REVISED DRAFT of the Statistical Summary of the Caterpillar 1R Precision Matrix

09/25/2001

Caterpillar 1R Matrix Summary

- The 1R matrix is complete.
- Only WD, TGC, TLC, OC, ETOC, TGF, TLHC, UCWD and ALW analyzed to date. Is there more?
- Three oils (A, D, M) are in the matrix. There is some weak evidence of oil discrimination in Weighted Demerits and Average Oil Consumption and evidence of oil discrimination in End of Test Oil Consumption.
- No transformations necessary among the major parameters. TLHC needs a transformation.

Caterpillar 1R Matrix Summary

- High Copper may affect UCWD, but does not seem to affect other parameters. An unusually high UCWD result of 22 occurred in CMIR 41536 (Lab A, Oil M), but had High Copper early in the test.
- There are Lab effects in OC, ETOC and Liner Wear.
- CMIR 41547 (Lab B, Oil A) had unusually high test results in WD, TLC and TLHC.
- There are positive correlations among the parameters especially TGF/TGC and OC/ETOC.
- There are Lab and Stand differences in Torque & Blowby

Caterpillar 1R Matrix Summary

- Average humidity for CMIR 41543 (Lab D, Oil M) of 18.2 was different from all other tests which ran at 17.8 or 17.9.
- Average coolant flow of 63 L/m in CMIRs 41535, 41536 and 41537 (all Lab A) did not meet the 75 L/m specification. After investigation, the 1R Task Force concluded that the matrix test results were unaffected by the Coolant Flow difference.
- The Average Liner Wear of 0.03 for CMIR 41537 is a mistake in the database. The result should be 0.003 mm.
- The End of Test Oil Consumption of 9.4 for CMIR 41760 is a mistake in the database. The result should be 11.1.

Caterpillar 1R Matrix Summary

- Reference Oil targets for Oils A and M may be based on the analysis of the entire matrix, or the summary statistics for each individual reference oil.

Caterpillar 1R Matrix

Lab A			Lab B	Lab G			Lab D	Lab F
Stand 1	Stand 2	Stand 3	Stand 1	Stand 1	Stand 2	Stand 3	Stand 1	Stand 7
M	M	A	M	M	M	A	A	M
A	D	M	A	A	D	M	M	A

Caterpillar 1R Correlations

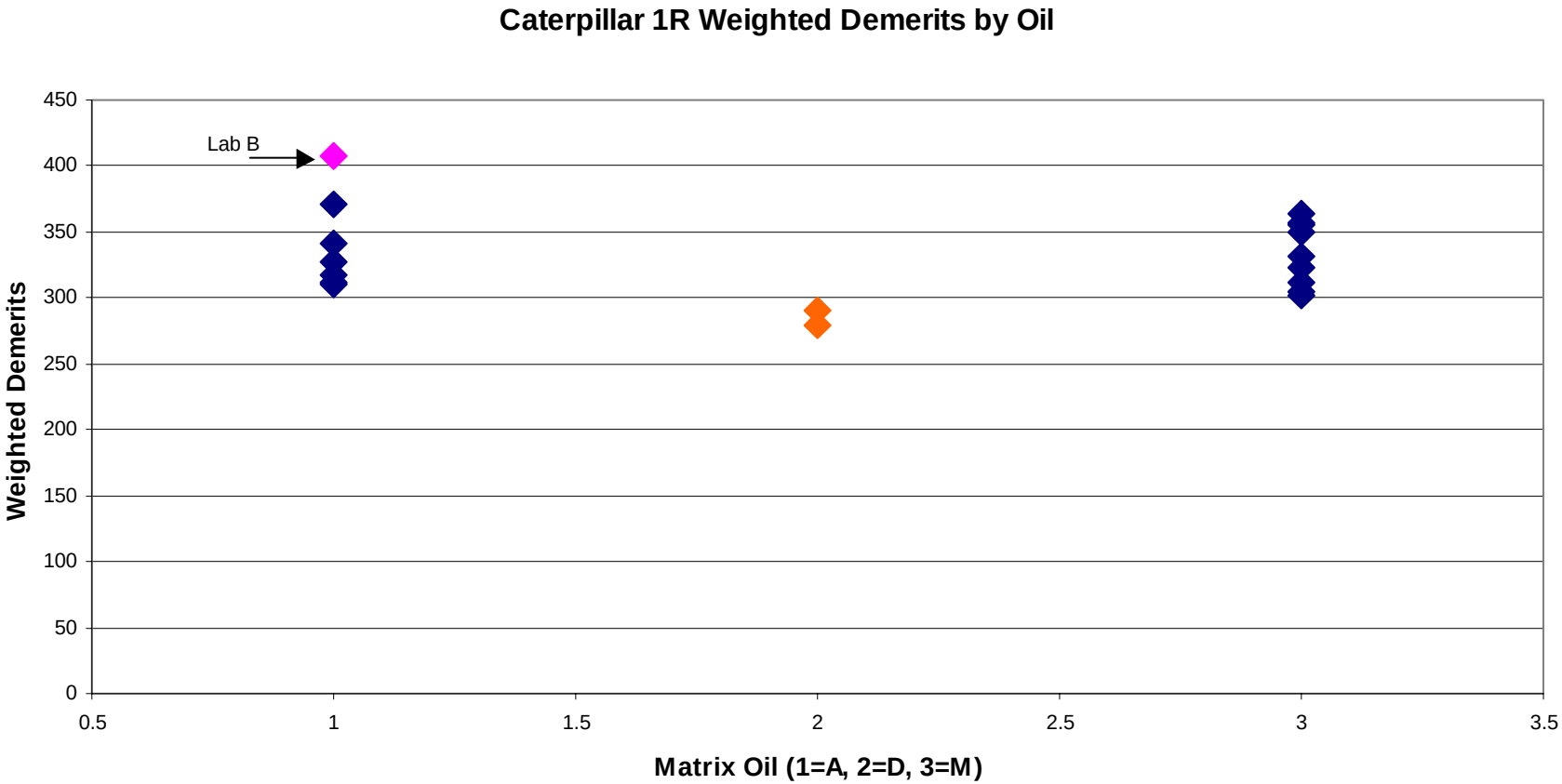
WD	0.66	0.64	0.07	0.16	0.69	0.48	0.17	-0.01
0.57	TGC	0.64	0.25	0.25	**0.95**	0.58	-0.12	-0.28
0.50	0.57	TLC	0.30	0.42	0.66	0.75	-0.19	0.06
0.35	0.28	0.49	OC	**0.89**	0.24	0.35	-0.01	0.03
0.55	0.31	0.66	0.89	ETOC	0.27	0.41	-0.09	-0.03
0.71	**0.95**	0.63	0.18	0.31	TGF	0.34	-0.03	-0.09
0.31	0.48	0.79	0.39	0.47	0.53	TLHC*	-0.04	-0.24
0.27	-0.31	-0.08	-0.33	-0.23	-0.09	-0.09	UCWD	-0.14
0.13	-0.37	-0.22	-0.48	-0.38	-0.21	-0.27	0.69	ALW

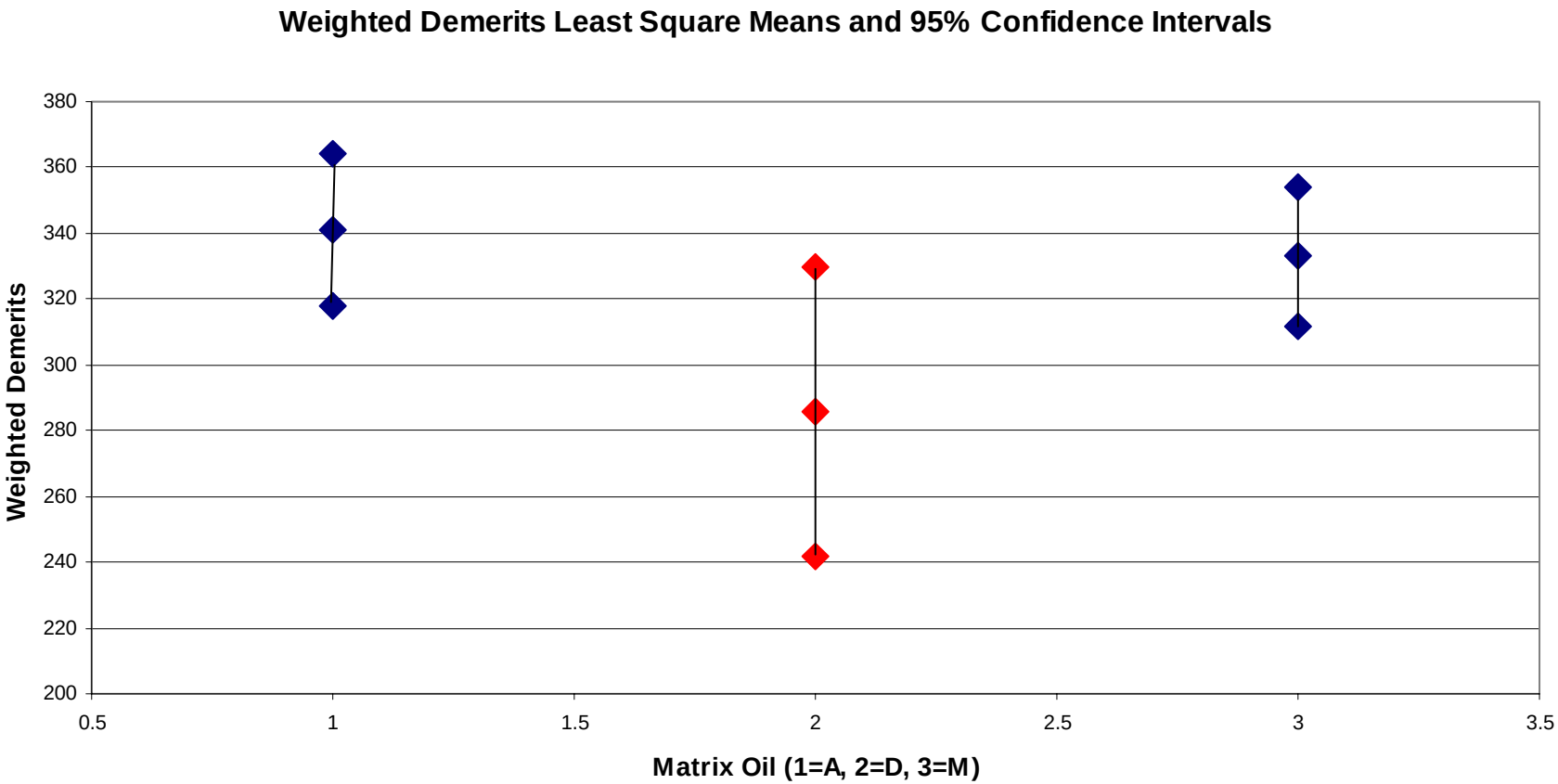
Raw Data Correlations on Upper Triangle; Partial Correlations on Lower Triangle

Weighted Deposits (WD)

- Model factors considered include Lab (A,B,D,F,G), Stand within Lab (A1,A2,A3,G1,G2,G3) and Oil (A,D,M)
- Some evidence that Oil D is Lower than Oils A and M
  - Root MSE = 29.03 (15 df – Oil Model)
  - $R^2 = 0.28$
  - CMIR 41547 (Lab B, Oil A) had a large Studentized residual

p-values in Hypothesis Test of No Difference				Least Square Mean
	Oil A	Oil D	Oil M	
Oil A		0.08	0.85	341.2
Oil D	0.08		0.13	285.9
Oil M	0.85	0.13		333.3

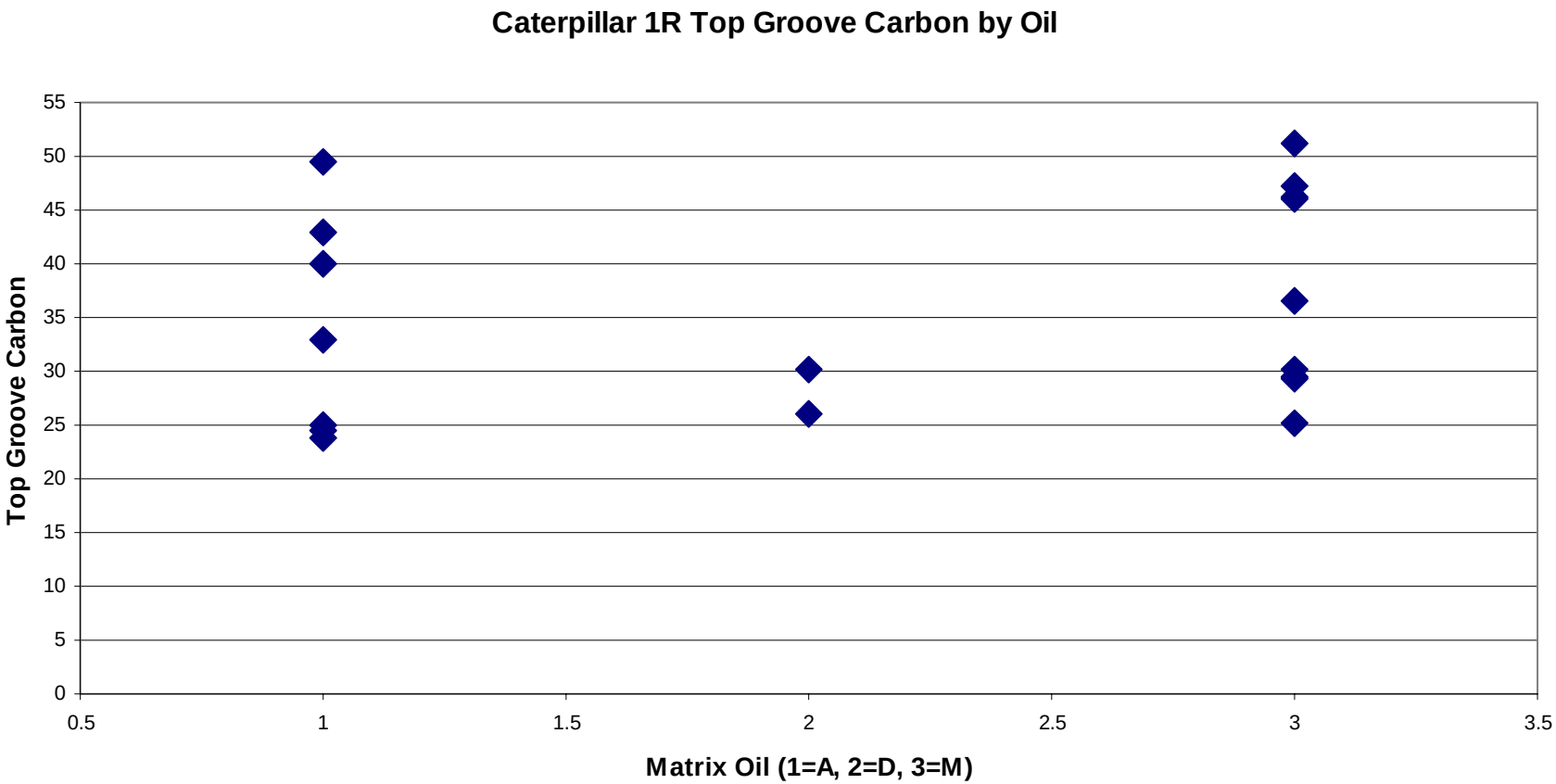

Caterpillar 1R Weighted Demerits by Oil
Lab B
Weighted Demerits
450
400
350
300
250
200
150
100
50
0
0.5
1
1.5
2
2.5
3
3.5
Matrix Oil (1=A, 2=D, 3=M)

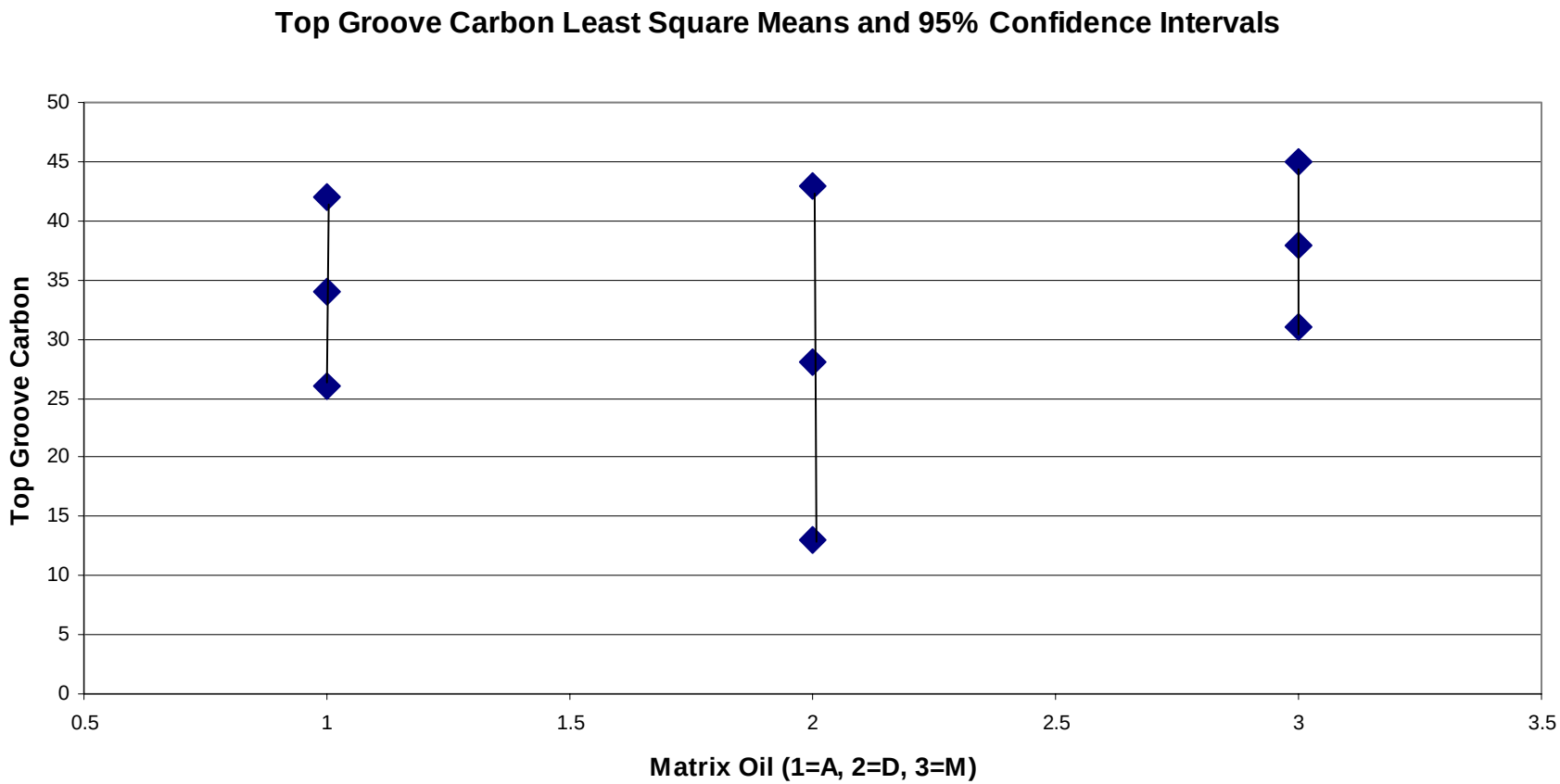

Weighted Demerits Least Square Means and 95% Confidence Intervals
Weighted Demerits
380
360
340
320
300
280
260
240
220
200
0.5
1
1.5
2
2.5
3
3.5
Matrix Oil (1=A, 2=D, 3=M)

Top Groove Carbon (TGC)

- Model factors considered include Lab (A,B,D,F,G), Stand within Lab (A1,A2,A3,G1,G2,G3) and Oil (A,D,M)
- No evidence of any effects
  - Root MSE = 9.70 (15 df – Oil Model)
  - $R^2 = 0.11$
  - No observations had large Studentized residuals

p-values in Hypothesis Test of No Difference				Least Square Mean
	Oil A	Oil D	Oil M	
Oil A		0.73	0.72	34.1
Oil D	0.73		0.42	28.1
Oil M	0.72	0.42		37.9

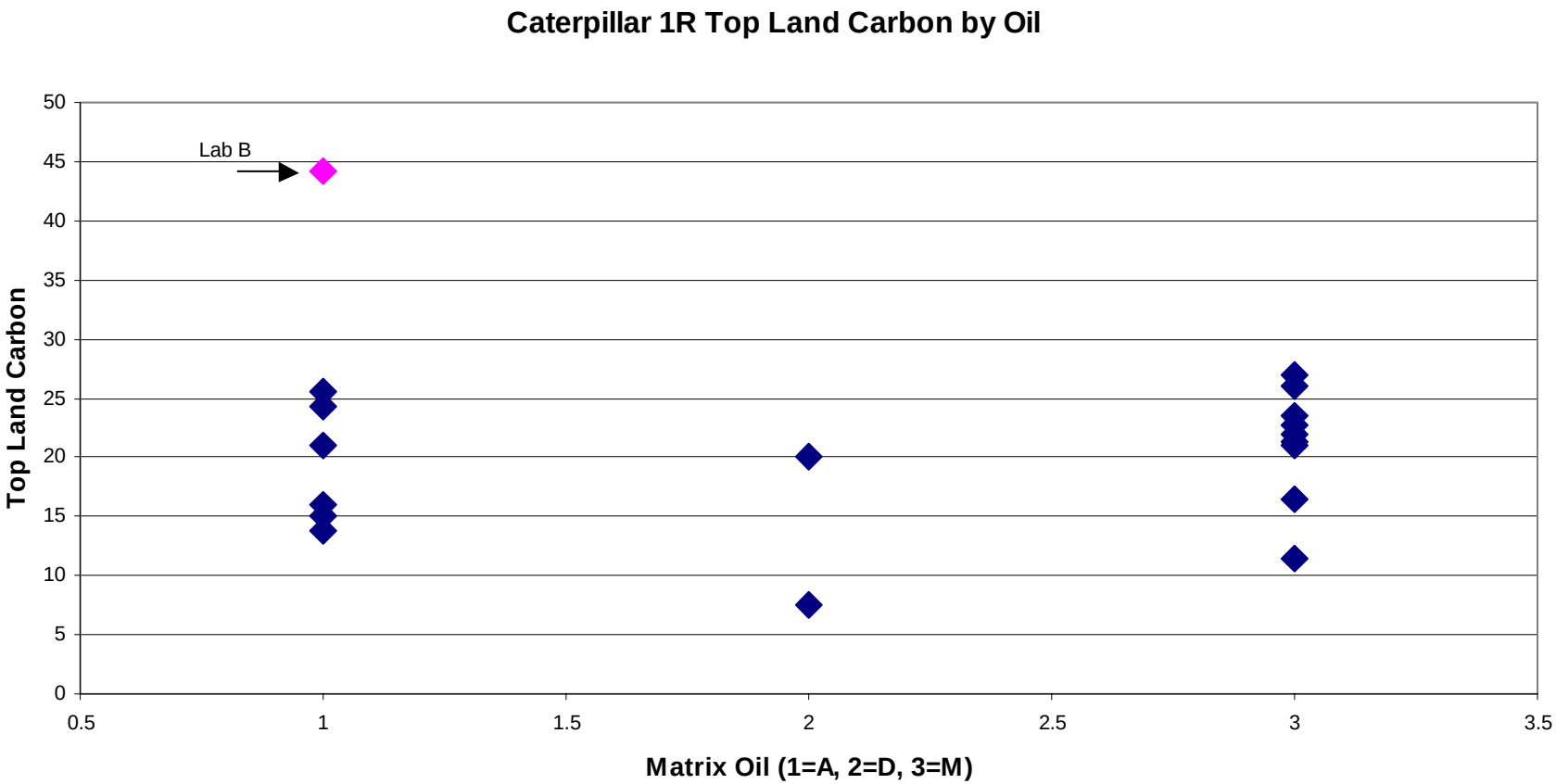

Caterpillar 1R Top Groove Carbon by Oil
Top Groove Carbon
55
50
45
40
35
30
25
20
15
10
5
0
0.5
1
1.5
2
2.5
3
3.5
Matrix Oil (1=A, 2=D, 3=M)

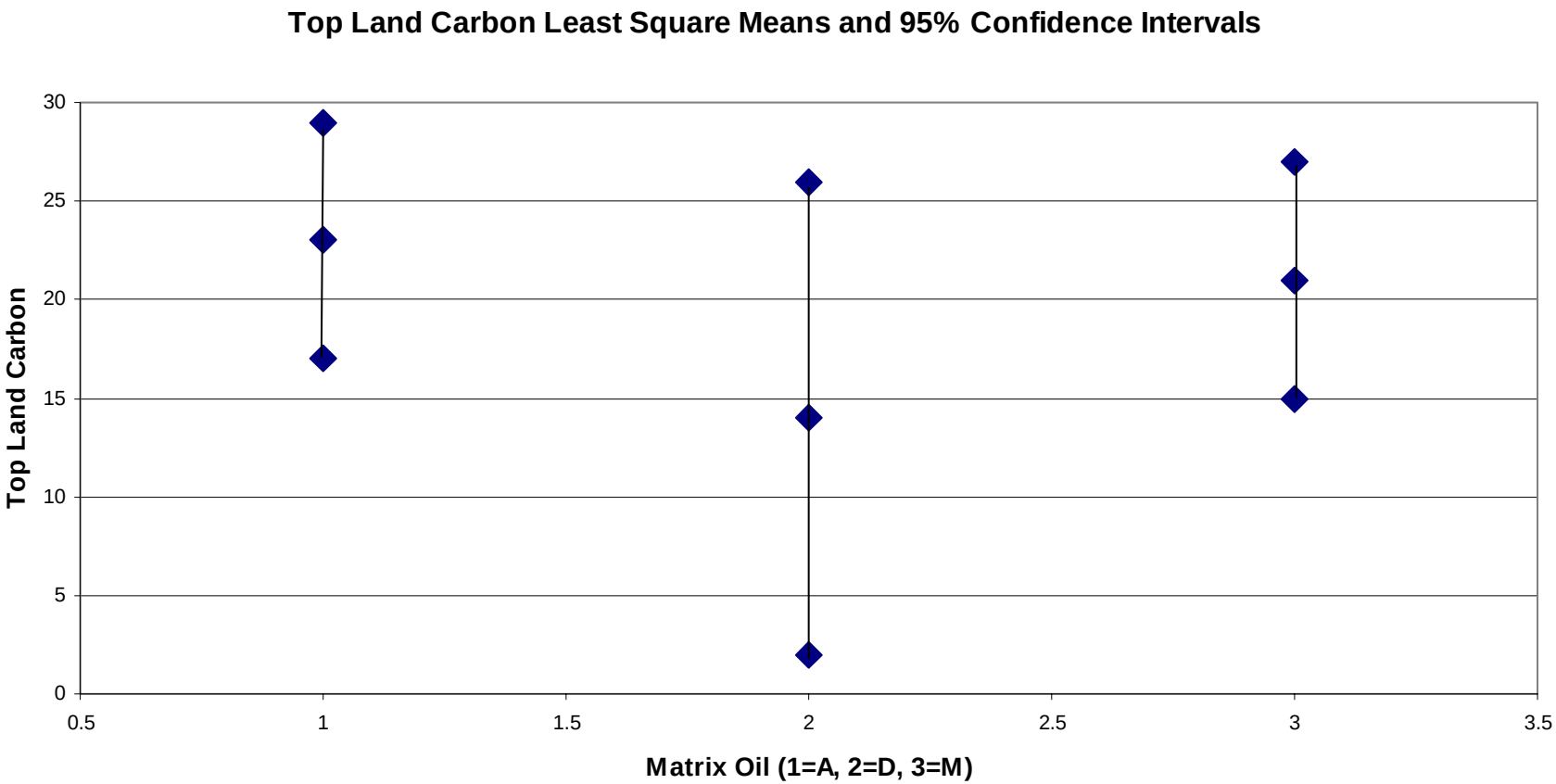

Top Groove Carbon Least Square Means and 95% Confidence Intervals
Top Groove Carbon
50
45
40
35
30
25
20
15
10
5
0
0.5
1
1.5
2
2.5
3
3.5
Matrix Oil (1=A, 2=D, 3=M)

Top Land Carbon (TLC)

- Model factors considered include Lab (A,B,D,F,G), Stand within Lab (A1,A2,A3,G1,G2,G3) and Oil (A,D,M)
- No evidence of any effects
  - Root MSE = 7.84 (15 df – Oil Model)
  - $R^2 = 0.12$
  - CMIR 41547 (Lab B, Oil A) had a large Studentized residual

p-values in Hypothesis Test of No Difference				Least Square Mean
	Oil A	Oil D	Oil M	
Oil A		0.34	0.92	22.8
Oil D	0.34		0.45	13.8
Oil M	0.92	0.45		21.3


Caterpillar 1R Top Land Carbon by Oil
Lab B
Top Land Carbon
Matrix Oil (1=A, 2=D, 3=M)
50
45
40
35
30
25
20
15
10
5
0
0.5
1
1.5
2
2.5
3
3.5


Top Land Carbon Least Square Means and 95% Confidence Intervals
Top Land Carbon
30
25
20
15
10
5
0
0.5
1
1.5
2
2.5
3
3.5
Matrix Oil (1=A, 2=D, 3=M)

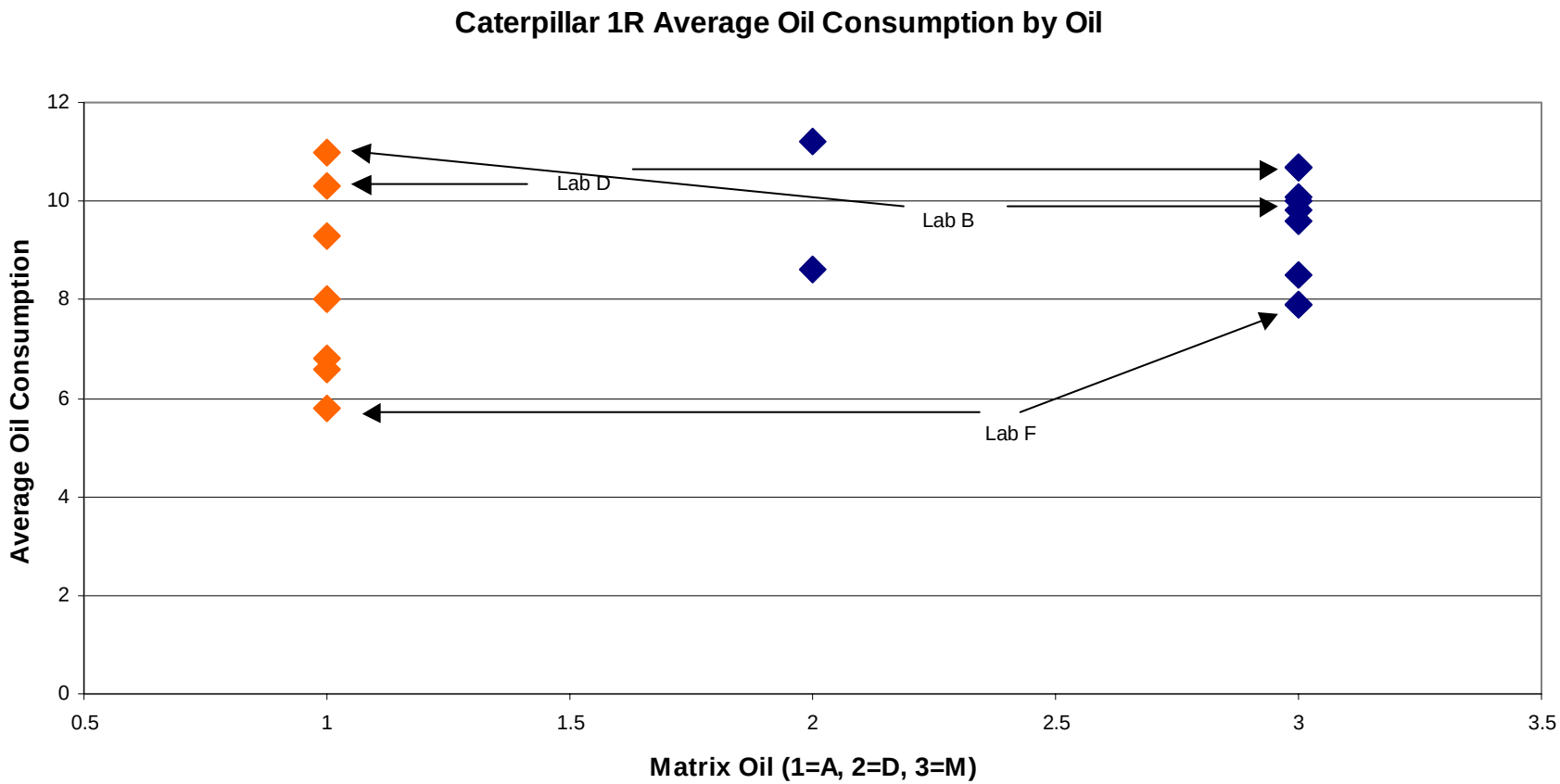
Average Oil Consumption (OC)

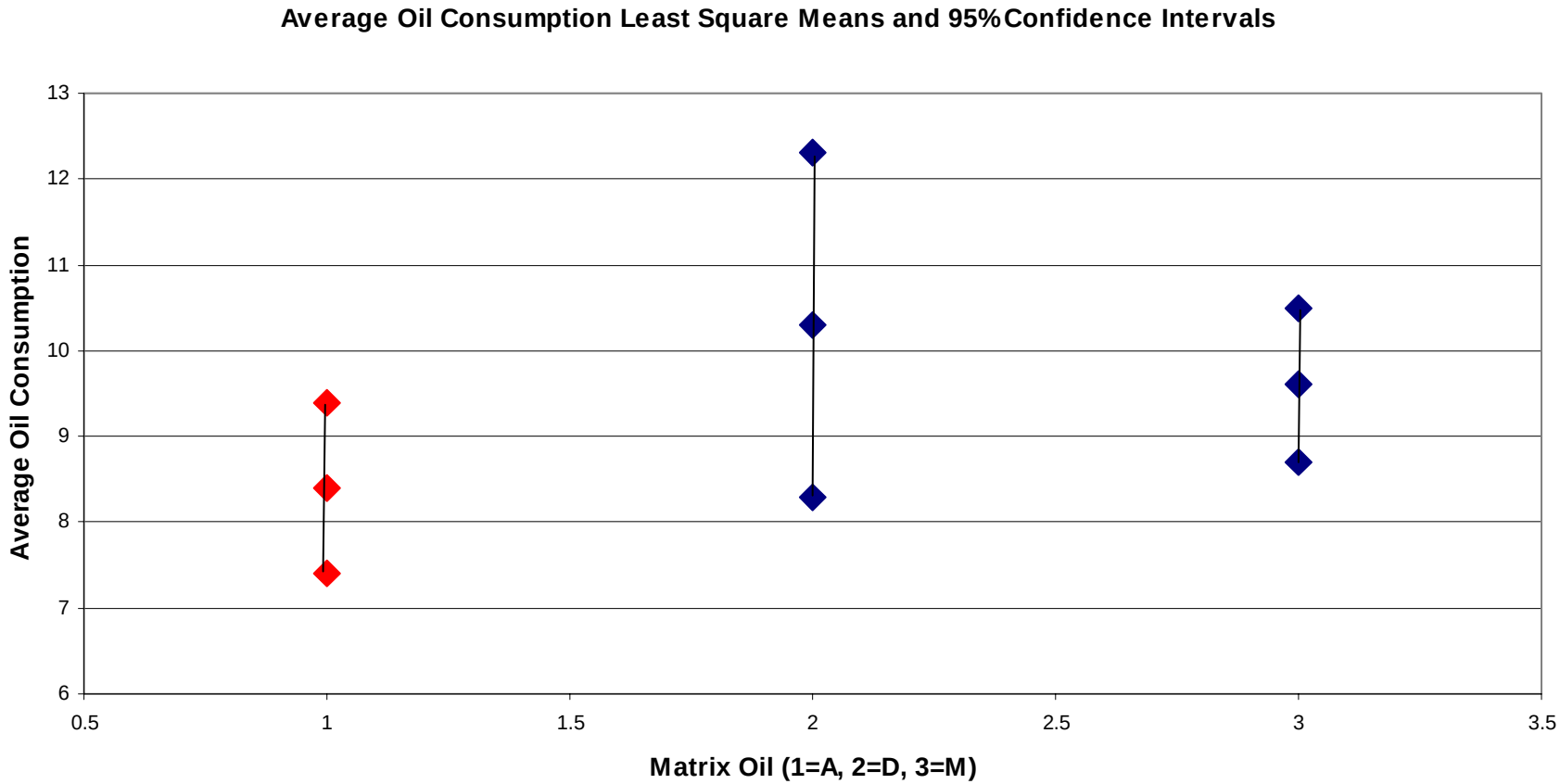
- Model factors considered include Lab (A,B,D,F,G), Stand within Lab (A1,A2,A3,G1,G2,G3) and Oil (A,D,M)
- Some evidence that Lab F is Lower than Labs B and D and some weak evidence that Oil A is Lower than Oils D & M
  - Root MSE = 1.19 (11 df – Lab and Oil Model)
  - $R^2 = 0.65$
  - No observations had large Studentized residuals

p-values in Hypothesis Test of No Difference				Least Square Mean
	Oil A	Oil D	Oil M	
Oil A		0.17	0.13	8.37
Oil D	0.17		0.77	10.31
Oil M	0.13	0.77		9.65

Average Oil Consumption (OC)

p-values in Hypothesis Test of No Difference						Least Square Mean
	Lab A	Lab B	Lab D	Lab F	Lab G	
Lab A		0.56	0.56	0.27	0.81	9.41
Lab B	0.56		1.00	0.07	0.22	10.93
Lab D	0.56	1.00		0.07	0.22	10.93
Lab F	0.27	0.07	0.07		0.64	7.28
Lab G	0.81	0.22	0.22	0.64		8.66


Caterpillar 1R Average Oil Consumption by Oil
Average Oil Consumption
12
10
8
6
4
2
0
0.5
1
1.5
2
2.5
3
3.5
Matrix Oil (1=A, 2=D, 3=M)
Lab D
Lab B
Lab F


Average Oil Consumption Least Square Means and 95%Confidence Intervals
Average Oil Consumption
13
12
11
10
9
8
7
6
0.5
1
1.5
2
2.5
3
3.5
Matrix Oil (1=A, 2=D, 3=M)

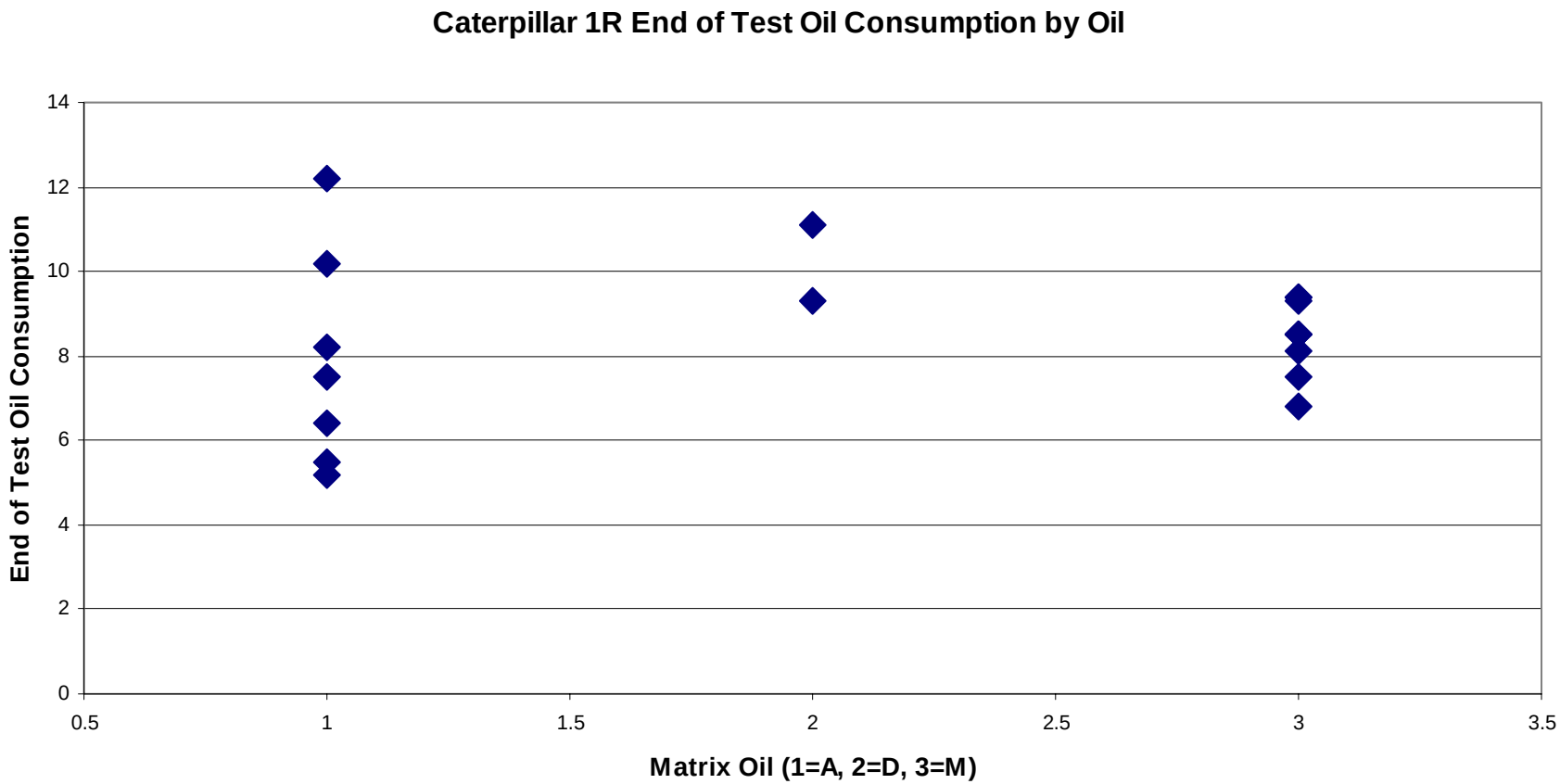
End of Test Oil Consumption (ETOC)

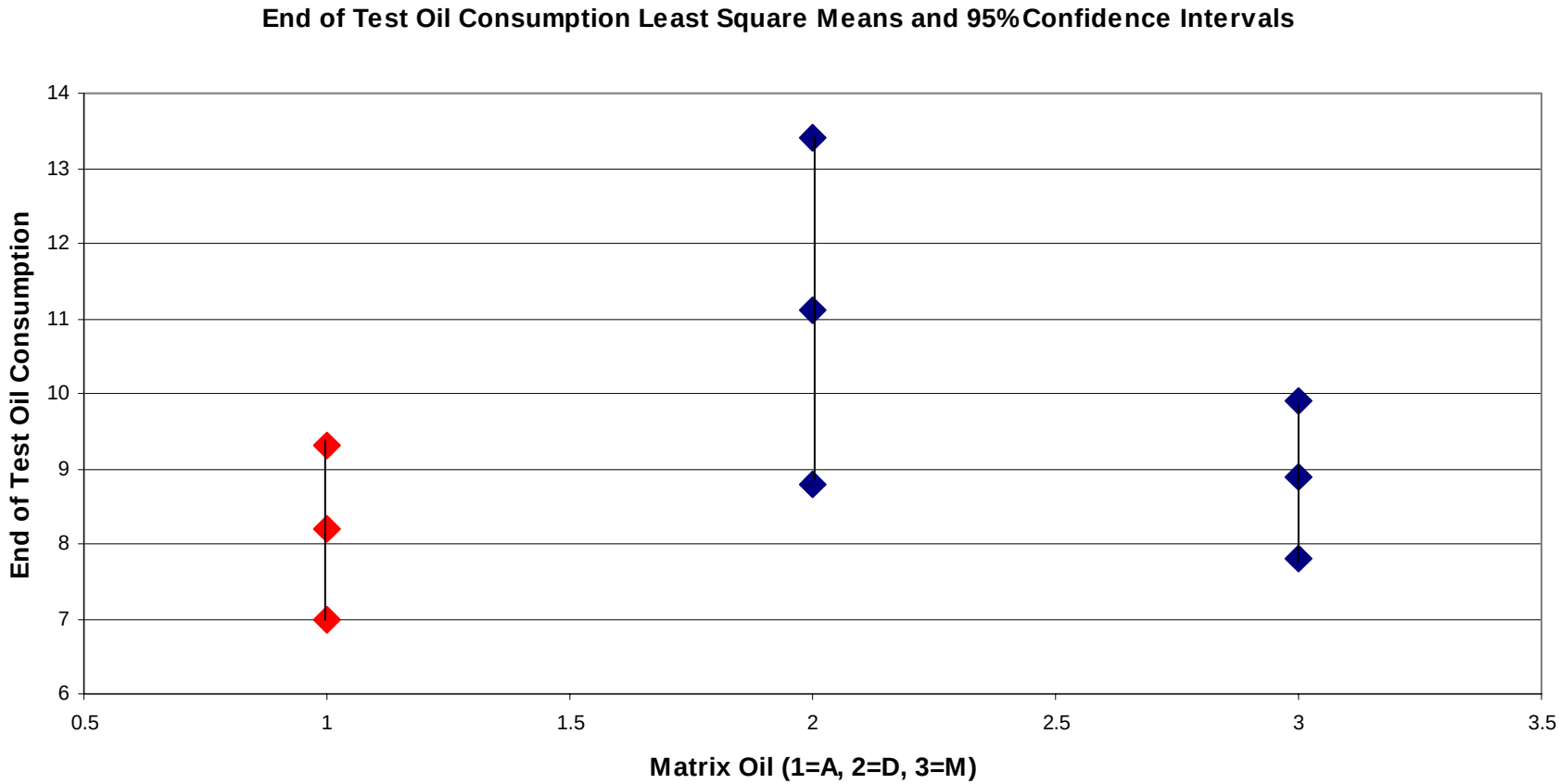
- Model factors considered include Lab (A,B,D,F,G), Stand within Lab (A1,A2,A3,G1,G2,G3) and Oil (A,D,M)
- Evidence that Oil D is Higher than Oil A and some evidence that it is Higher than Oil M
- Evidence that Lab B is Higher than Lab G and some evidence that it is Higher than Lab F
  - Root MSE = 1.35 (11 df – Lab and Oil Model)
  - $R^2 = 0.64$
  - No observations had large Studentized residuals

p-values in Hypothesis Test of No Difference				Least Square Mean
	Oil A	Oil D	Oil M	
Oil A		0.05	0.57	8.15
Oil D	0.05		0.13	11.14
Oil M	0.57	0.13		8.86

End of Test Oil Consumption (ETOC)

p-values in Hypothesis Test of No Difference						Least Square Mean
	Lab A	Lab B	Lab D	Lab F	Lab G	
Lab A		0.16	0.49	0.86	0.87	8.81
Lab B	0.16		0.95	0.09	0.05	11.63
Lab D	0.49	0.95		0.25	0.21	10.68
Lab F	0.86	0.09	0.25		1.00	7.73
Lab G	0.87	0.05	0.21	1.00		8.08


Caterpillar 1R End of Test Oil Consumption by Oil
End of Test Oil Consumption
14
12
10
8
6
4
2
0
0.5
1
1.5
2
2.5
3
3.5
Matrix Oil (1=A, 2=D, 3=M)


End of Test Oil Consumption Least Square Means and 95% Confidence Intervals
End of Test Oil Consumption
14
13
12
11
10
9
8
7
6
0.5
1
1.5
2
2.5
3
3.5
Matrix Oil (1=A, 2=D, 3=M)

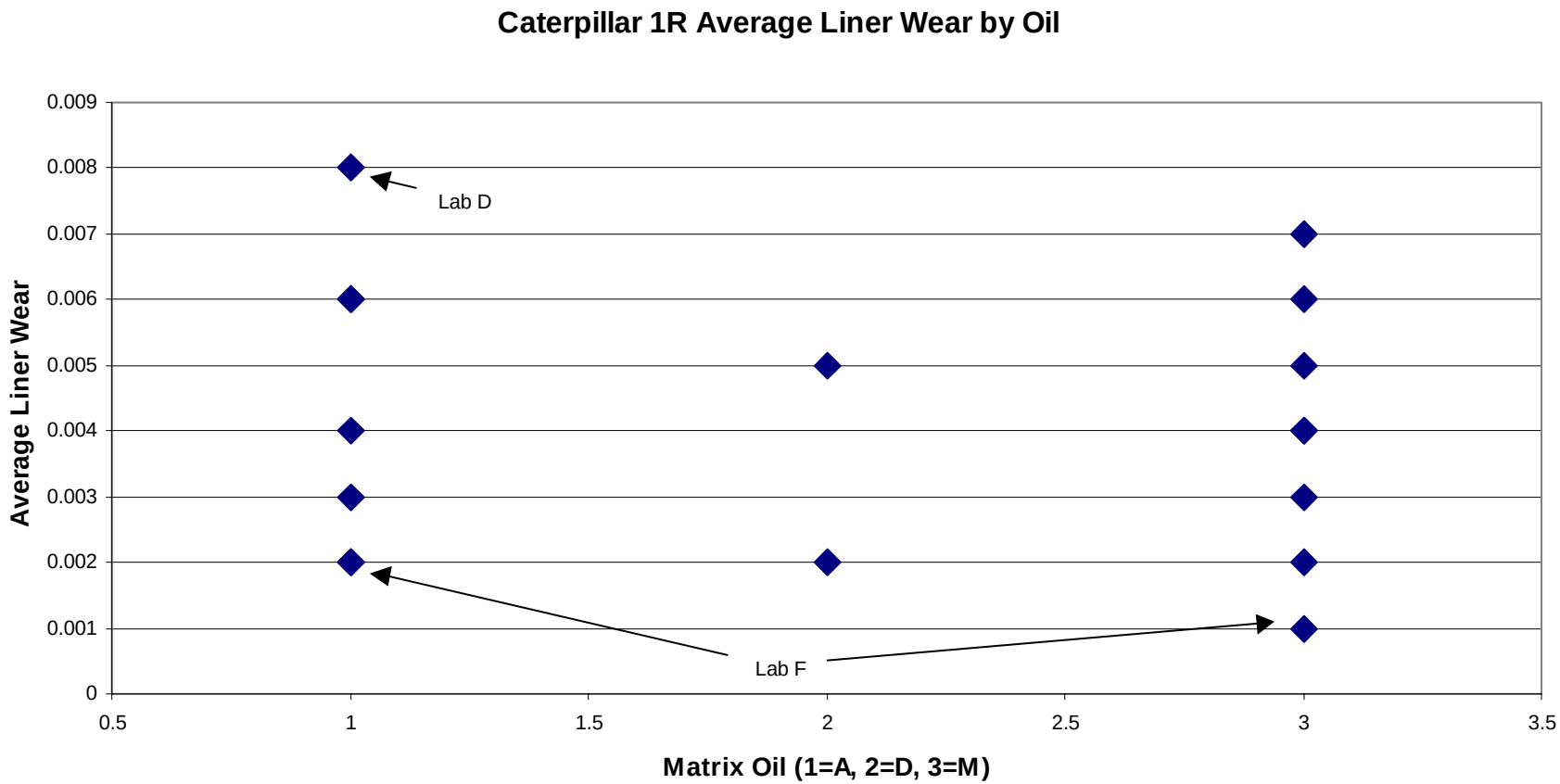
Average Liner Wear (ALW)

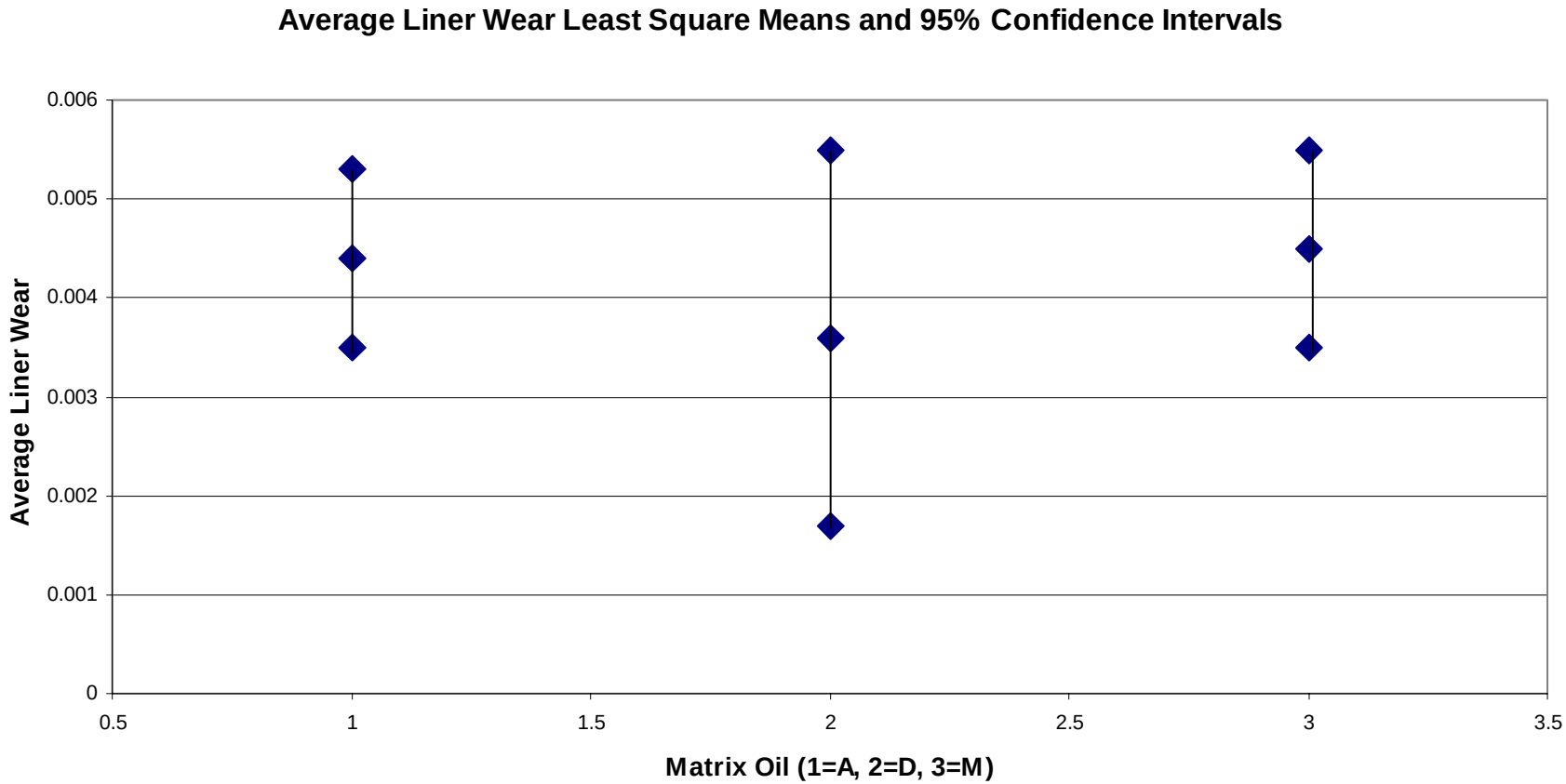
- Model factors considered include Lab (A,B,D,F,G), Stand within Lab (A1,A2,A3,G1,G2,G3) and Oil (A,D,M)
- Evidence that Labs differ ($p<0.05$)
  - Root MSE = 0.001064 (10 df – Lab and Oil Model)
  - $R^2 = 0.83$
  - No observations had large Studentized residuals
  - ALW for CMIR 41543 (Lab D, Oil M) is missing

p-values in Hypothesis Test of No Difference				Least Square Mean
	Oil A	Oil D	Oil M	
Oil A		0.60	0.99	0.0044
Oil D	0.60		0.56	0.0036
Oil M	0.99	0.56		0.0045

Average Liner Wear (ALW)

p-values in Hypothesis Test of No Difference						Least Square Mean
	Lab A	Lab B	Lab D	Lab F	Lab G	
Lab A		0.77	0.01	0.49	0.01	0.0027
Lab B	0.77		0.08	0.21	0.31	0.0037
Lab D	0.01	0.08		0.00	0.41	0.0077
Lab F	0.49	0.21	0.00		0.00	0.0012
Lab G	0.01	0.31	0.41	0.00		0.0055

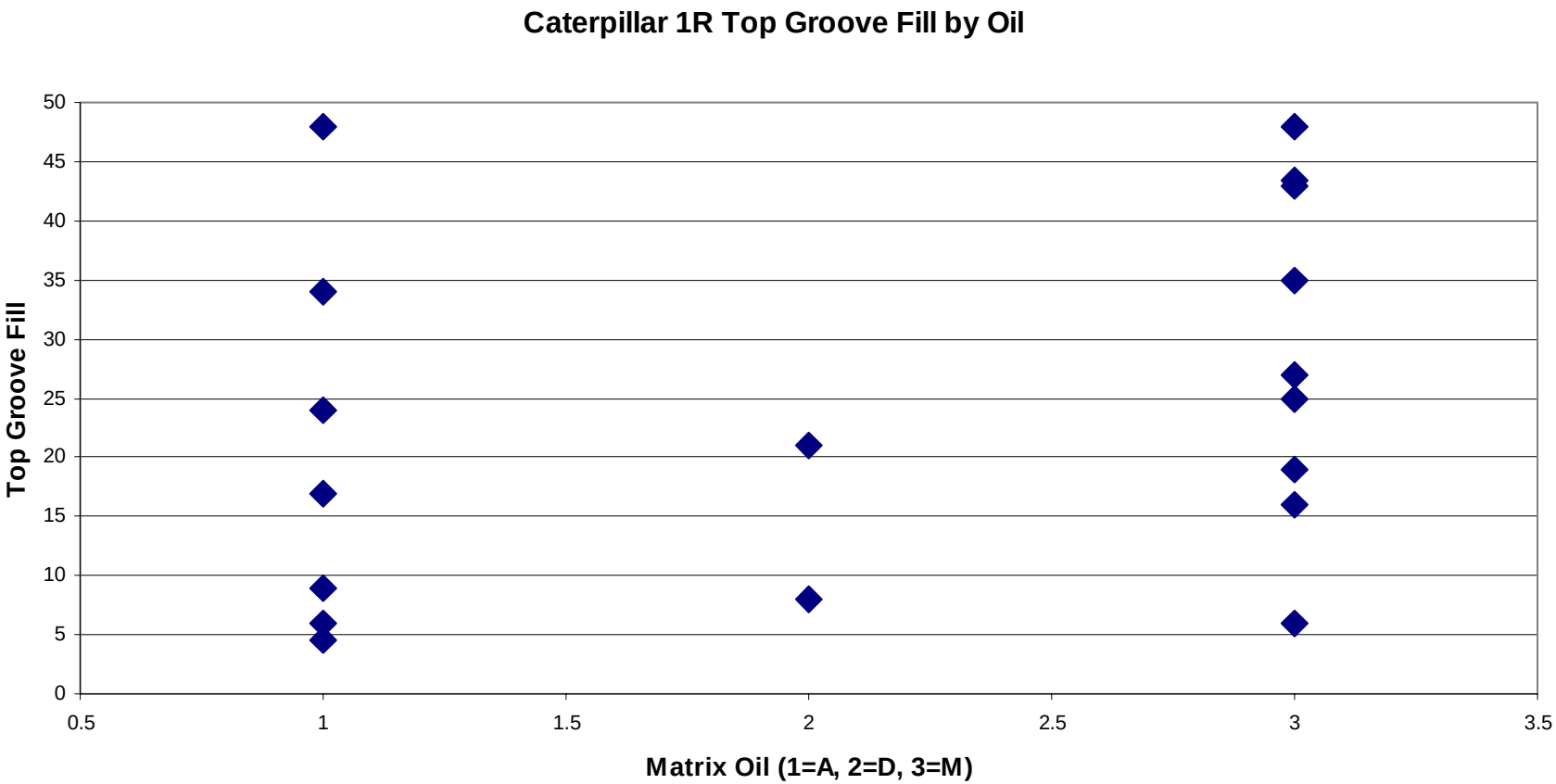

Caterpillar 1R Average Liner Wear by Oil
Average Liner Wear
0.009
0.008
0.007
0.006
0.005
0.004
0.003
0.002
0.001
0
0.5
1
1.5
2
2.5
3
3.5
Lab D
Lab F
Matrix Oil (1=A, 2=D, 3=M)

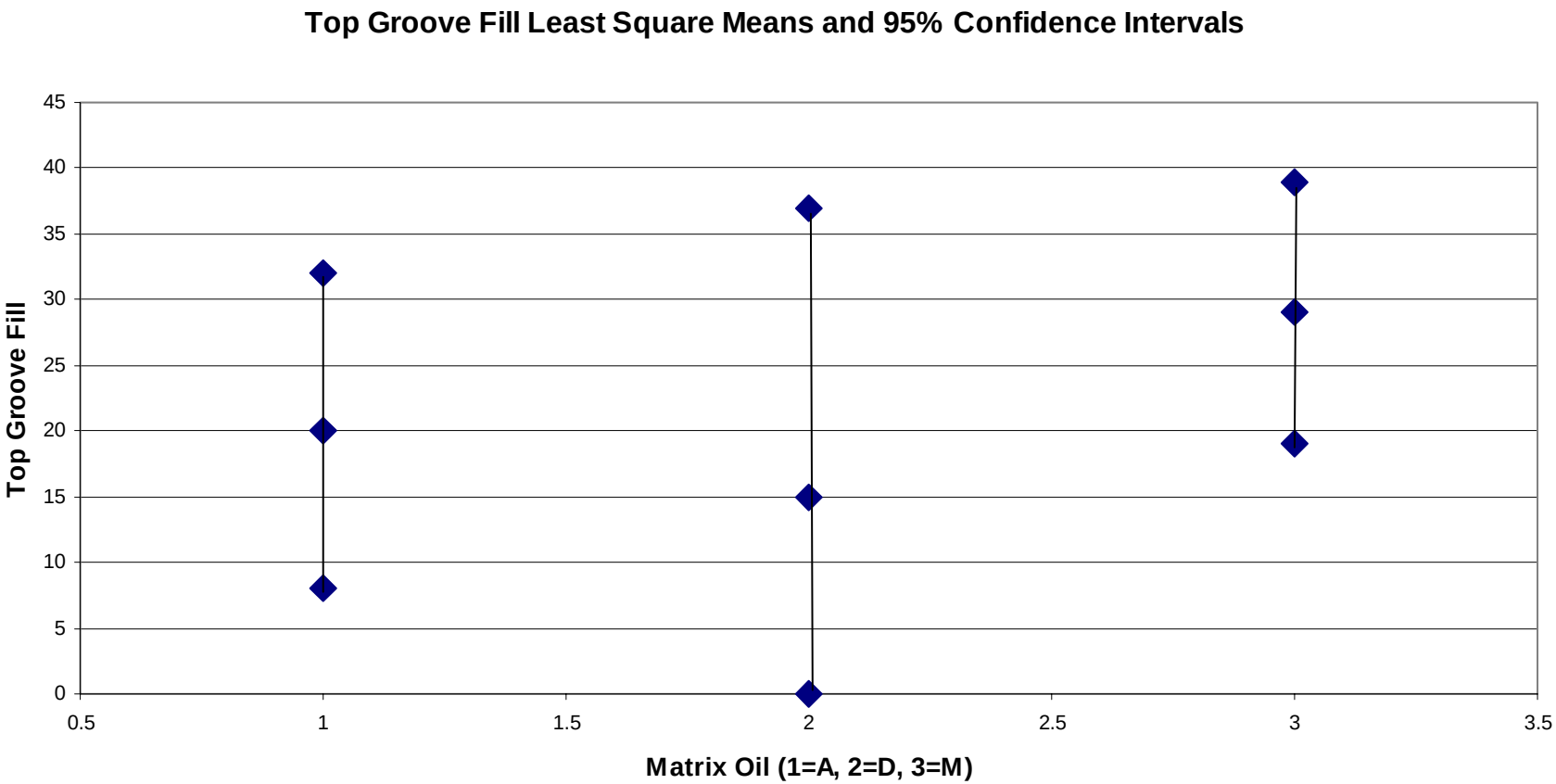

Average Liner Wear Least Square Means and 95% Confidence Intervals
Average Liner Wear
0.006
0.005
0.004
0.003
0.002
0.001
0
0.5
1
1.5
2
2.5
3
3.5
Matrix Oil (1=A, 2=D, 3=M)

Top Groove Fill (TGF)

- Model factors considered include Lab (A,B,D,F,G), Stand within Lab (A1,A2,A3,G1,G2,G3) and Oil (A,D,M)
- No evidence of any effects
  - Root MSE = 14.75 (15 df – Oil Model)
  - $R^2 = 0.14$
  - No observations had large Studentized residuals

p-values in Hypothesis Test of No Difference				Least Square Mean
	Oil A	Oil D	Oil M	
Oil A		0.92	0.43	20.4
Oil D	0.92		0.46	14.5
Oil M	0.43	0.46		29.2

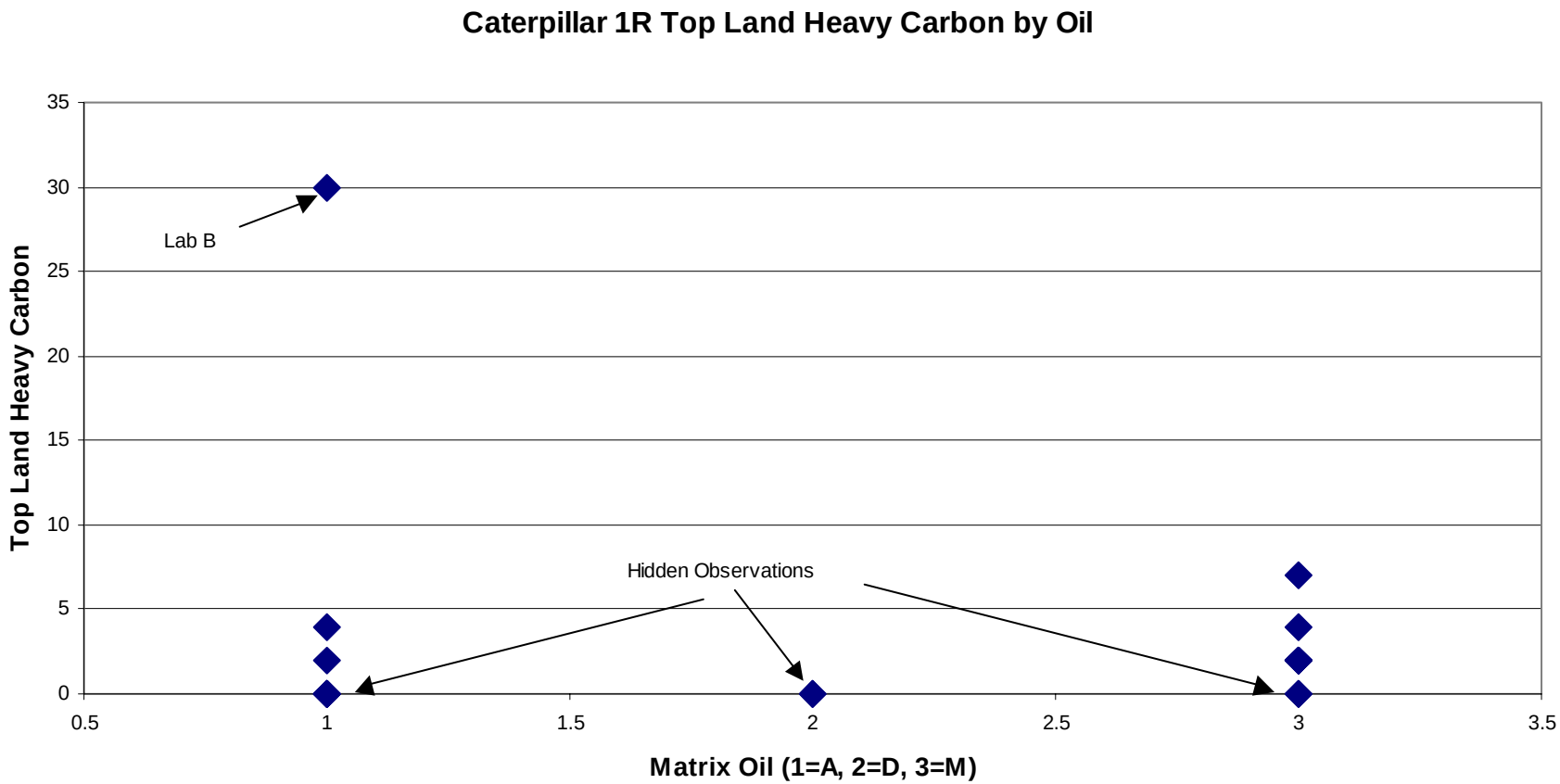

Caterpillar 1R Top Groove Fill by Oil
Top Groove Fill
50
45
40
35
30
25
20
15
10
5
0
0.5
1
1.5
2
2.5
3
3.5
Matrix Oil (1=A, 2=D, 3=M)

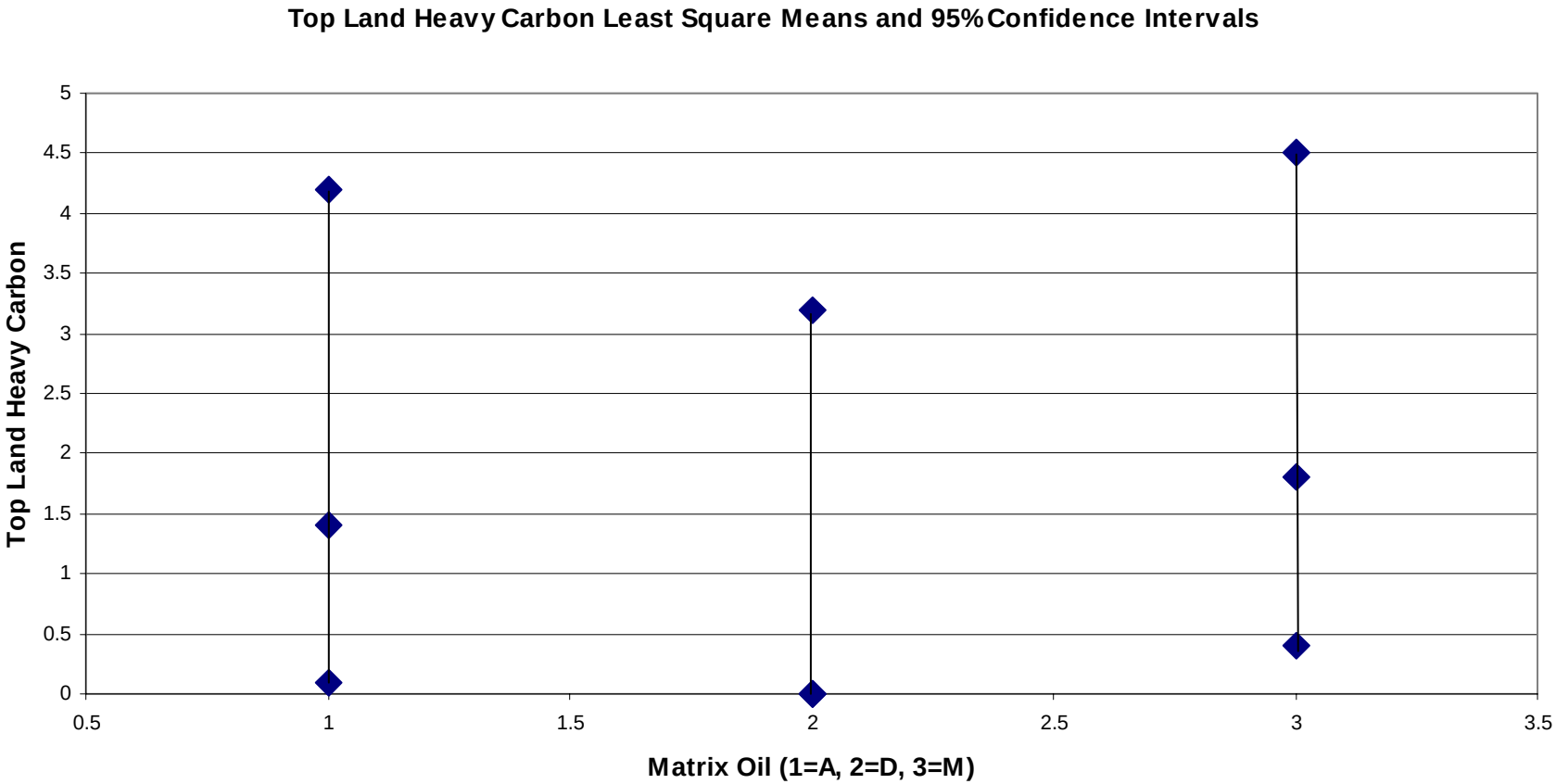

Top Groove Fill Least Square Means and 95% Confidence Intervals
Top Groove Fill
45
40
35
30
25
20
15
10
5
0
0.5
1
1.5
2
2.5
3
3.5
Matrix Oil (1=A, 2=D, 3=M)

Top Land Heavy Carbon (TLHC)

- Model factors considered include Lab (A,B,D,F,G), Stand within Lab (A1,A2,A3,G1,G2,G3) and Oil (A,D,M)
- LOG(TLHC+1) transformation used (historical reasons)
- No evidence of any effects
  - Root MSE = 0.95854 (15 df – Oil Model) on Log Scale
  - $R^2 = 0.11$
  - CMIR 41547 (Lab B, Oil A) had a large Studentized residual

p-values in Hypothesis Test of No Difference				Least Square Mean
	Oil A	Oil D	Oil M	
Oil A		0.50	0.95	0.8774 (1.4)
Oil D	0.50		0.38	0 (0)
Oil M	0.95	0.38		1.02 (1.8)


Caterpillar 1R Top Land Heavy Carbon by Oil
Top Land Heavy Carbon
35
30
25
20
15
10
5
0
Lab B
Hidden Observations
0.5
1
1.5
2
2.5
3
3.5
Matrix Oil (1=A, 2=D, 3=M)


Top Land Heavy Carbon Least Square Means and 95% Confidence Intervals
Top Land Heavy Carbon
5
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0
0.5
1
1.5
2
2.5
3
3.5
Matrix Oil (1=A, 2=D, 3=M)

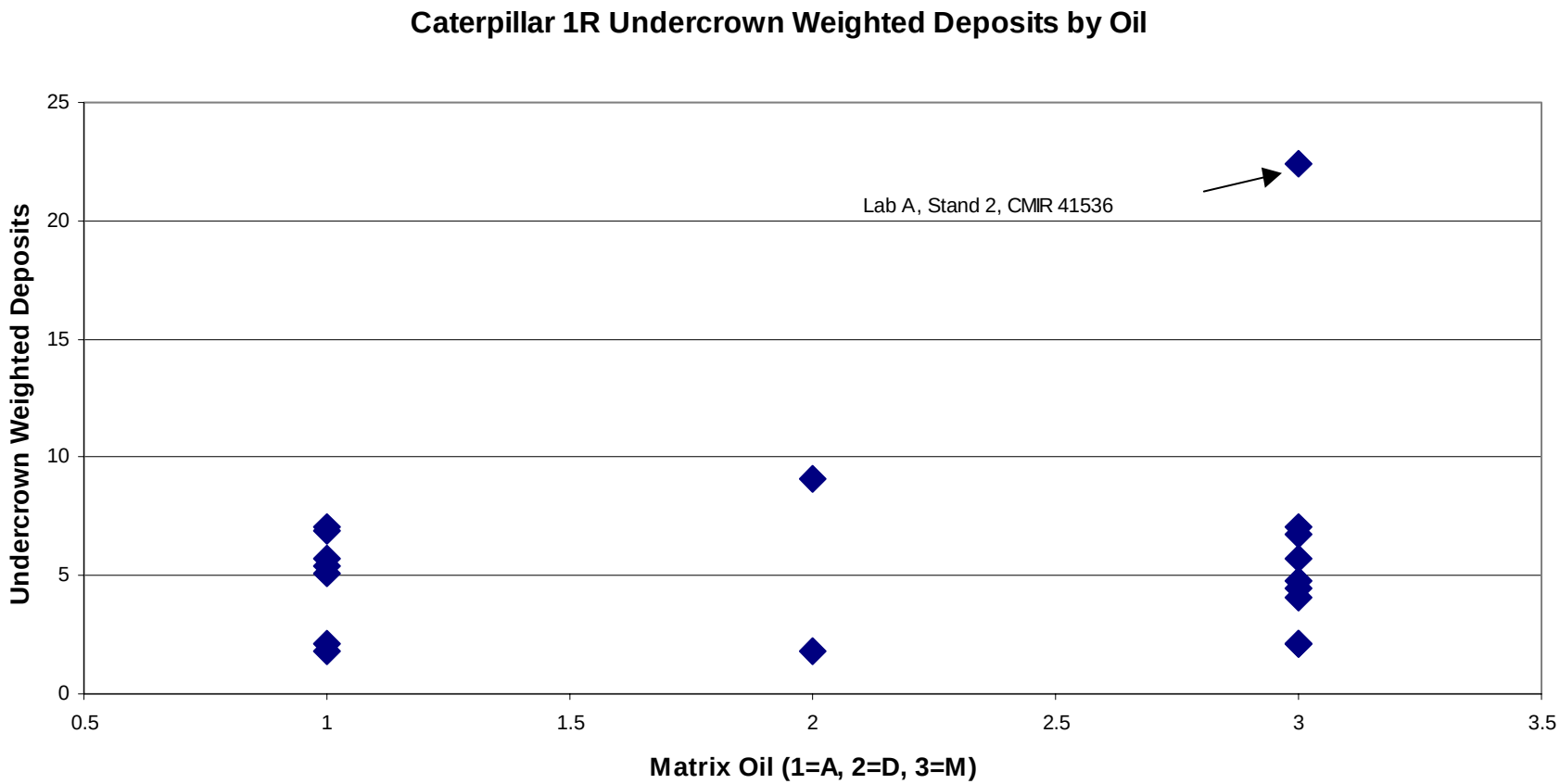
Under Crown Weighted Deposits (UCWD)

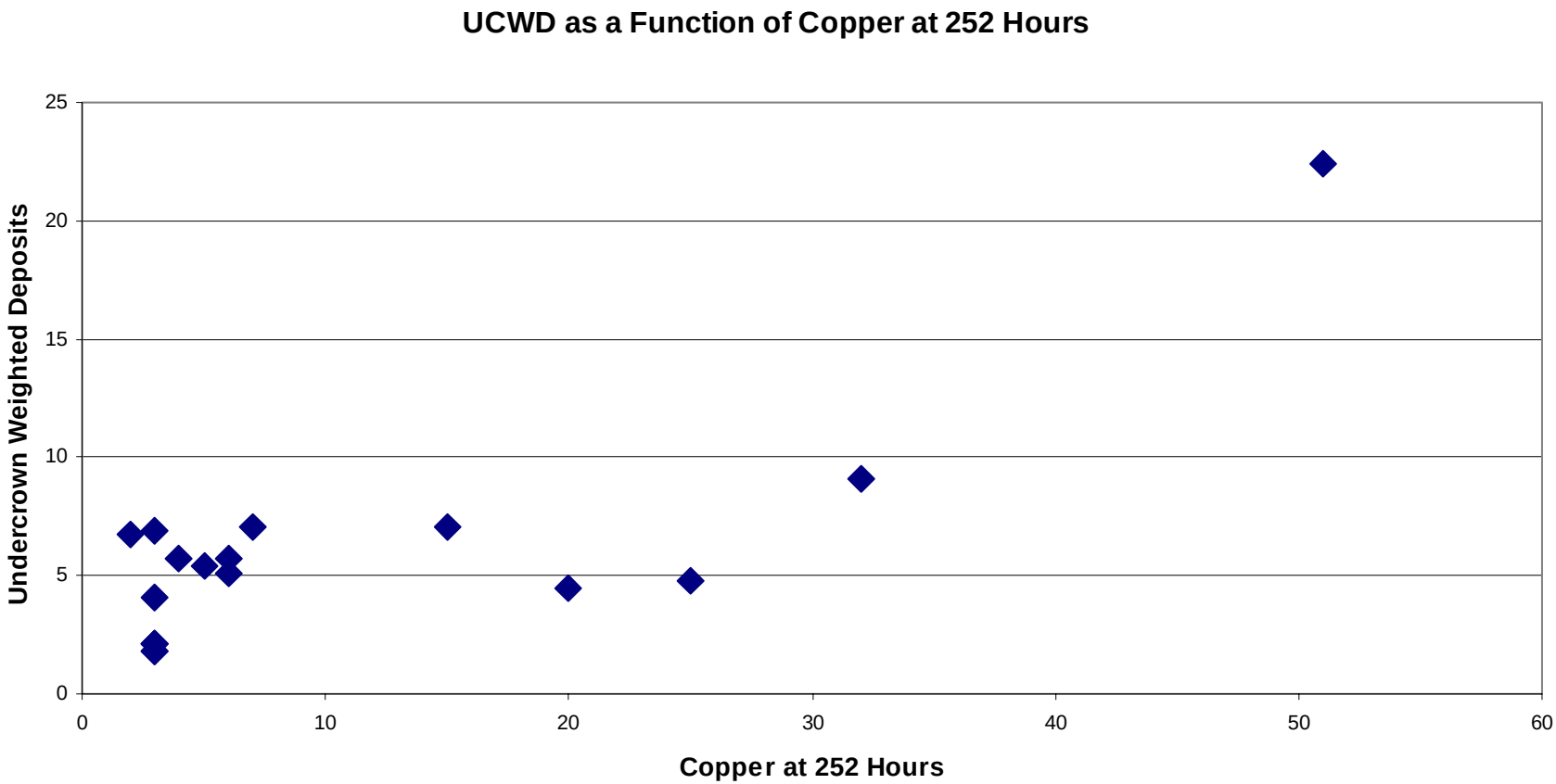
- Model factors considered include Lab (A,B,D,F,G), Stand within Lab (A1,A2,A3,G1,G2,G3) and Oil (A,D,M)
- CMIR 41536 (Oil M in A2) had a large studentized residual and may drive possible conclusions (not made here) for a transformation and lab/stand effect. The drains indicate high Copper early in the test
- Some weak evidence of a Lab effect ($0.1<p<0.2$)
  - Root MSE = 4.89 (15 df – Oil Model)
  - $R^2 = 0.03$
- This model is one possible way to analyze the data, BUT different analysis paths lead to other possible conclusions concerning lab/stand effects and transformations

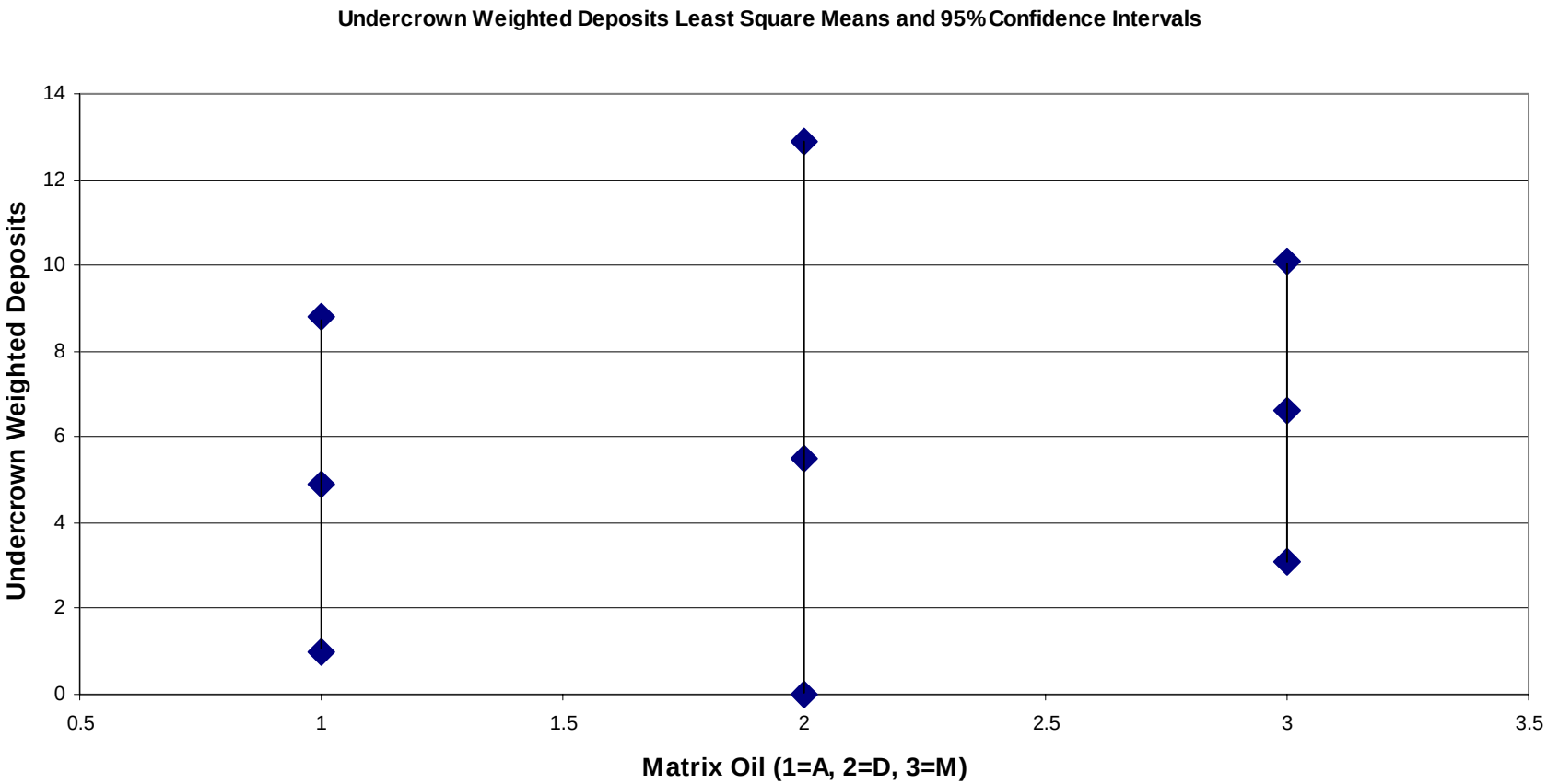
p-values in Hypothesis Test of No Difference				Least Square Mean
	Oil A	Oil D	Oil M	
Oil A		0.99	0.76	4.9
Oil D	0.99		0.95	5.5
Oil M	0.76	0.95		6.6

Under Crown Weighted Deposits (UCWD)

p-values in Hypothesis Test of No Difference						Least Square Mean
	Lab A	Lab B	Lab D	Lab F	Lab G	
Lab A		0.60	0.58	0.74	0.06	9.6
Lab B	0.60		1.00	1.00	0.95	4.6
Lab D	0.58	1.00		1.00	0.96	4.5
Lab F	0.74	1.00	1.00		0.87	5.5
Lab G	0.06	0.95	0.96	0.87		2.2


Caterpillar 1R Undercrown Weighted Deposits by Oil
Undercrown Weighted Deposits
25
20
15
10
5
0
0.5
1
1.5
2
2.5
3
3.5
Lab A, Stand 2, CMIR 41536
Matrix Oil (1=A, 2=D, 3=M)


UCWD as a Function of Copper at 252 Hours
Undercrown Weighted Deposits
25
20
15
10
5
0
0
10
20
30
40
50
60
Copper at 252 Hours


Undercrown Weighted Deposits Least Square Means and 95% Confidence Intervals
Undercrown Weighted Deposits
14
12
10
8
6
4
2
0
0.5
1
1.5
2
2.5
3
3.5
Matrix Oil (1=A, 2=D, 3=M)

Summary of 1R Least Square Oil Means and Test Standard Deviations from Best Model and Simple Oil Means

	WD		TGC		TLC	
	LS Mean	Mean	LS Mean	Mean	LS Mean	Mean
Oil A	341.2	341.2 (36.17)	34.1	34.1 (10.28)	22.8	22.8 (10.50)
Oil D	285.9	285.9 (6.51)	28.1	28.1 (3.01)	13.8	13.8 (8.84)
Oil M	333.3	333.3 (24.36)	37.9	37.9 (9.79)	21.3	21.3 (4.76)
Std Dev	29.03	NA	9.70	NA	7.84	NA

Summary of 1R Least Square Oil Means and Test Standard Deviations from Best Model and Simple Oil Means

	OC		ETOC		ALW	
	LS Mean	Mean	LS Mean	Mean	LS Mean	Mean
Oil A	8.37	8.26 (1.99)	8.15	7.89 (2.56)	0.0044	0.0044 (0.0023)
Oil D	10.31	9.90 (1.84)	11.14	10.20 (1.27)	0.0036	0.0035 (0.0021)
Oil M	9.65	9.47 (1.10)	8.86	8.44 (0.89)	0.0045	0.0040 (0.0020)
Std Dev	1.19	NA	1.35	NA	0.001064	NA

Summary of 1R Least Square Oil Means and Test Standard Deviations from Best Model and Simple Oil Means

	TGF		LN(TLHC+1)		UCWD	
	LS Mean	Mean	LS Mean	Mean	LS Mean	Mean
Oil A	20.4	20.4 (16.13)	0.8774 *1.4*	0.8774 (1.304)	4.9	4.9 (2.12)
Oil D	14.5	14.5 (9.19)	0 *0*	0 (0)	5.5	5.5 (5.16)
Oil M	29.2	29.2 (14.2)	1.020 *1.8*	1.020 (0.669)	6.6	6.6 (6.17)
Std Dev	14.75	NA	0.95854	NA	4.89	NA

Summary of 1R Lab Means

	WD	TGC	TLC	OC	ETOC	TGF	TLHC	UCWD	ALW
Lab A	322	33	17	9.4	8.8	19	1.3	10	0.003
Lab B	353	45	30	10.9	11.6	39	3.1	5	0.004
Lab D	298	28	19	10.9	10.7	15	0.7	5	0.008
Lab F	318	33	18	7.3	7.7	21	0.3	5	0.001
Lab G	317	32	20	8.7	8.1	21	0.4	2	0.006

Caterpillar 1R Matrix Data

lab	cmir	stand	oil	date	wd	tgc	tlc	oc	etoc	tgf	tlhc	alw	ucwd
A	41535	1	M	20010704	364.6	51.25	22	9.8	8.5	48	2	0.003	7.05
A	41536	2	M	20010705	350.3	30.25	16.5	7.9	6.8	25	2	0.005	22.38
A	41537	3	A	20010707	341.2	43	24.25	9.3	8.2	24	4	0.03	6.9
F	41545	1	M	20010710	356.7	46.25	26	7.9	8.5	43.4	2	0.001	5.7
G	41539	1	M	20010711	323.2	47.25	27	10.1	8.1	43	7	0.004	2.1
G	41541	3	A	20010711	310.6	24.5	15	6.6	5.5	6	0	0.006	1.8
B	41554	1	M	20010712	331.3	46	21.25	10	9.3	35	0	0.004	4.5
G	41540	2	M	20010712	356.1	29.5	22.75	10.7	9.4	16	0	0.006	4.8
A	41538	1	A	20010731	327.8	33	25.5	8	7.5	17	2	0.002	7.06
A	41760	2	D	20010801	290.5	26	7.5	11.2	11.1	8	0	0.002	9.1
A	41573	3	M	20010802	301.5	25.25	11.5	9.6	8.5	6	2	0.002	6.74
G	41542	1	A	20010803	371.6	40	16	6.8	6.4	34	0	0.006	2.1
G	41761	2	D	20010804	281.3	30.25	20	8.6	9.3	21	0	0.005	1.8
F	41546	1	A	20010804	311.7	25	13.75	5.8	5.2	4.5	0	0.002	5.7
G	41570	3	M	20010805	304.9	29.25	23.5	8.5	7.5	19	2	0.007	2.1
D	41968	1	A	20010805	317.9	23.75	21	10.3	10.2	9	0	0.008	5.4
B	41547	1	A	20010814	407.5	49.5	44.25	11	12.2	48	30	0.004	5.1
D	41543	1	M	20010902	311.2	36.5	21	10.7	9.4	27	4	.	4.06