact on Yi Results

- Summary of liner 'E' Yi results with & without ICF:
 - With current IRPH ICF = 0 and KV40P ICF = + 0.857:
 - IRPH and KV40P Yi results are +1.87 & 0.605 standard deviations above target*

TESTKEY	LTMSDATE	LTMSLAB	IND	Liner	TESTLEN	IRPH360	IRPHFNL	IRPHyi	ICF	IRPH_Corrected	IRPH_Yi_Calc_wICF
195078-T13	20250924	A	823-1	E	360	129.2	129.2	1.793	0	129.2	1.793
197307-T13	20250704	B	823-1	E	360	127.8	127.8	1.667	0	127.8	1.667
197218-T13	20250523	D	823-1	E	360	127.5	127.5	1.640	0	127.5	1.640
197308-T13	20250601	G	823-1	E	360	133.6	133.6	2.189	0	133.6	2.189
199069-T13	20250816	G	823-1	E	360	132	132	2.045	0	132.0	2.045

Yi Avg = 1.867

KV40PC	Sqrt(KV40PFNL)	ICF	Sqrt(KV40P_Corrected)	KV40P_Yi_Calc_wICF
60.5	7.778	0.857	8.635	0.534
57.3	7.570	0.857	8.427	0.310
63.4	7.962	0.857	8.819	0.732
67.7	8.228	0.857	9.085	1.018
59	7.681	0.857	8.538	0.430

Yi Avg = 0.605

- With IRPH ICF = -19.9 and KV40P ICF = +0.361:
 - IRPH and KV40P Yi results are +0.074 & 0.071 standard deviations above target*

TESTKEY	LTMSDATE	LTMSLAB	IND	Liner	TESTLEN	IRPH360	IRPHFNL	IRPHyi	ICF	IRPH_Corrected	IRPH_Yi_Calc_wICF
195078-T13	20250924	A	823-1	E	360	129.2	129.2	1.793	-19.9	109.3	0.000
197307-T13	20250704	B	823-1	E	360	127.8	127.8	1.667	-19.9	107.9	-0.126
197218-T13	20250523	D	823-1	E	360	127.5	127.5	1.640	-19.9	107.6	-0.153
197308-T13	20250601	G	823-1	E	360	133.6	133.6	2.189	-19.9	113.7	0.396
199069-T13	20250816	G	823-1	E	360	132	132	2.045	-19.9	112.1	0.252

Yi Avg = 0.074

KV40PC	Sqrt(KV40PFNL)	ICF	Sqrt(KV40P_Corrected)	KV40P_Yi_Calc_wICF
60.5	7.778	0.361	8.139	0.000
57.3	7.570	0.361	7.931	-0.224
63.4	7.962	0.361	8.323	0.199
67.7	8.228	0.361	8.589	0.484
59	7.681	0.361	8.042	-0.104

Yi Avg = 0.071

Summary

- Both IRPH and KV40 Severity have increased since 2023
 - Possibly due to of new Liner Batches (D and E), Brazil Rings introduced with kit 1002, increases in OC and Soot, slight miscalculation of targets for RO 823-1 or a combination of all the above
- Evidence of Severity confirmed by numerous model iterations
 - Models in the Appendix
- Chose Median of Liner Batch E Results as 'Fairness' way to estimate ICF for IRPH and SQRT(KV40C)
- Recommendations
 - Reset Control Charts starting with Liner E
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 - Implement an ICF for IRPH of **-19.9**
 - **Revisit ICFs and Targets in 2026**
 - **Consider Soot Correction Factors**

Appendix I

Appendix I: Large Dataset

- Analysis Dataset will include the following:
 - Humidity Control, Fuel Control, and Coolant Filter Usage = Once data implemented on April 18, 2017
 - Data prior to this date will be excluded
 - Chartable = 'Y' data
 - Test Keys 126960 and 137324 have missing hardware batch data & will be excluded from the analysis dataset
 - Dataset will include:
 - Liner Batches 'A', 'B', 'C', 'D', and 'E' data
 - Piston Rings and Main Bearing batches will not be included in the ICF analysis
 - RO's 823, 823-1, and 824 data
 - Labs A, B, D, and G data
- Analysis dataset consists of $N = 71$ results

Appendix I: Large Dataset

- Summary of available data for analysis is provided below:
 - There are currently 5 results on Liner 'E' batch hardware
 - Statistics team should re-evaluate when more Liner 'E' and/or Piston Ring batch data is available

Lab	N
A	21
B	11
D	15
G	24

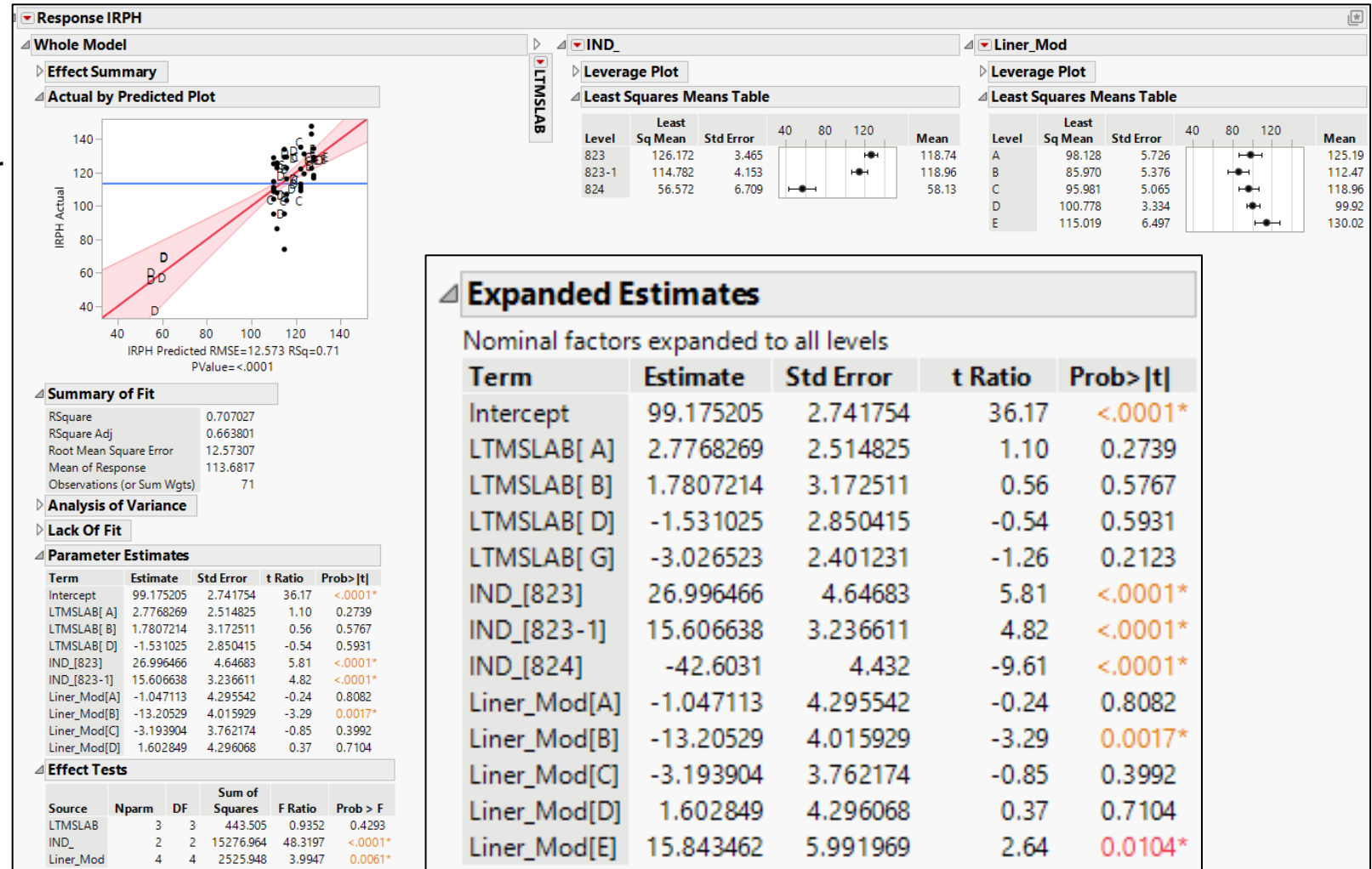
IND	N
823	45
823-1	20
824	6

Liner	N
A	15
B	22
C	9
D	20
E	5

- Original targets were based on PM data with RO823 and Liner 'A' hardware
 - Due to the data selected for this analysis, the generated Targets will be similar – but not identical to the targets generated with the PM analysis
- Potential ICF will be based on the contrast between the LSMeans for Liner 'E' vs. 'A' with RO823 & equal weighting across labs

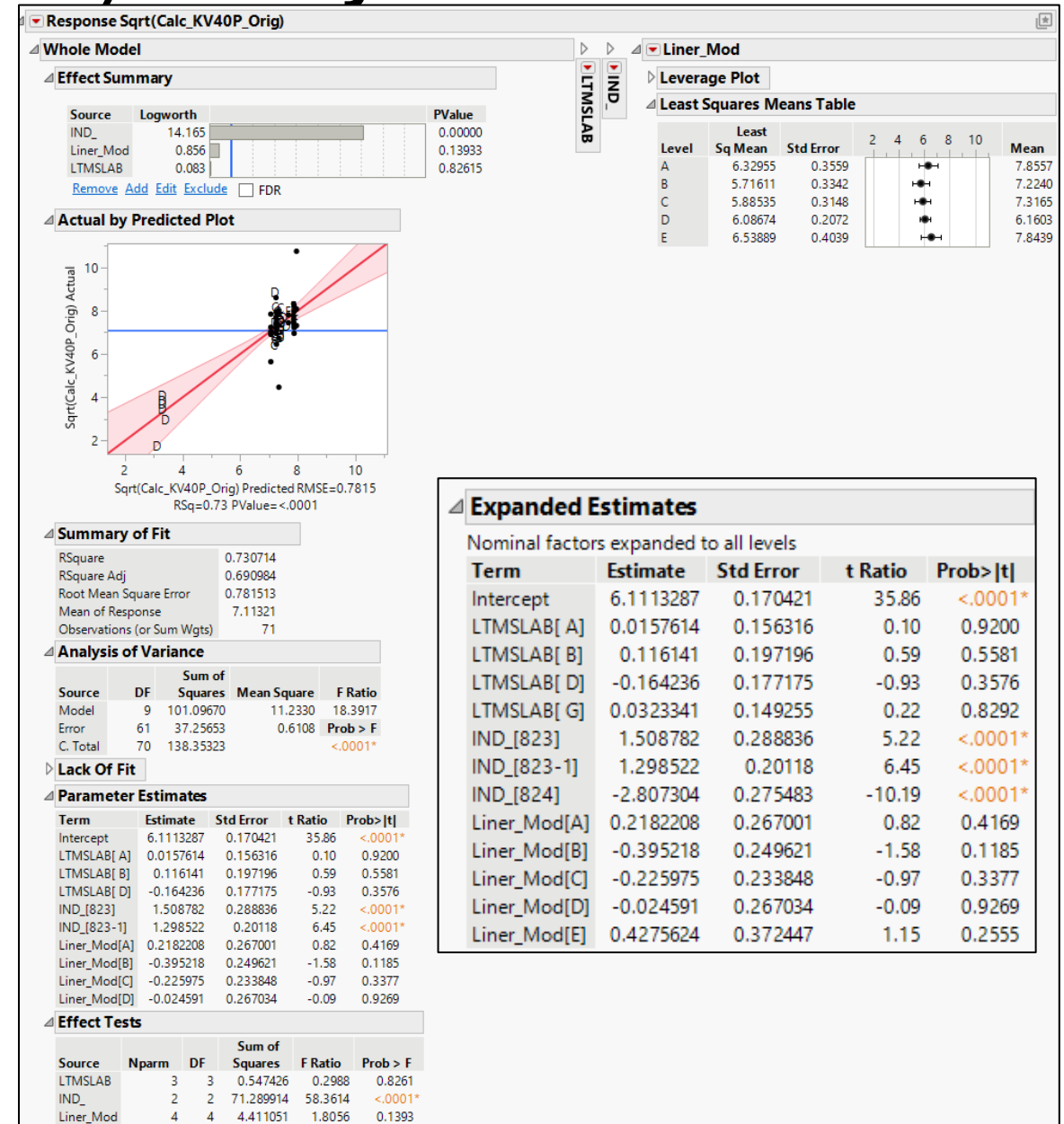
Appendix I: IRPH Analysis

- RO & Liner Batch significant
- Expanded estimates:
predicted means and ICF for
IRPH summarized below:
- ¹RO823 & Liner 'A' = 125.1 (vs.
127.4 original target)
- ¹RO823 & Liner 'E' = 142.0
- IRPH ICF=(125.1 - 142.0)= -16.9



Appendix I: SQRT(KV40P) Analysis

- RO is significant, but Liner Batch does not meet the minimum $p < 0.10$ threshold
- Expanded estimates: predicted means and ICF for IRPH summarized below:
 - ¹RO823 & Liner 'A' = 7.8
 - ¹RO823 & Liner 'E' = 8.0
 - IRPH ICF = $(7.8 - 8.0) = -0.2$
 - No need for KV40P ICF (ICF = 0)



10/15/2025

Note 1: Predicted means include equal weighting across labs

Appendix II

Appendix II: Reduced Dataset

- Been through many Procedural and Parts Changes over the Past Decade
- What is the Best Subset of the T-13 Reference Data?
 - NOT to set Targets
 - Dataset to best estimate Impact of Recent Liners that did not see earlier Test Procedures
 - Want Largest Dataset that Eliminates Known and Unknown Covariates that do not Cross Over with Current Liners D and E
 - Evaluate Distribution of X's (Features) to Spot Outliers and Eliminate
 - ABLOBY>300; ABLOBY<50
 - TGA_H360>4; TGA_H360<1.5
 - OC>40
 - Remove stands with just 1 run
 - Liner Batch B (Started 4/21/2019) and the Start of the +0.857 ICF for KV40
 - Delete Test Results with RO824 because it was only tested in Liner Batch D
 - This is Post Humidity Control and Operational Change in the Test
 - This is the Start of the +0.857 ICF for KV40
 - 46 Test Results

Appendix II: First Model for IRPH

- Severity has Increased from Liner B to C to D to E

Factor Information

Factor	Type	Levels	Values
RO	Fixed	2	823.0, 823.1
LAB	Fixed	4	A, B, D, G
LABSTAND(LAB)	Fixed	11	A2(A), A4(A), A6(A), A8(A), B1(B), B3(B), D1(D), D2(D), G1(G), G2(G), G3(G)
PartsID	Fixed	4	B_PNB, C_PNB, D_PNB, E

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
RO	1	405.1	405.05	2.79	0.105
LAB	3	176.3	58.78	0.40	0.751
PartsID	3	1618.5	539.51	3.71	0.022
LABSTAND(LAB)	7	846.7	120.96	0.83	0.569
Error	31	4504.1	145.29		
Lack-of-Fit	17	1396.1	82.12	0.37	0.973
Pure Error	14	3107.9	222.00		
Total	45	7286.4			

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
12.0537	38.18%	10.27%	0.00%

Means

Term	Fitted Mean	SE Mean
RO		
823.0	128.74	5.43
823.1	115.14	3.83
LAB		
A	122.81	3.54
B	124.52	5.30
D	121.50	3.84
G	118.92	3.55
PartsID		
B_PNB	108.33	5.10
C_PNB	114.16	4.22
D_PNB	124.38	5.71
E	140.88	7.13
LABSTAND(LAB)		
A2(A)	126.29	6.87
A4(A)	122.30	7.72
A6(A)	120.23	7.33
A8(A)	122.42	7.37
B1(B)	117.86	7.31
B3(B)	131.18	7.54
D1(D)	128.23	5.69
D2(D)	114.76	4.98
G1(G)	116.32	5.30
G2(G)	122.41	6.58
G3(G)	118.02	5.04

Note that these RO LS Means do not match up exactly with the RO Targets; Keep in Mind that this is a Slightly Different Dataset; Also Keep in Mind that with Liner Batch Confounding, some of the Severity of Liner Batch D is Accounted for in the 823-1 Target

At first Glance, Liner E could be 32+ Units Severe

Appendix II: Model for IRPH

- Evaluating Liner E vs B Suggests an ICF of -29 for Liner E
- Evaluating Liner E vs C Suggests an ICF of -22 for Liner E

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
RO	1	515.1	515.09	3.66	0.063
LAB	3	217.6	72.54	0.52	0.674
PartslD	3	1520.2	506.73	3.60	0.022
Error	38	5350.8	140.81		
Lack-of-Fit	11	694.7	63.16	0.37	0.958
Pure Error	27	4656.0	172.45		
Total	45	7286.4			

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
11.8663	26.56%	13.04%	0.00%

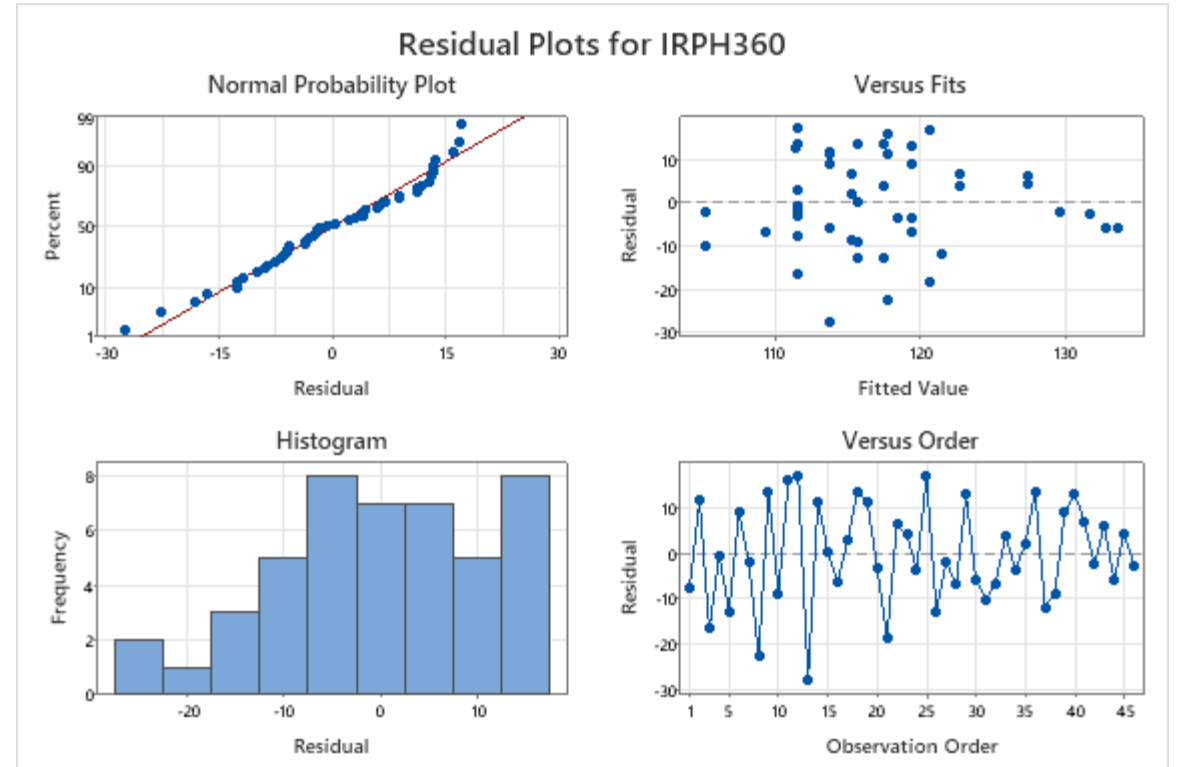
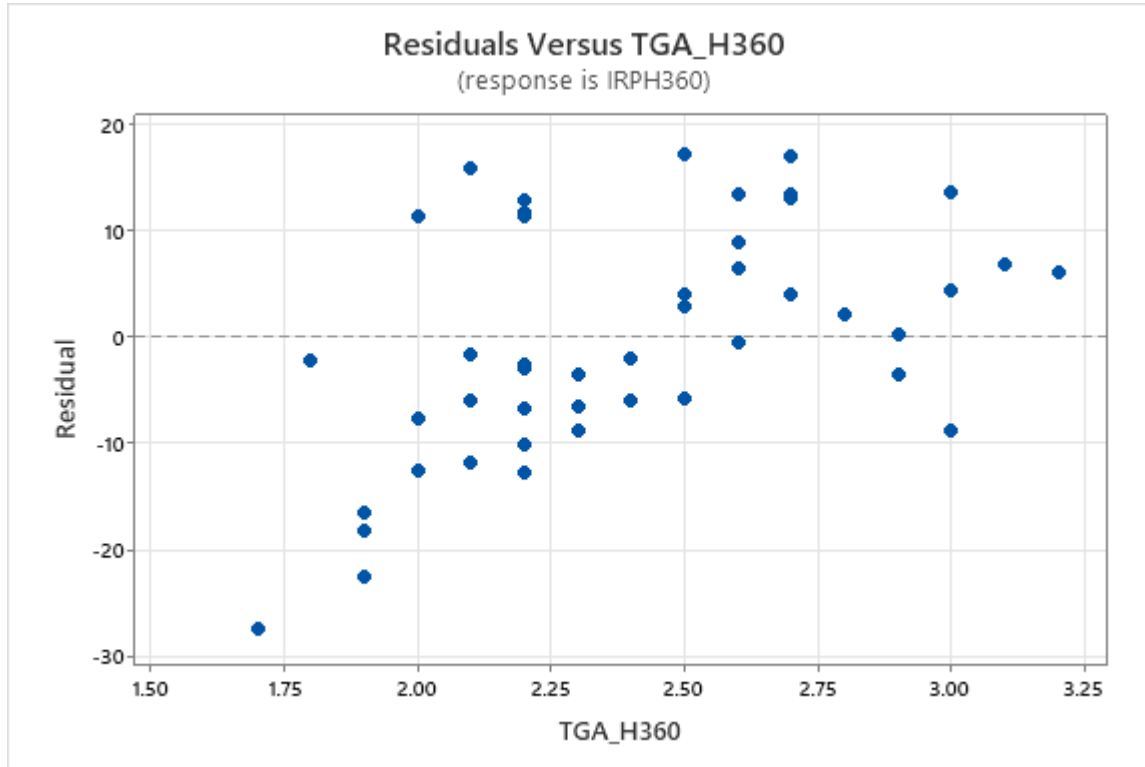
Means

Term	Fitted Mean	SE Mean
RO		
823.0	128.03	4.66
823.1	114.72	3.48
LAB		
A	122.40	3.46
B	124.42	5.12
D	120.45	3.73
G	118.22	3.30
PartslD		
B_PNB	108.06	4.44
C_PNB	115.01	4.04
D_PNB	125.11	4.74
E	137.31	6.33

Note that these RO LS Means do not match up exactly with the RO Targets; Keep in Mind that this is a Slightly Different Dataset; Also Keep in Mind that with Liner Batch Confounding, some of the Severity of Liner Batch D is Accounted for in the 823-1 Target

Appendix II: Model for IRPH

- We have also noted that severity increases with Soot



Appendix II: SQRT(KV40) with Current ICF

- Severity has Increased from Liner B to C to D to E

Factor Information

Factor	Type	Levels	Values
RO	Fixed	2	823.0, 823.1
LAB	Fixed	4	A, B, D, G
LABSTAND(LAB)	Fixed	11	A2(A), A4(A), A6(A), A8(A), B1(B), B3(B), D1(D), D2(D), G1(G), G2(G), G3(G)
PartsID	Fixed	4	B_PNB, C_PNB, D_PNB, E

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
RO	1	0.4520	0.4520	1.19	0.284
LAB	3	0.7951	0.2650	0.70	0.561
PartsID	3	2.2733	0.7578	1.99	0.135
LABSTAND(LAB)	7	2.2338	0.3191	0.84	0.563
Error	31	11.7861	0.3802		
Lack-of-Fit	17	4.4462	0.2615	0.50	0.913
Pure Error	14	7.3399	0.5243		
Total	45	16.2115			

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
0.616601	27.30%	0.00%	0.00%

Means

Term	Fitted Mean	SE Mean
RO		
823.0	8.660	0.278
823.1	8.206	0.196
LAB		
A	8.262	0.181
B	8.665	0.271
D	8.307	0.197
G	8.499	0.182
PartsID		
B_PNB	7.936	0.261
C_PNB	8.037	0.216
D_PNB	8.660	0.292
E	9.100	0.365
LABSTAND(LAB)		
A2(A)	7.977	0.352
A4(A)	8.412	0.395
A6(A)	8.707	0.375
A8(A)	7.952	0.377
B1(B)	8.328	0.374
B3(B)	9.003	0.385
D1(D)	8.408	0.291
D2(D)	8.205	0.255
G1(G)	8.238	0.271
G2(G)	8.677	0.337
G3(G)	8.582	0.258

In this Case, RO LS Means Line up with the RO Targets;

At first Glance, we could have Reduced the ICF for Liner D and could Reduce it Further for Liner E

Appendix II: SQRT(KV40) with Current ICF

- Evaluating Liner E vs B/C Suggests removing the ICF
- Again, other Models; What's right? What's fair?

Coefficients

Term	Coef	SE Coef	T-Value	P-Value	VIF
Constant	8.467	0.130	65.32	0.000	
RO					
823.0	0.146	0.146	1.00	0.325	2.68
LAB					
A	-0.153	0.154	-0.99	0.328	1.90
B	0.227	0.200	1.13	0.264	2.20
D	-0.115	0.161	-0.71	0.480	1.90
ID					
BorC_PNB	-0.389	0.207	-1.88	0.067	2.55
D_PNB	0.018	0.170	0.11	0.917	1.28

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
0.600227	13.33%	0.00%	0.00%

Means

Term	Fitted Mean	SE Mean
RO		
823.0	8.613	0.234
823.1	8.321	0.148
LAB		
A	8.315	0.186
B	8.694	0.266
D	8.353	0.199
G	8.508	0.180
ID		
BorC_PNB	8.078	0.157
D_PNB	8.485	0.221
E	8.839	0.306

Appendix II: Model for SQRT(KV40)

- We have also noted that severity increases with Soot

