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245 Anniston, AL Mainline Derailment

TOES & Wheel/Rail Analysis

January 9th, 2023

Jaisen Gil
Engineer Operations Research & Tests

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01 Consist Details

Train No 245A109

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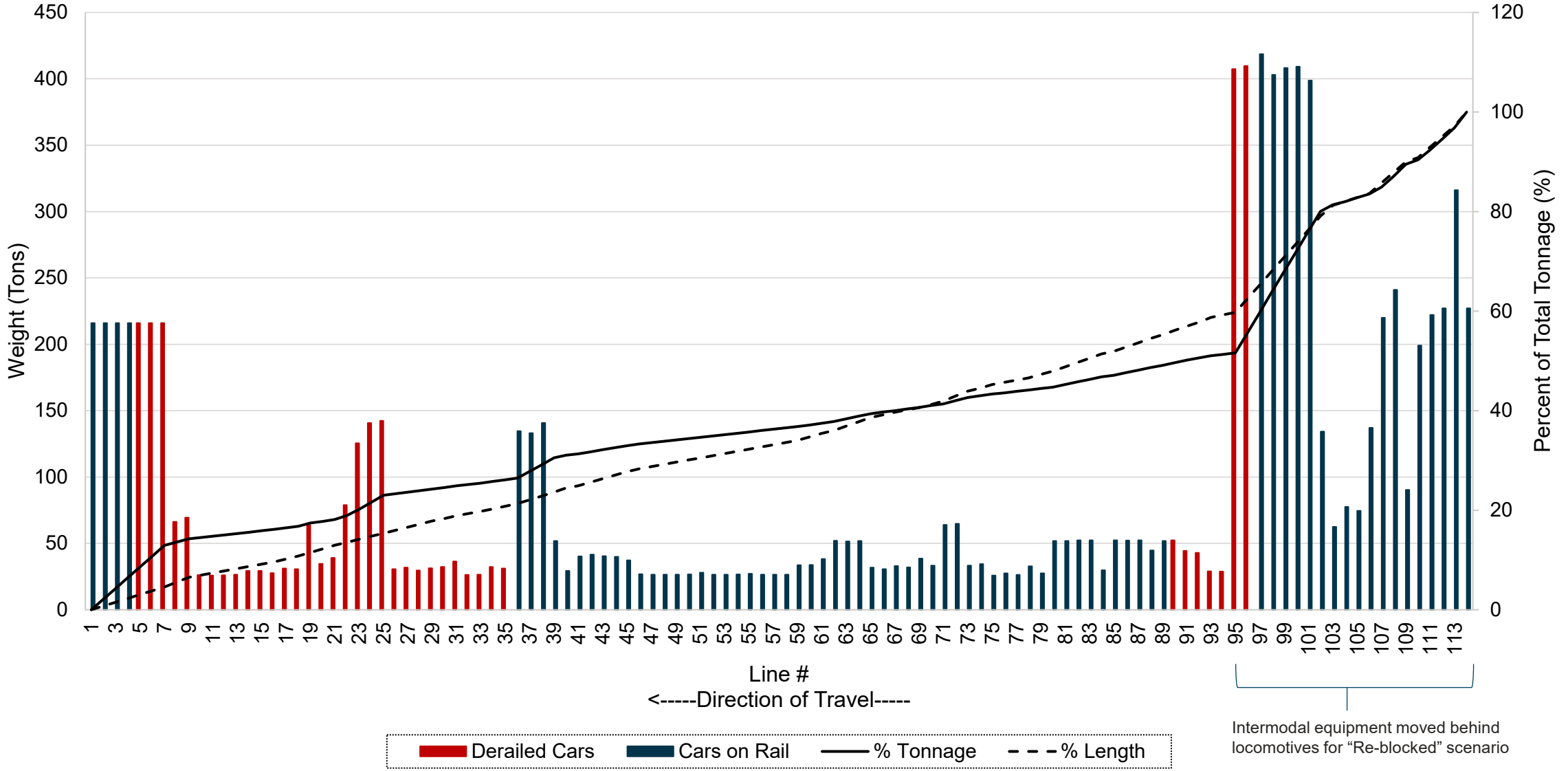

Train No 245A109

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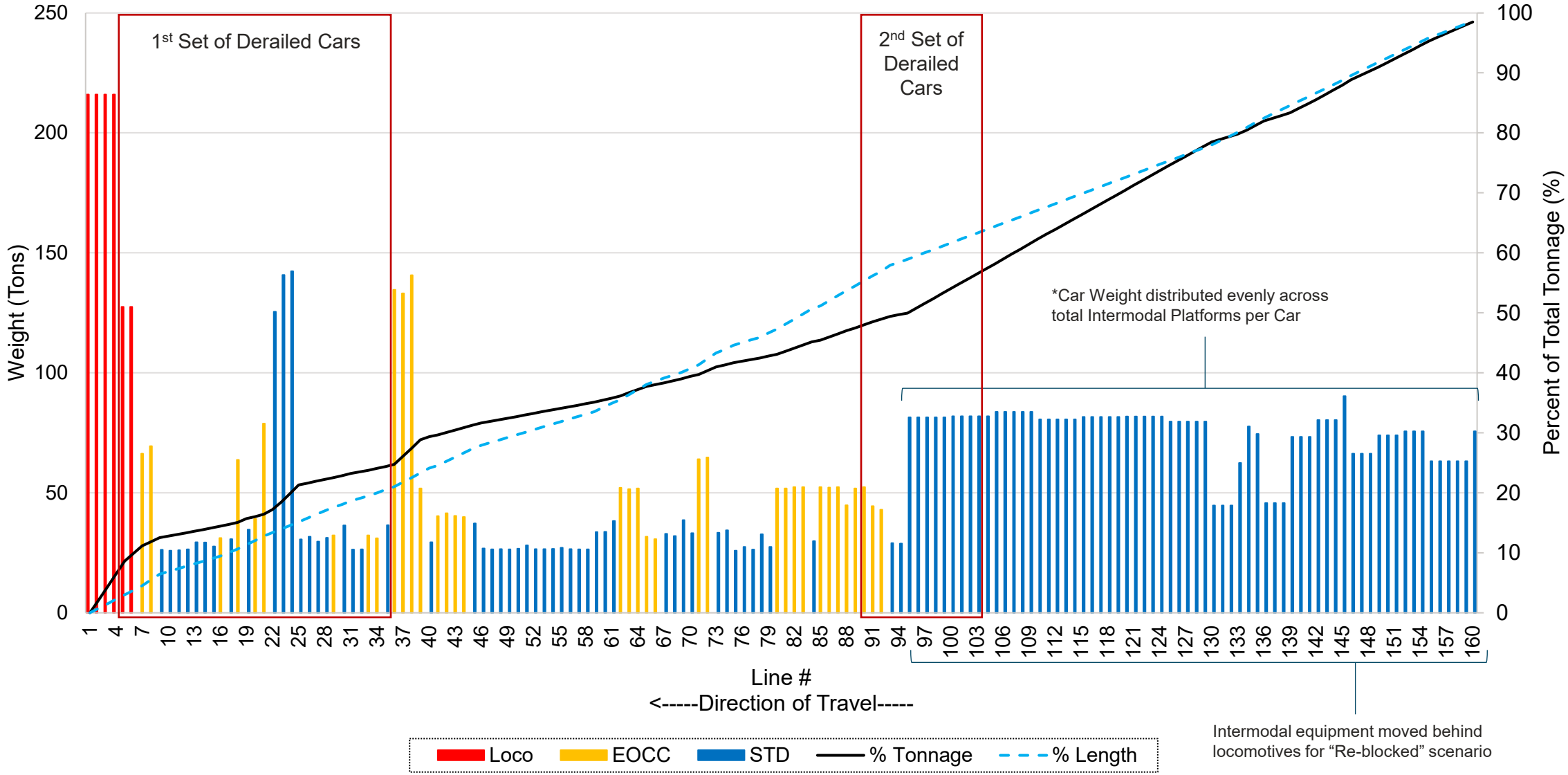

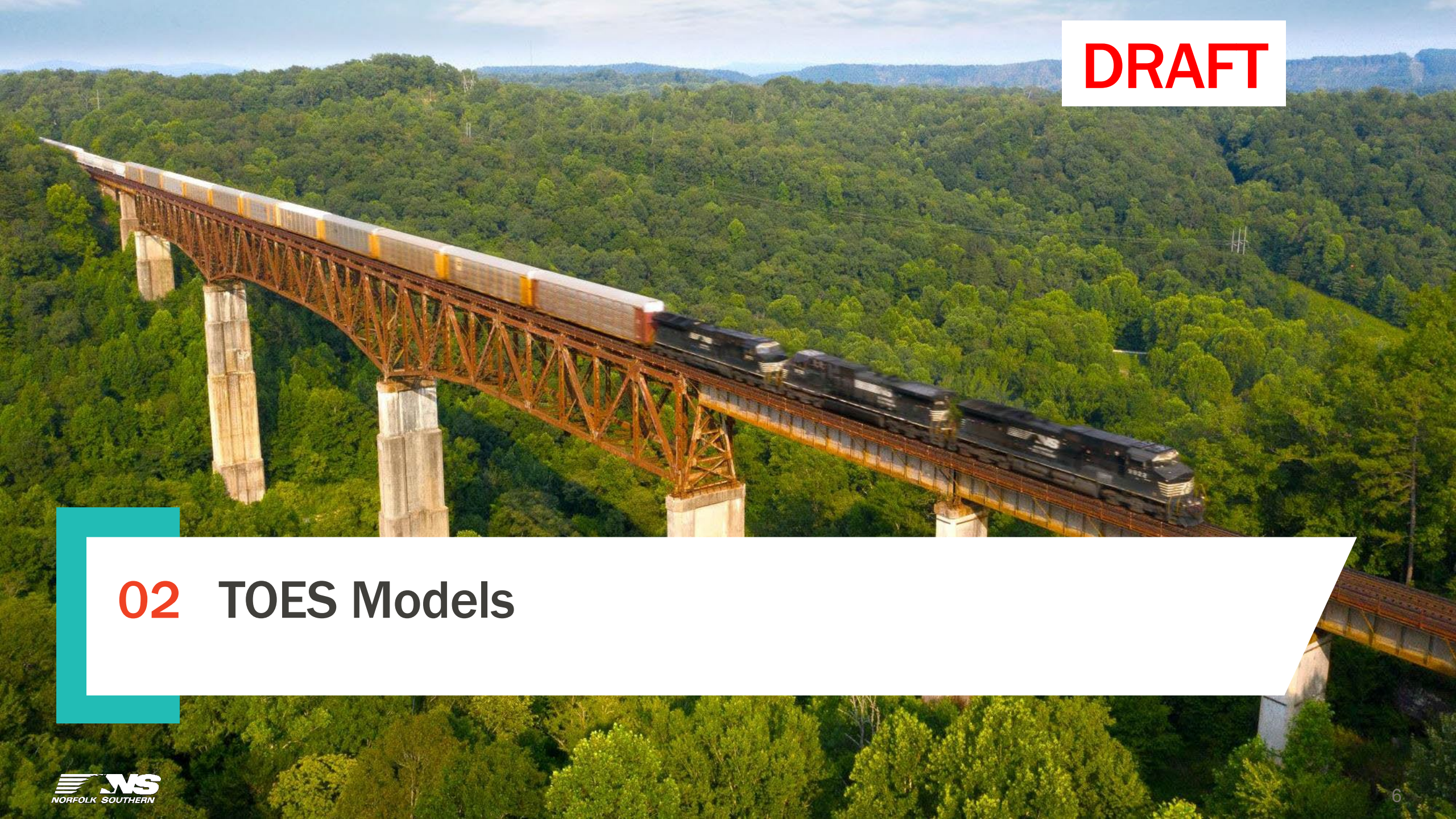

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02 TOES Models

Scenario 1: POD (TOES Plot)

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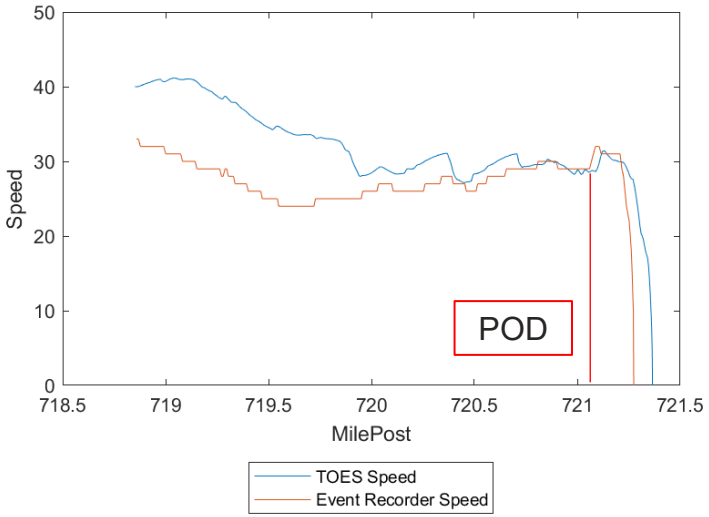

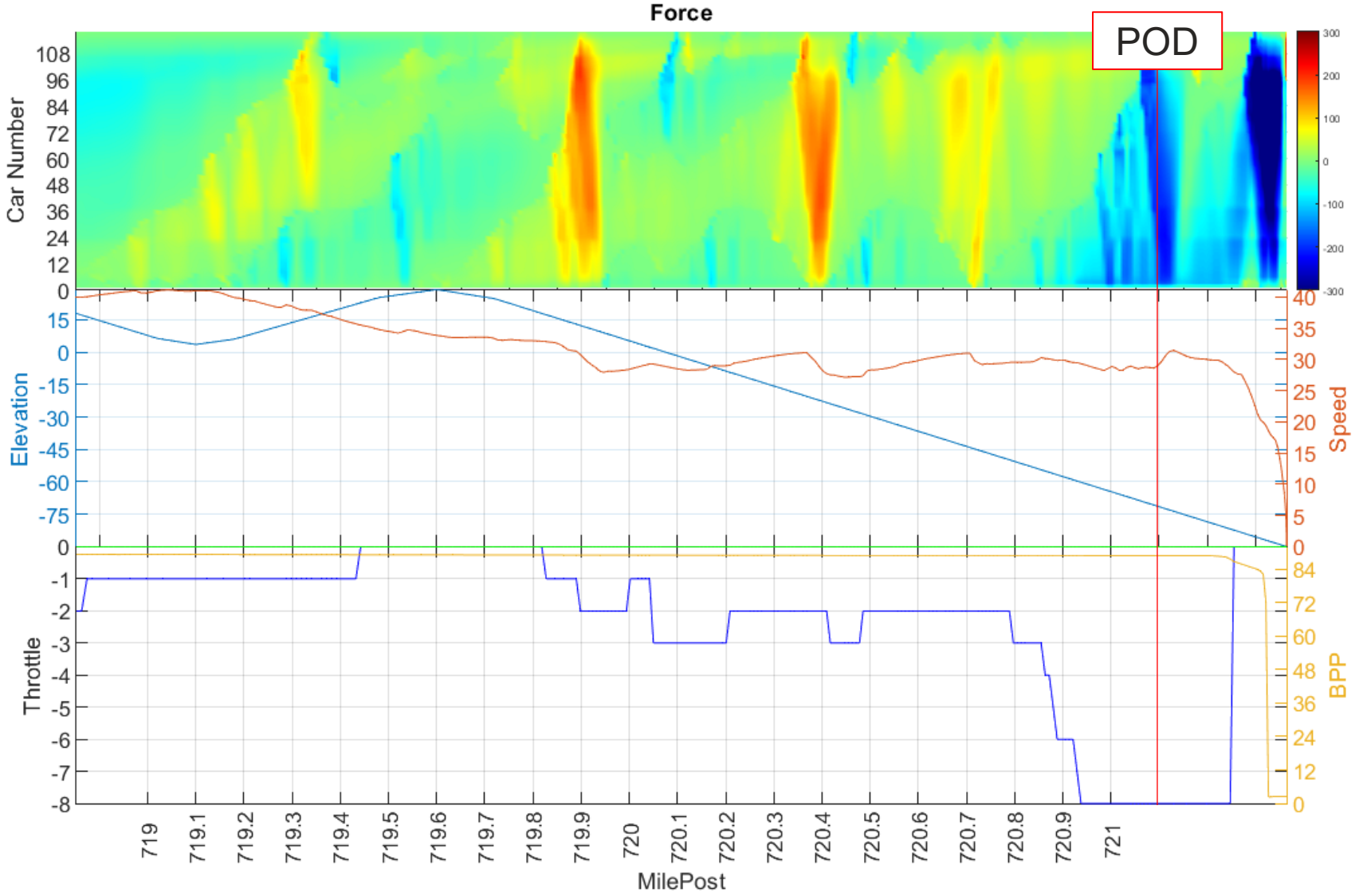

Scenario 1: POD (TOES Plot)

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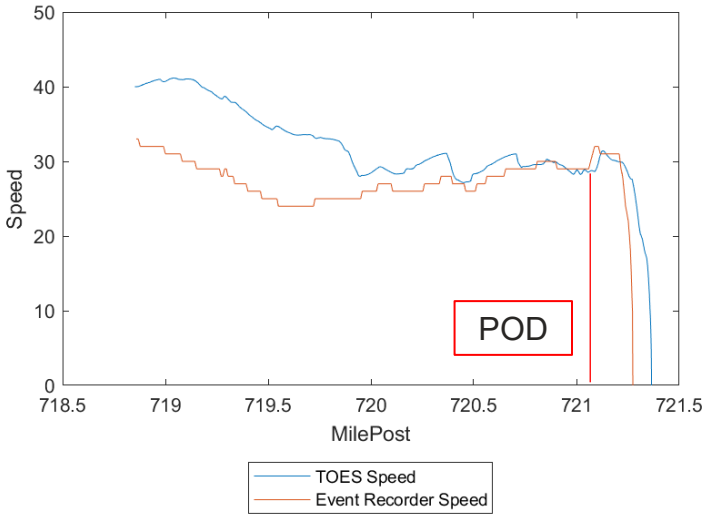

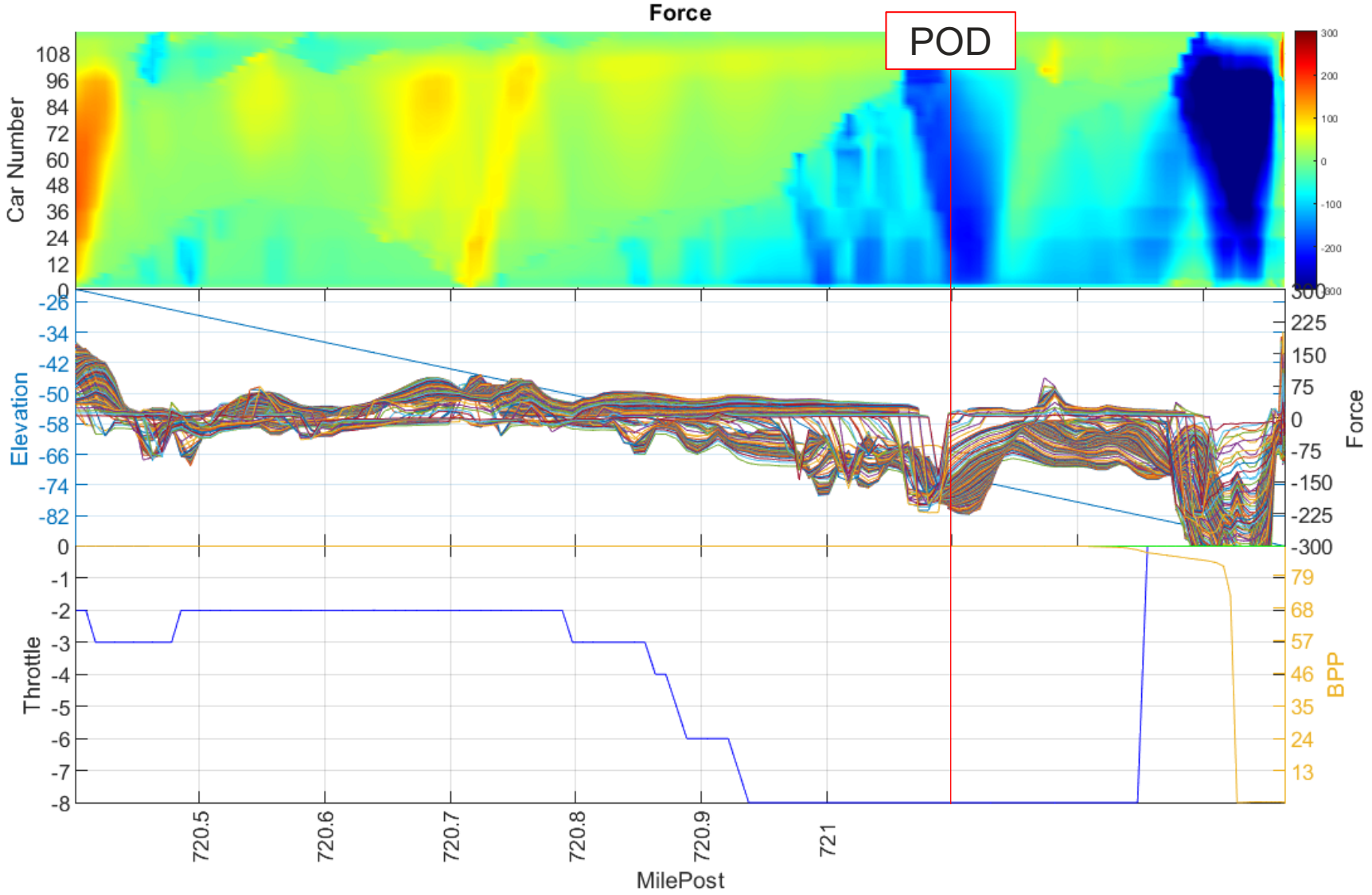

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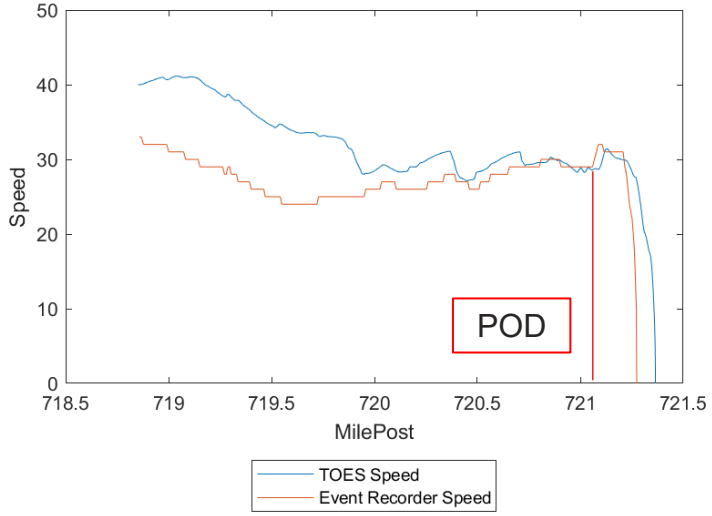
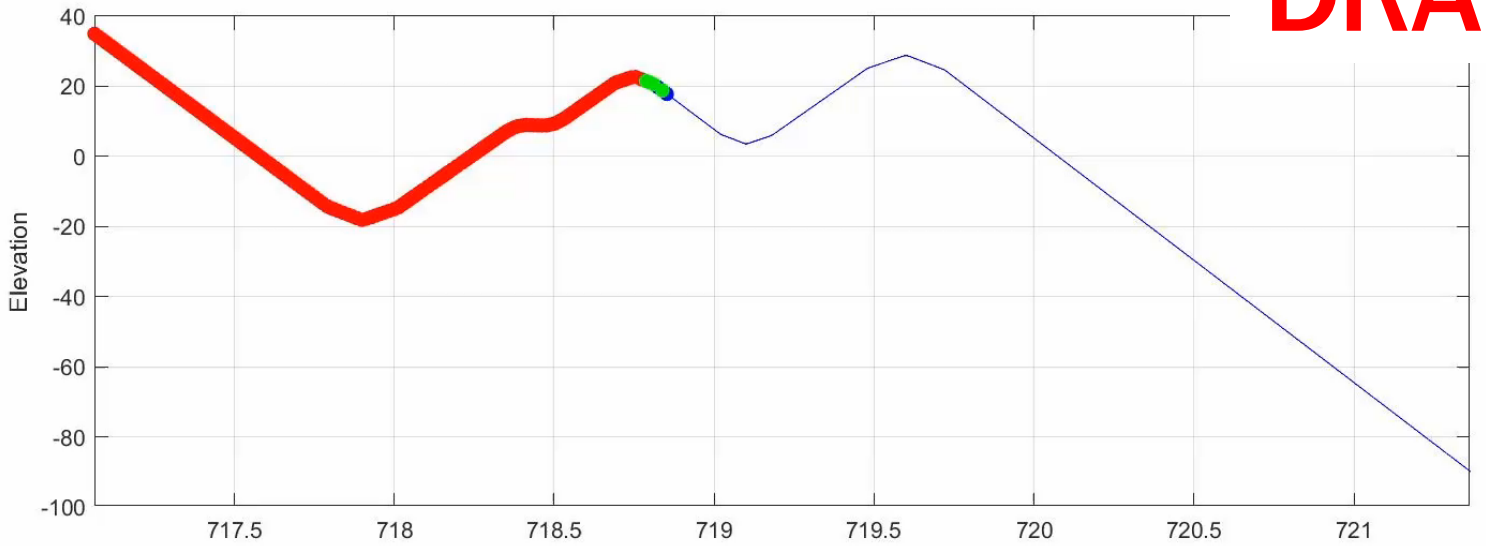
Scenario 1: POD

(TOES Animation)



DB-2 | BPP:89 | MPH:40 | TH-0 | BPP:89 | MPH:40



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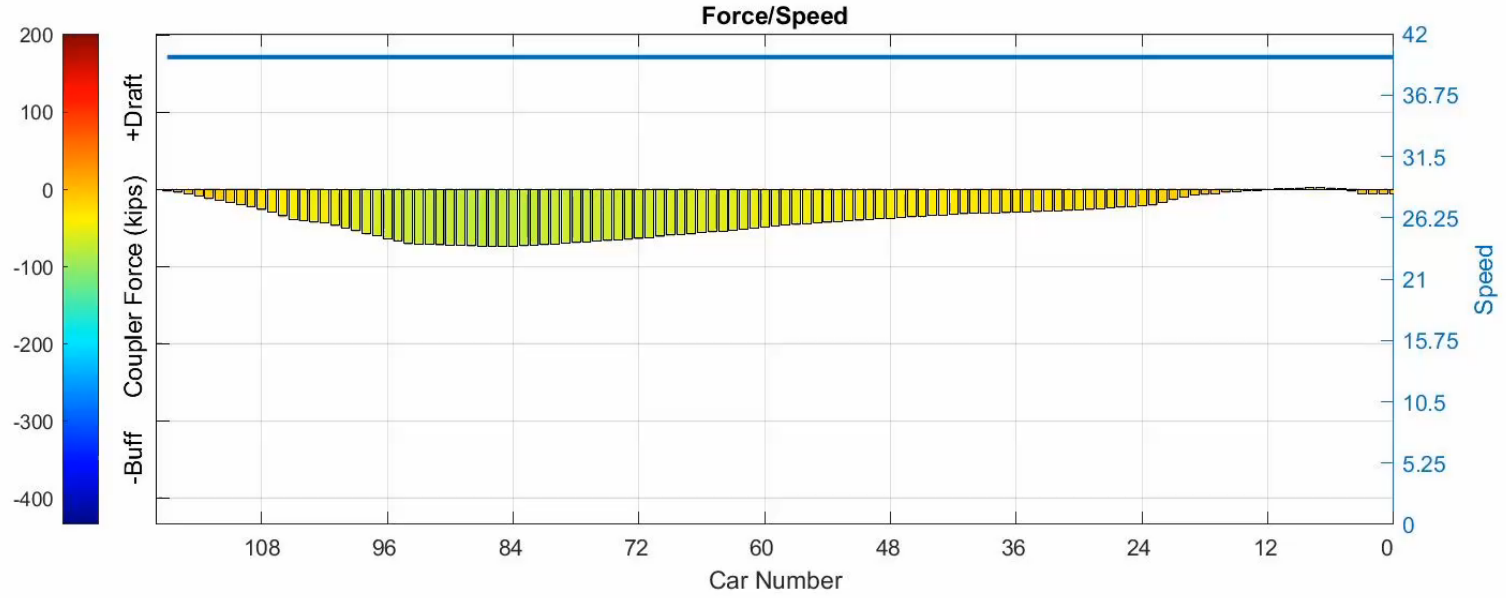

Scenario 2: MP 706.2 – 707.0 (TOES Plot)

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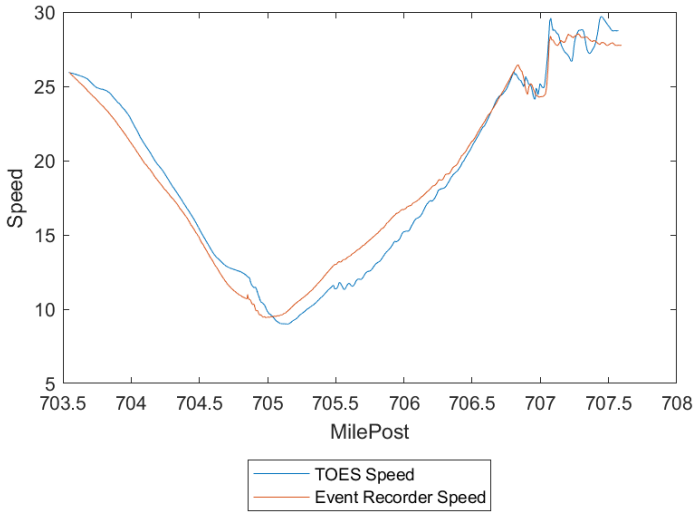
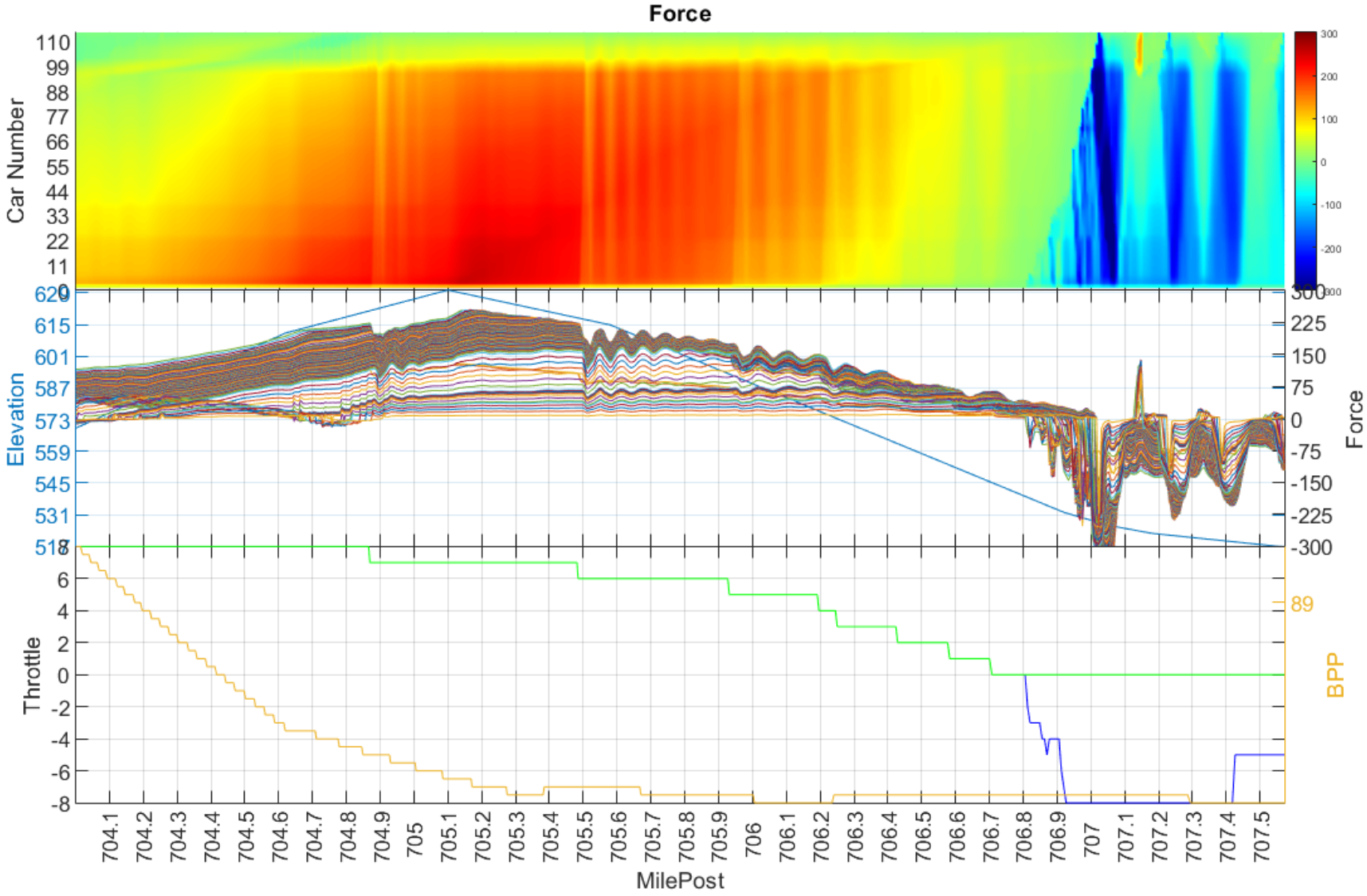
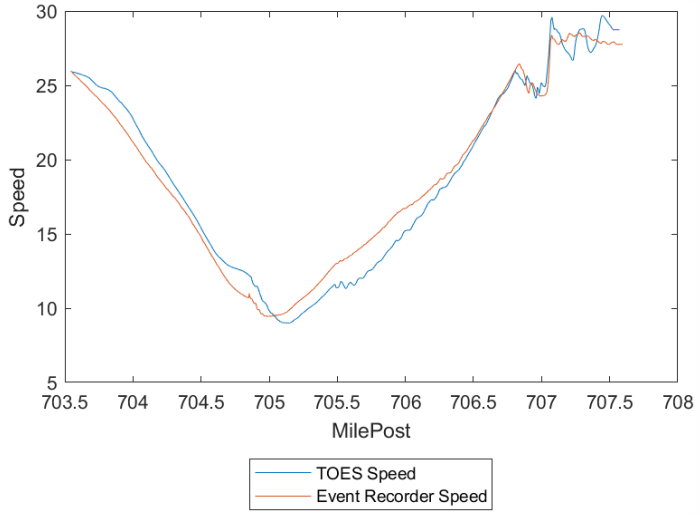




Scenario 2:

MP 706.2 – 707.0

(TOES Animation)



TH-8 | BPP:89 | MPH:26 | TH-8 | BPP:89 | MPH:26

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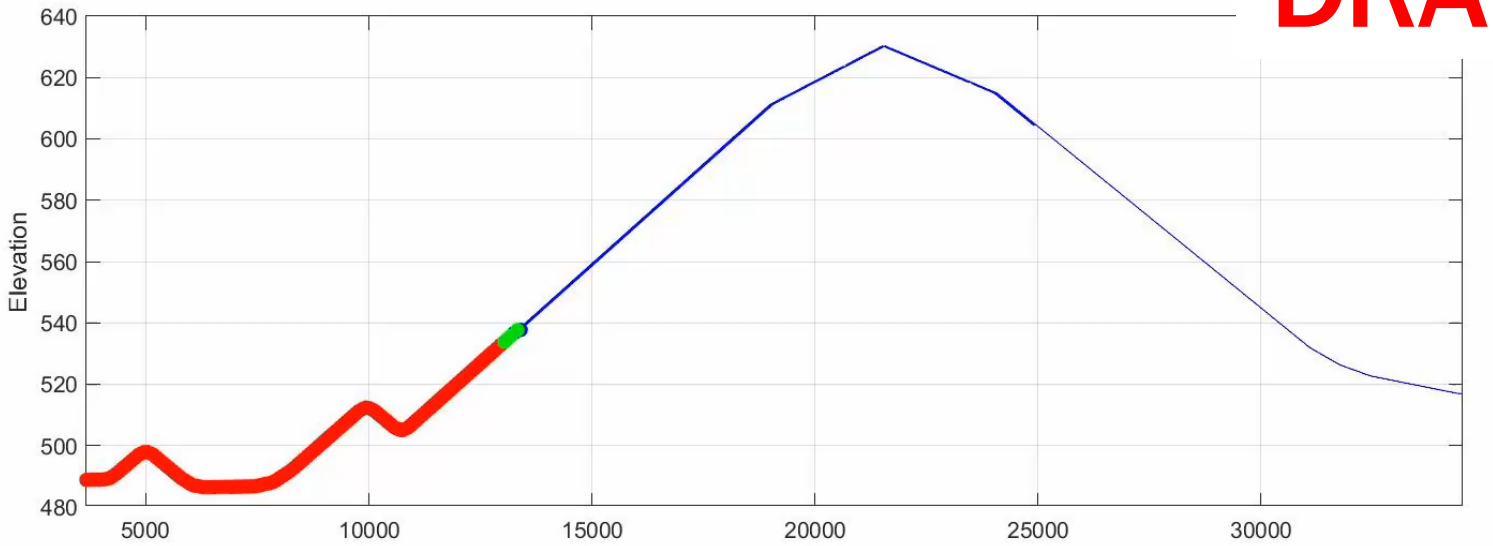

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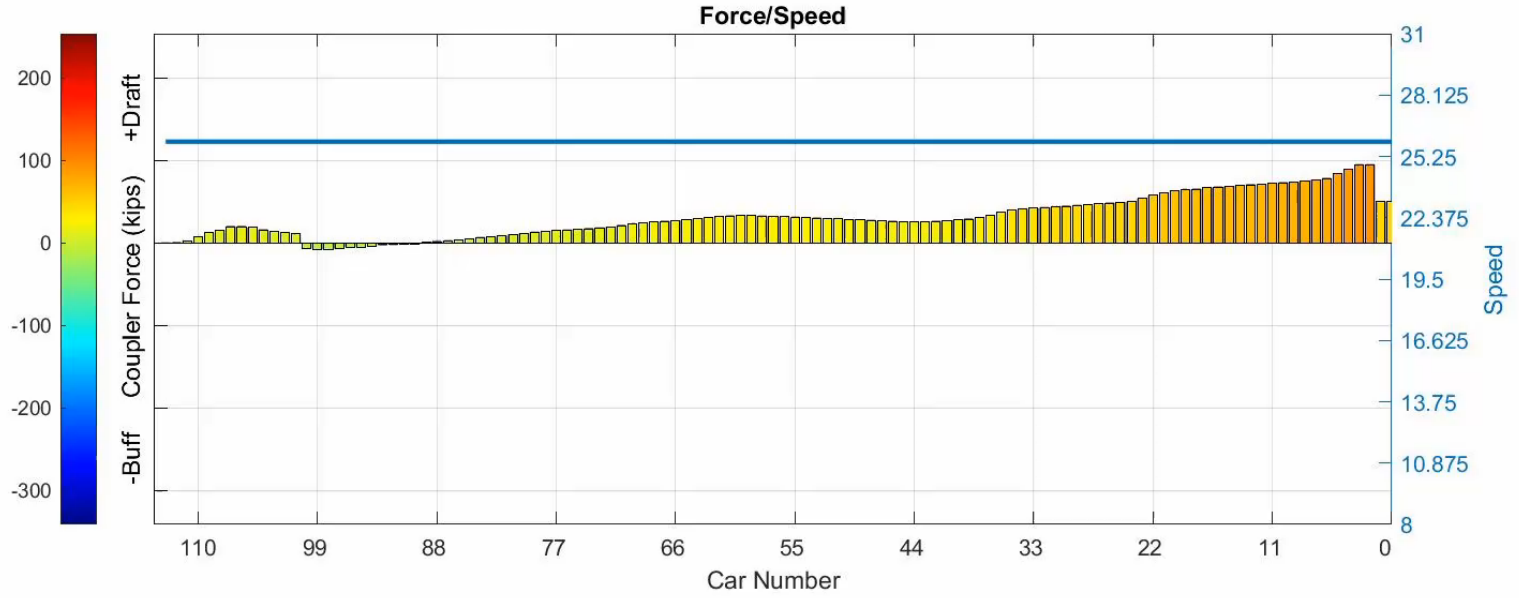

Scenario 3: POD w/ Reblocked Consist (TOES Plot)

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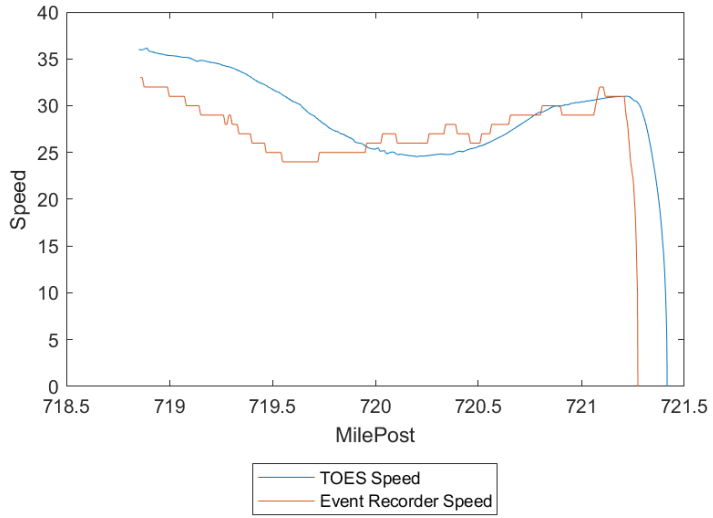

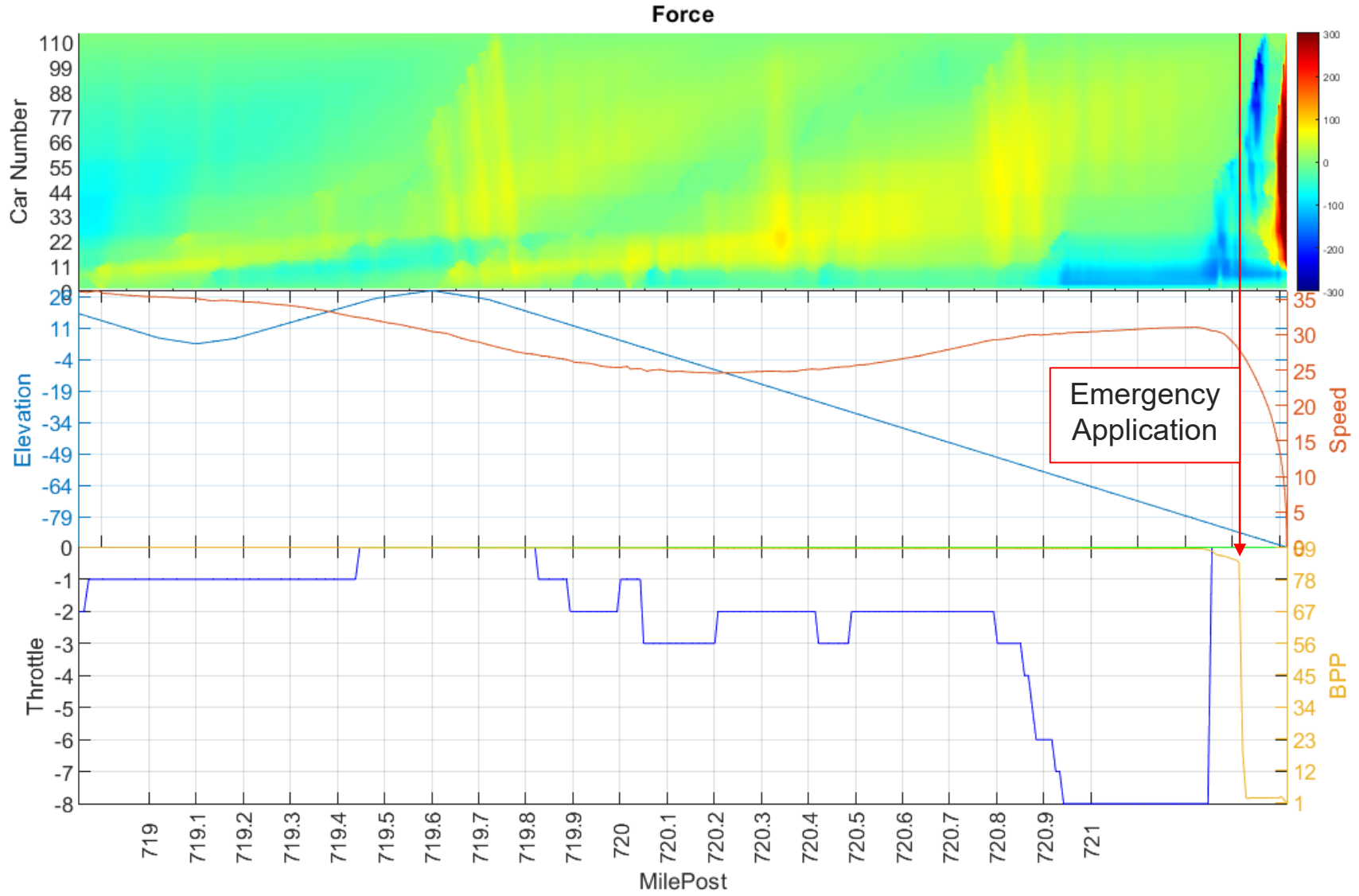

Scenario 3: POD w/ Reblocked Consist (TOES Plot)

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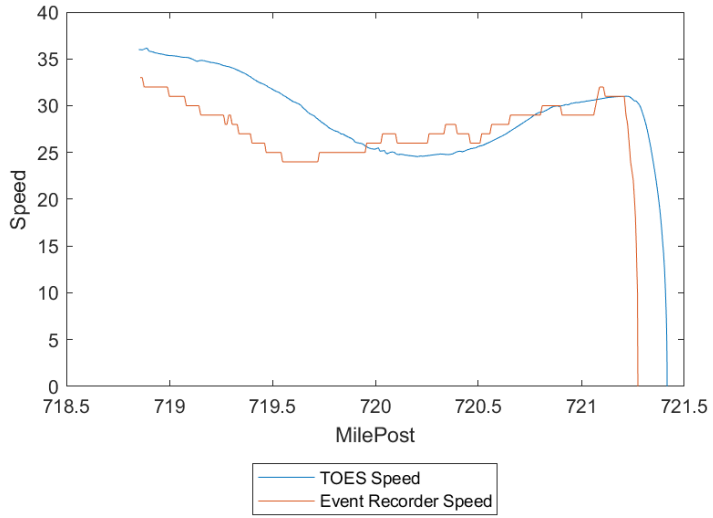

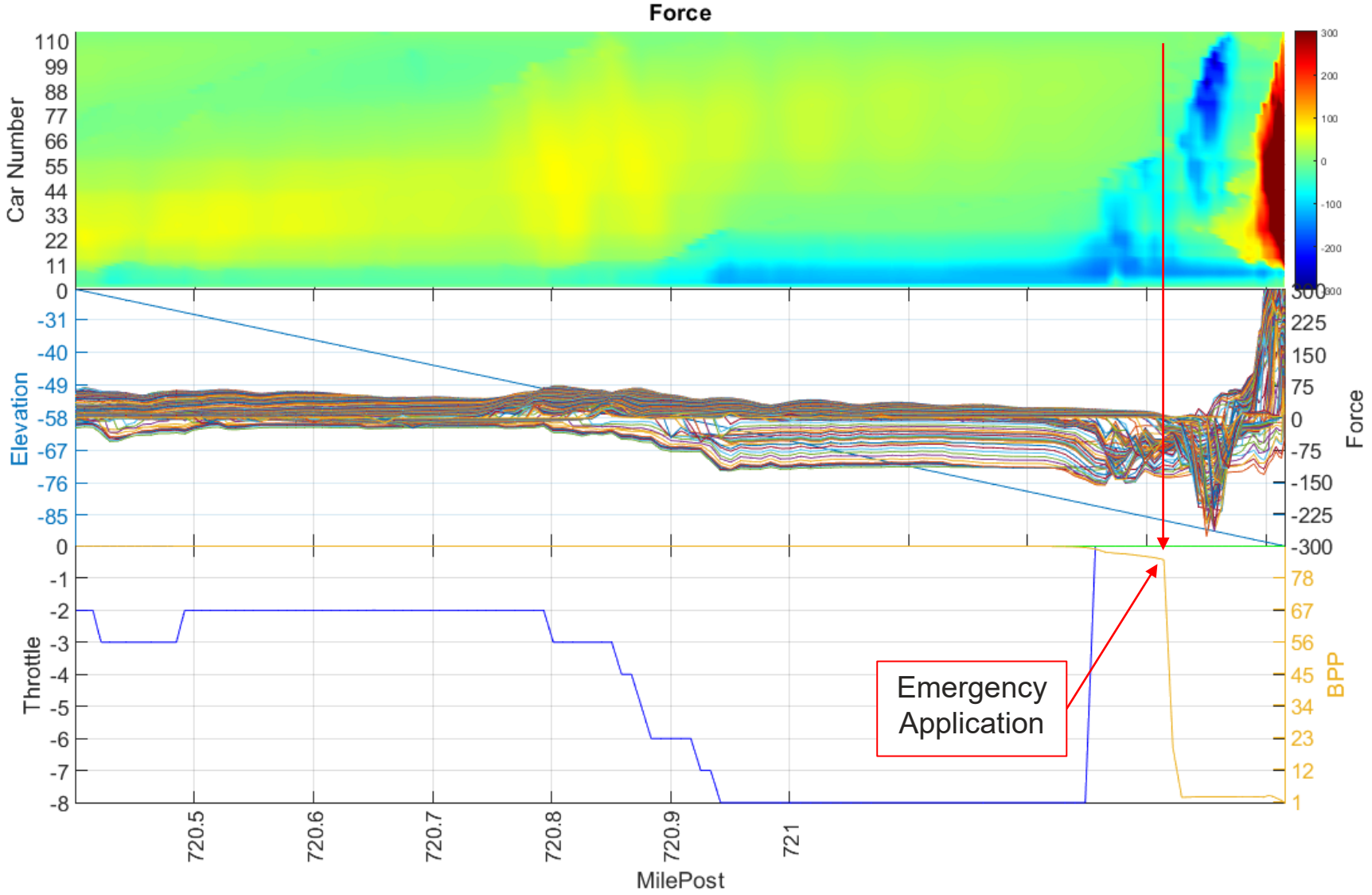

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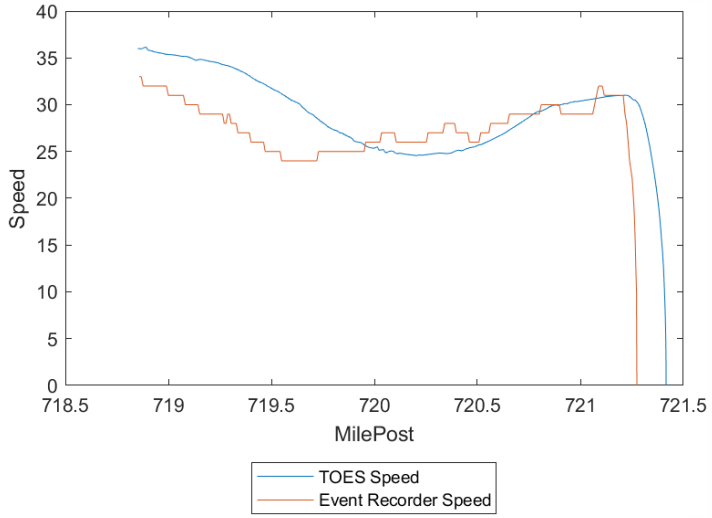
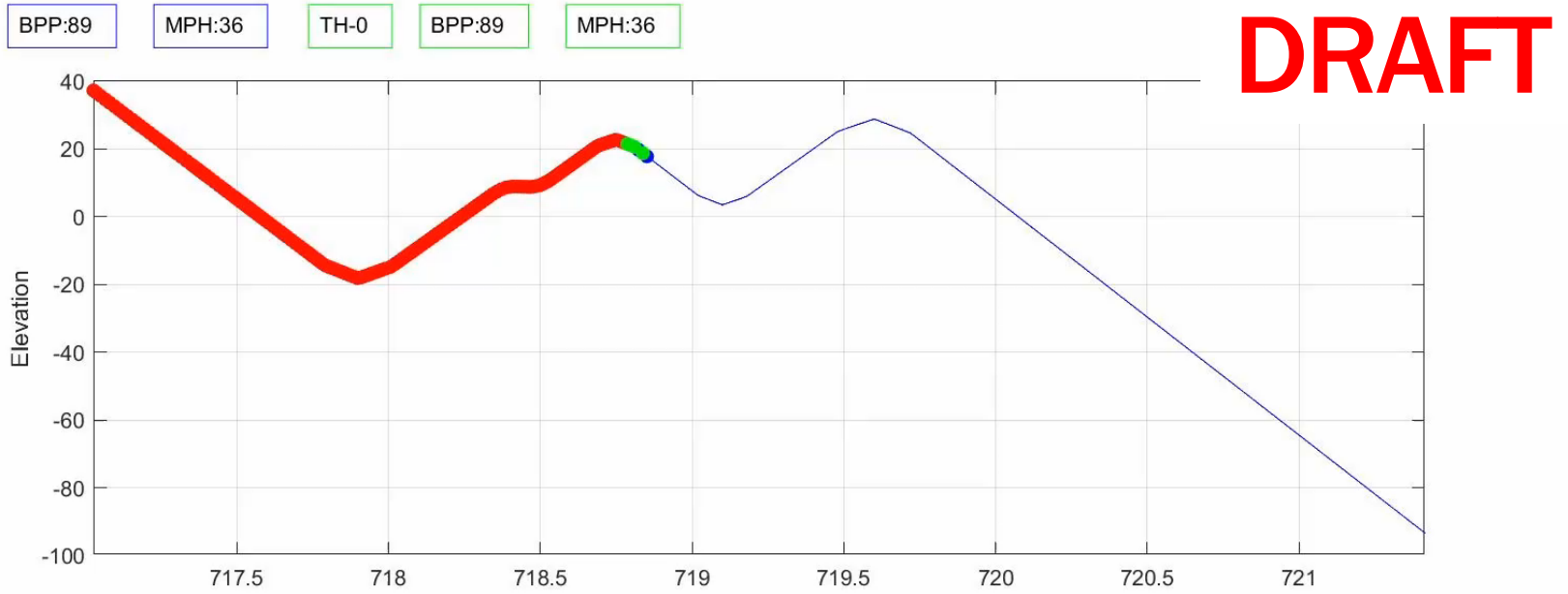
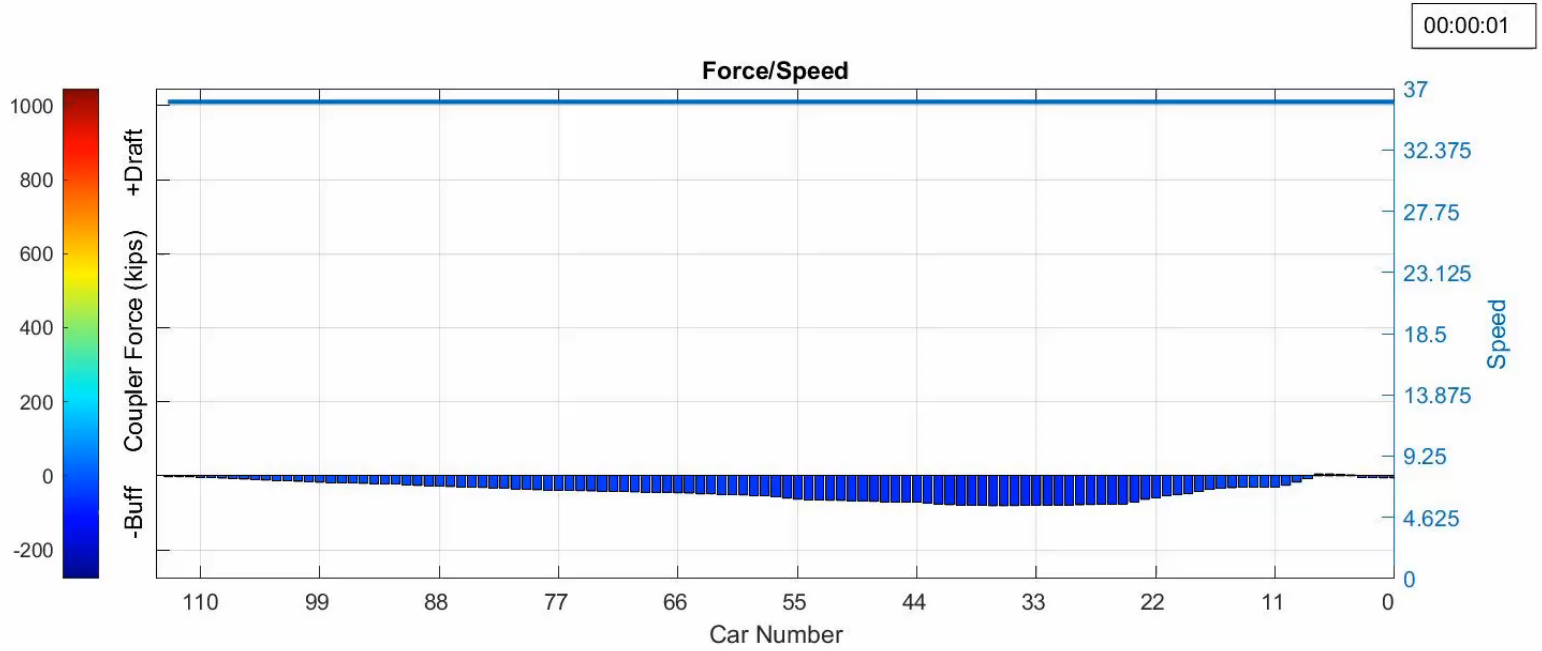
Scenario 3: POD Reblocked Consist

(TOES Animation)







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03 Wheel/Rail Interaction

UP 5574 & UP 9039 Wheels

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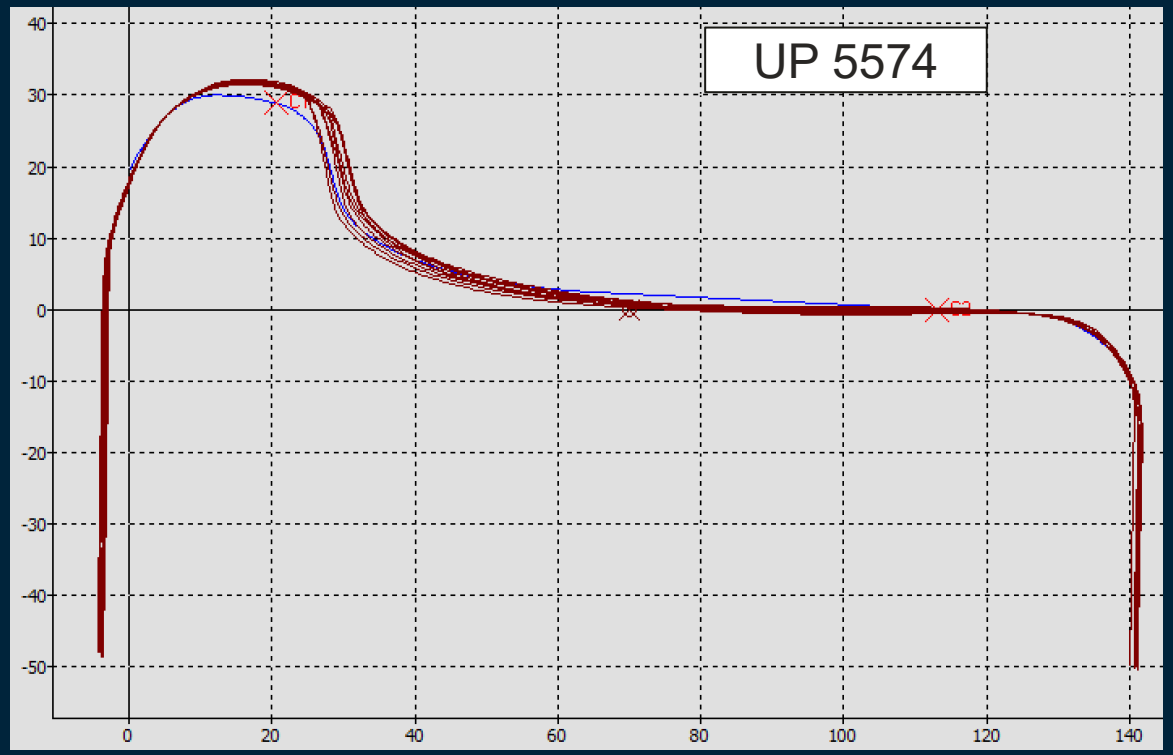

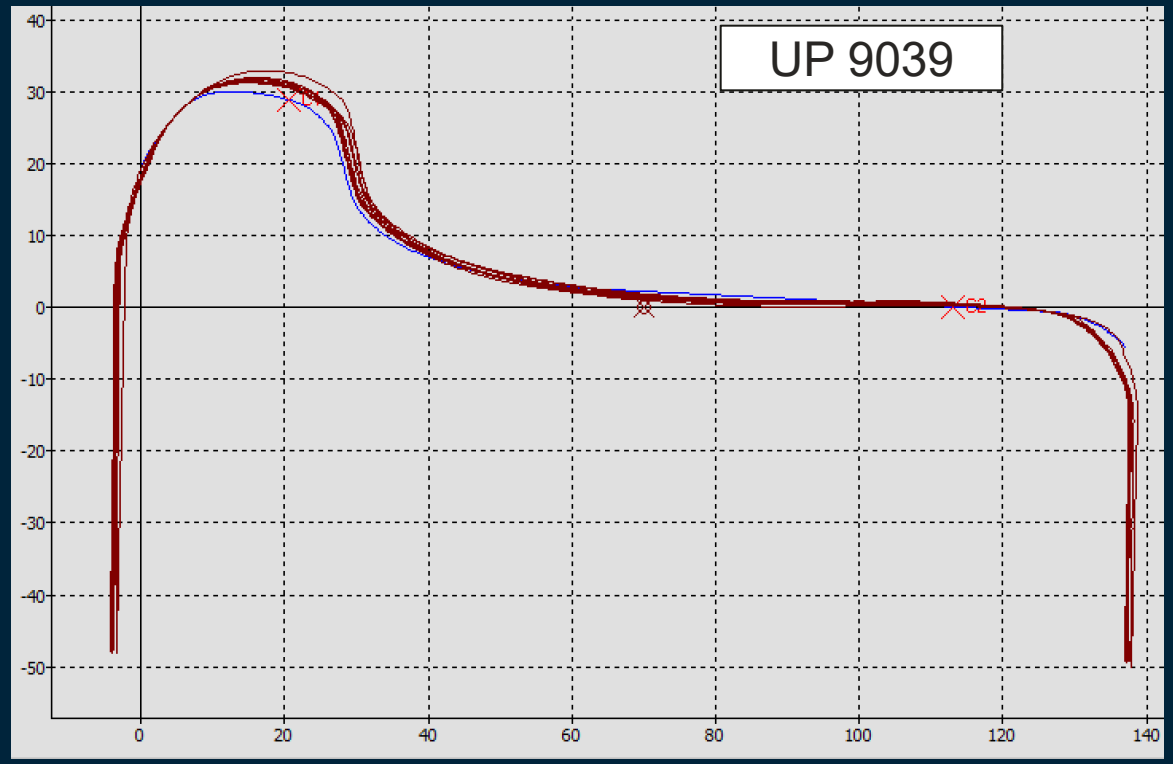

New AAR2A Profile shown in BLUE for reference.

NS 4408 & NS 9485 Wheels

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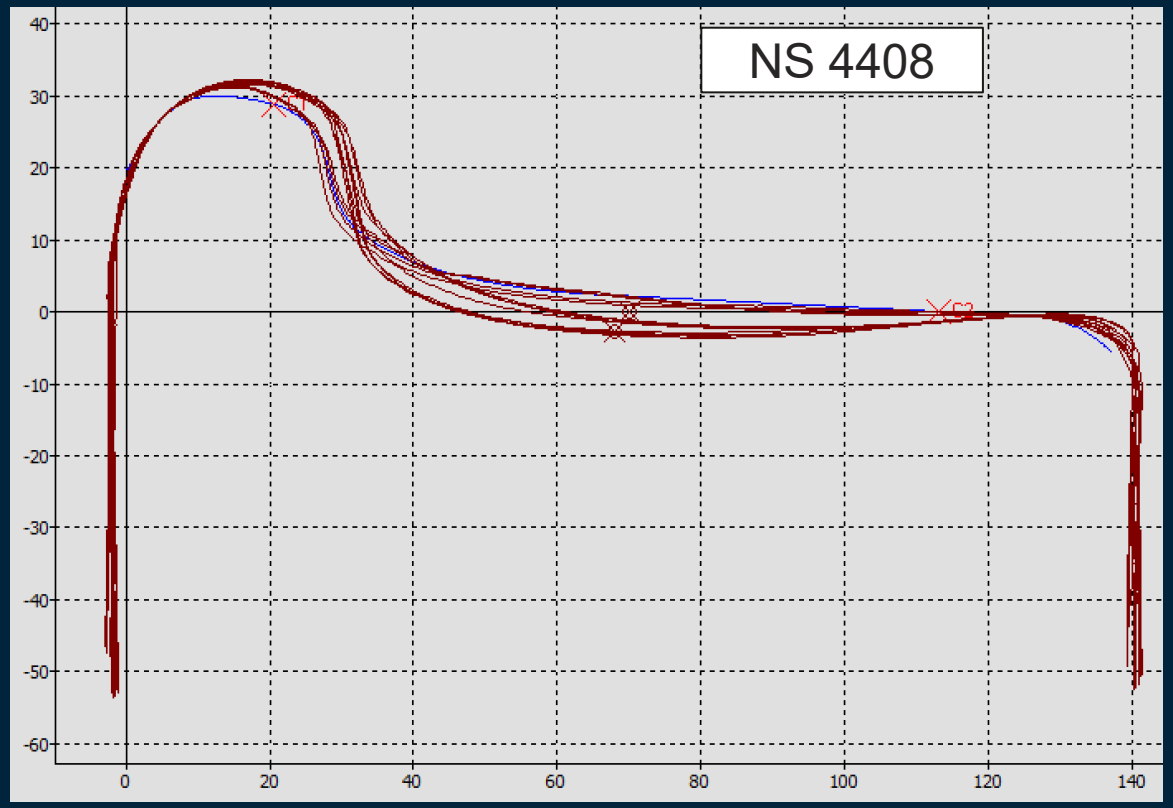

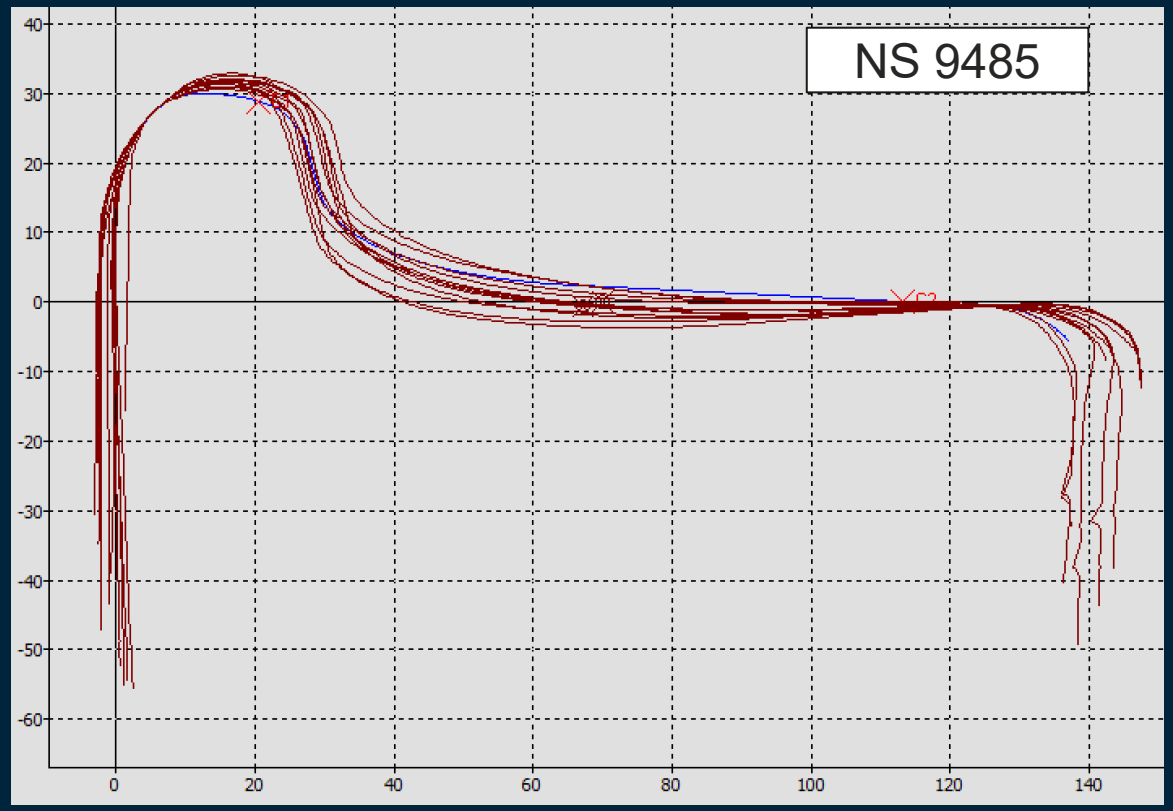

New AAR2A Profile shown in BLUE for reference.

RMEX 06 & RMEX 08 Wheels

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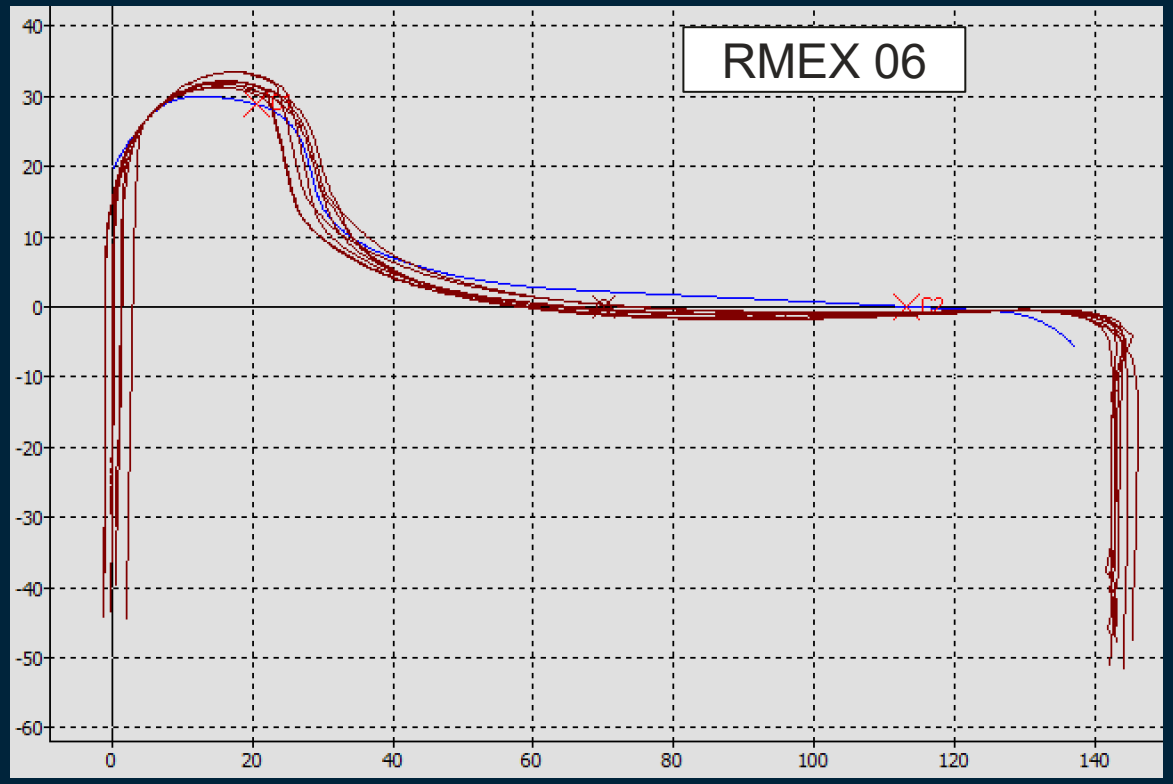

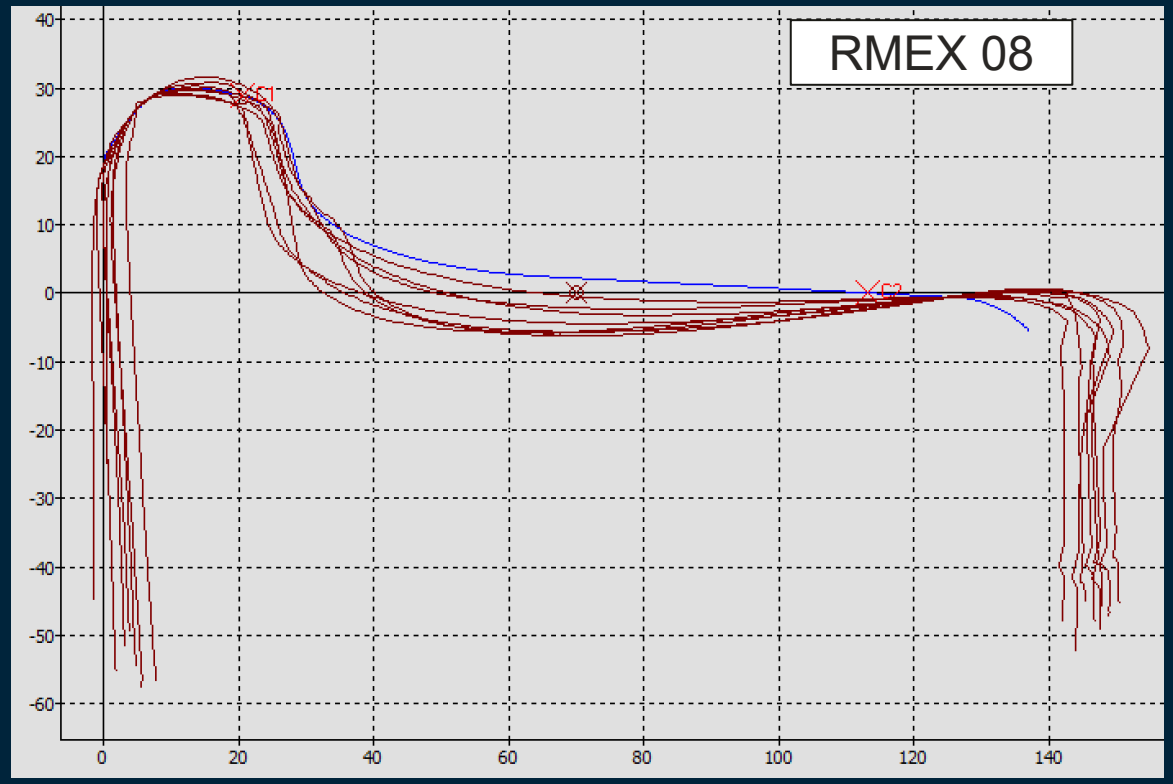

New AAR2A Profile shown in BLUE for reference.

New Rail vs Rail at POD

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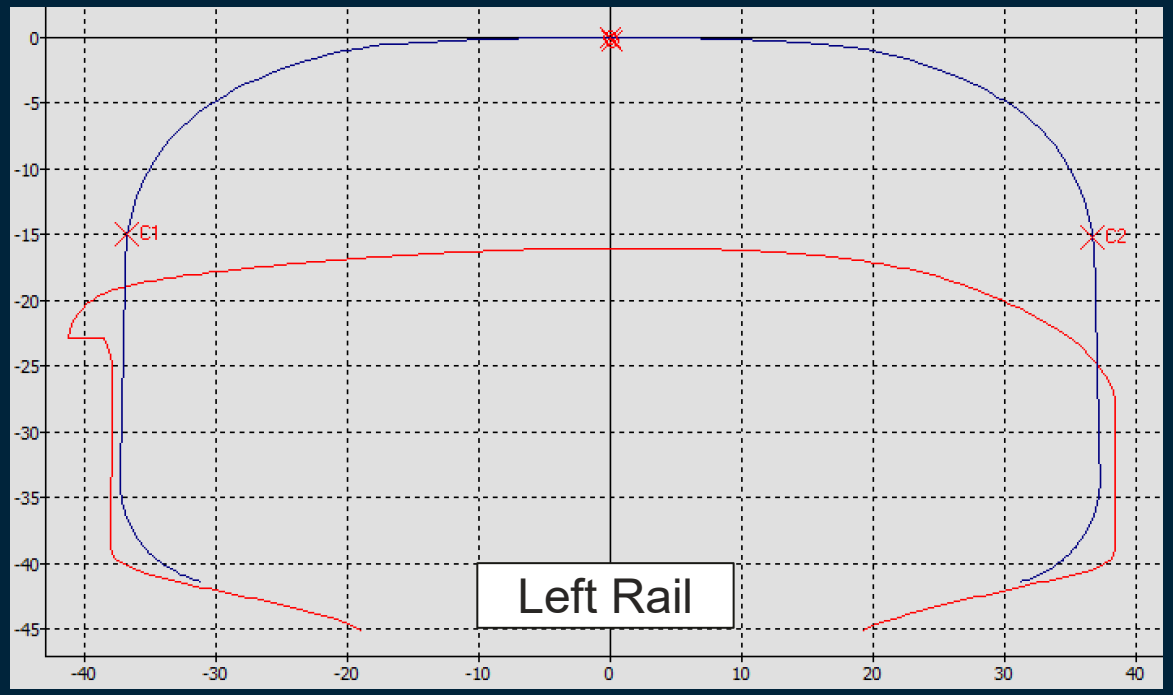

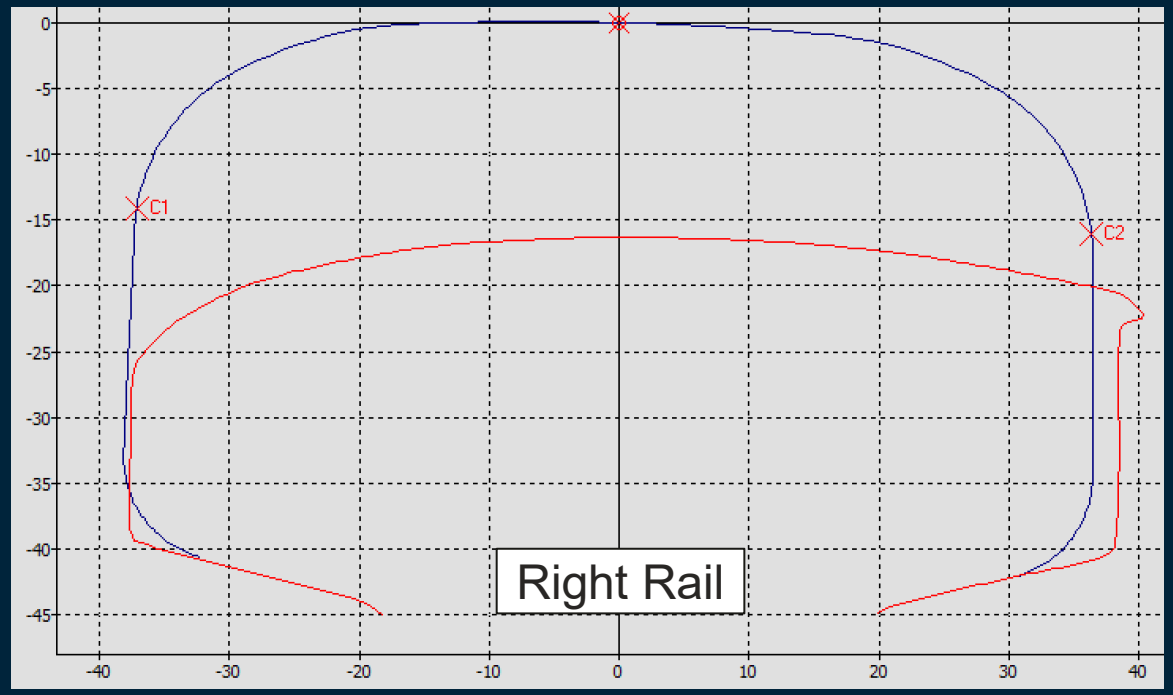

New 136 Rail Profile shown in BLUE for reference.

NS Standard for Top Rail = 10/16 inch = 15.8 mm

RMEX 6 – Wheel/Rail Interaction

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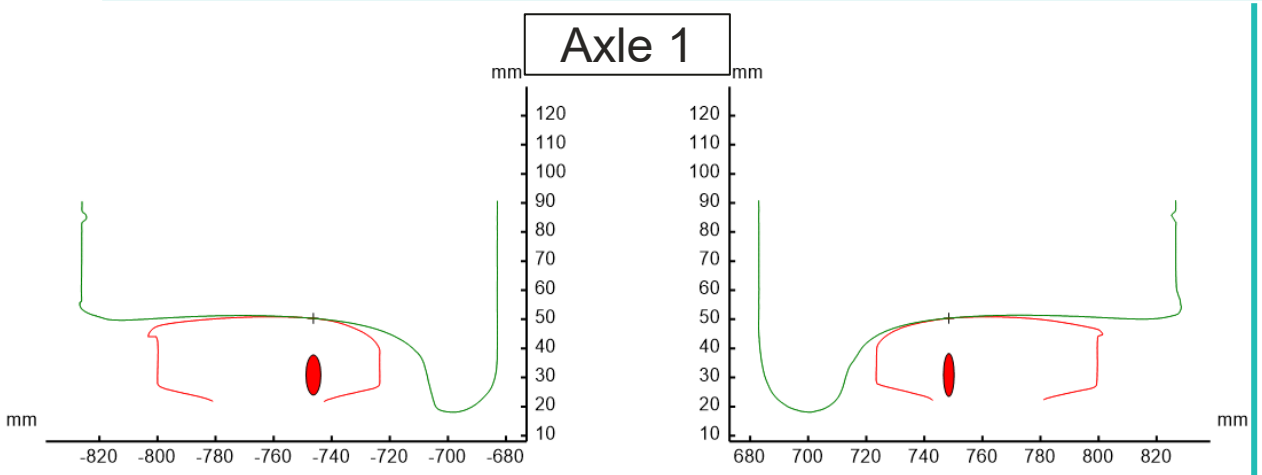
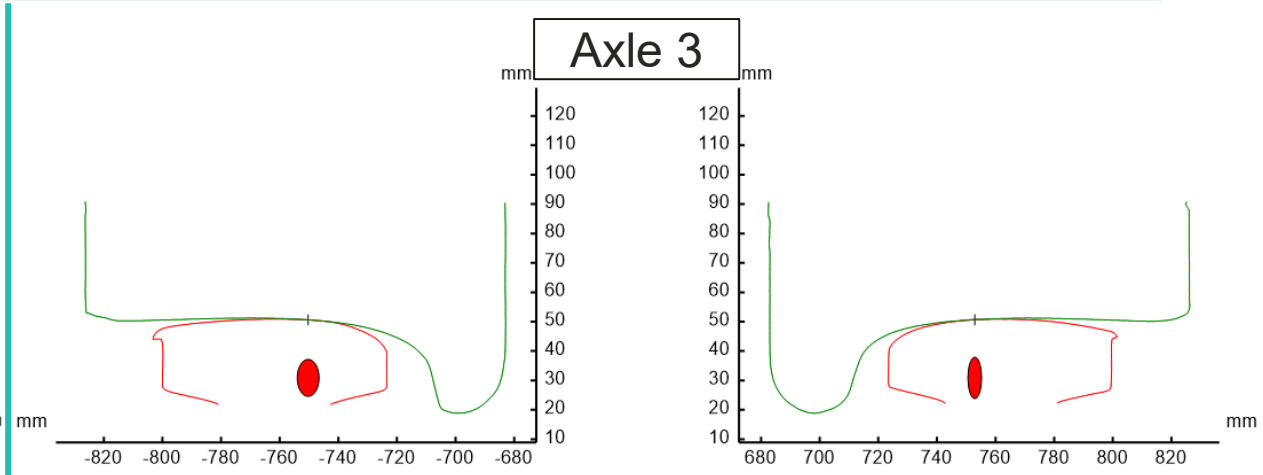
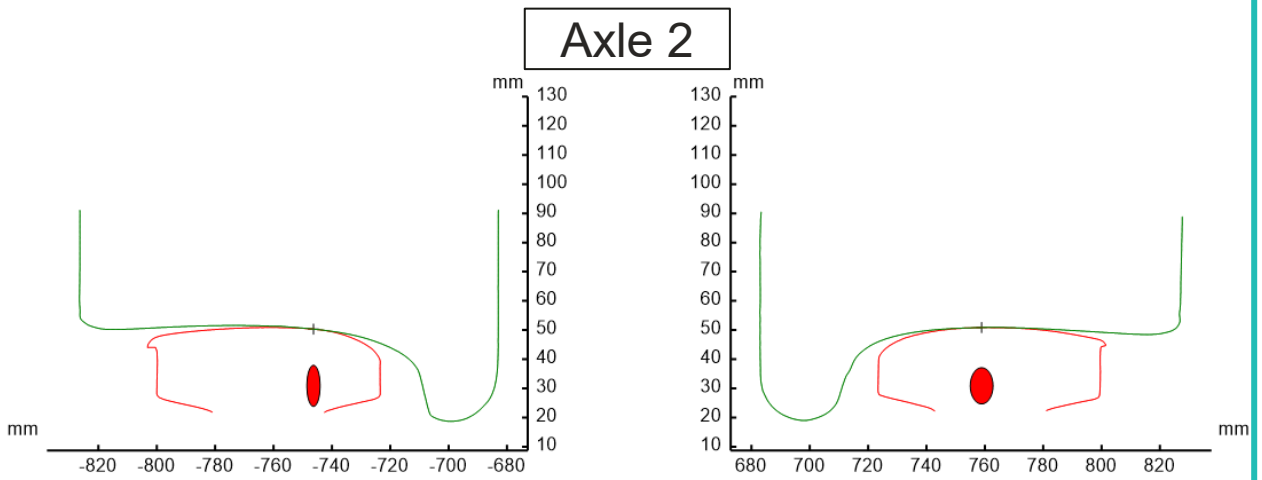
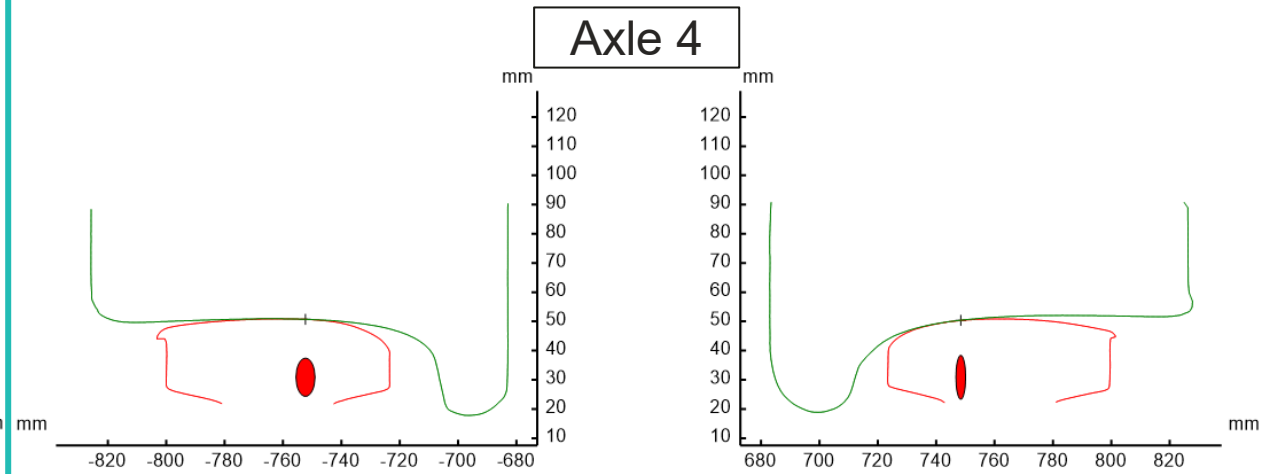
Plot Guide









RMEX 8 – Wheel/Rail Interaction

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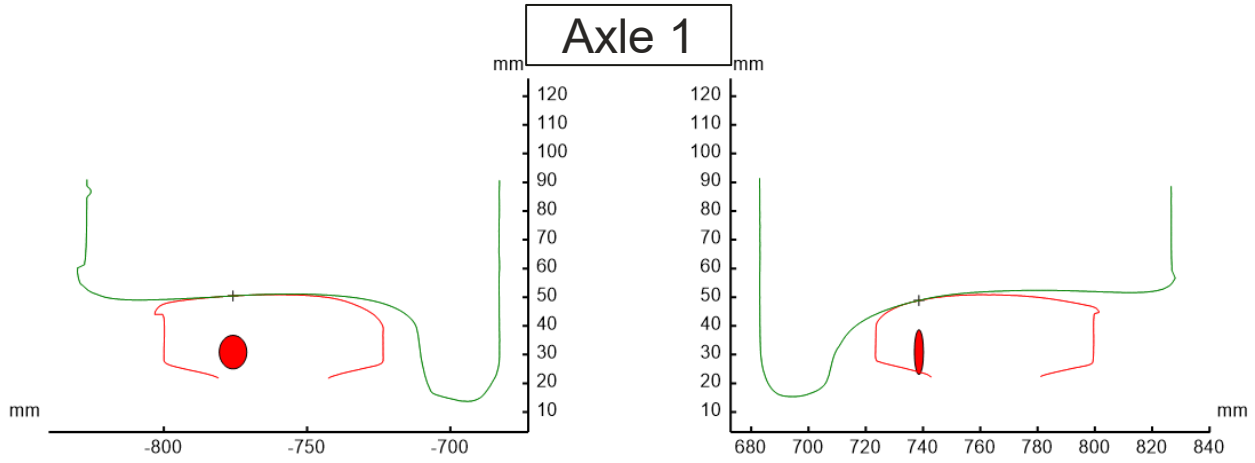
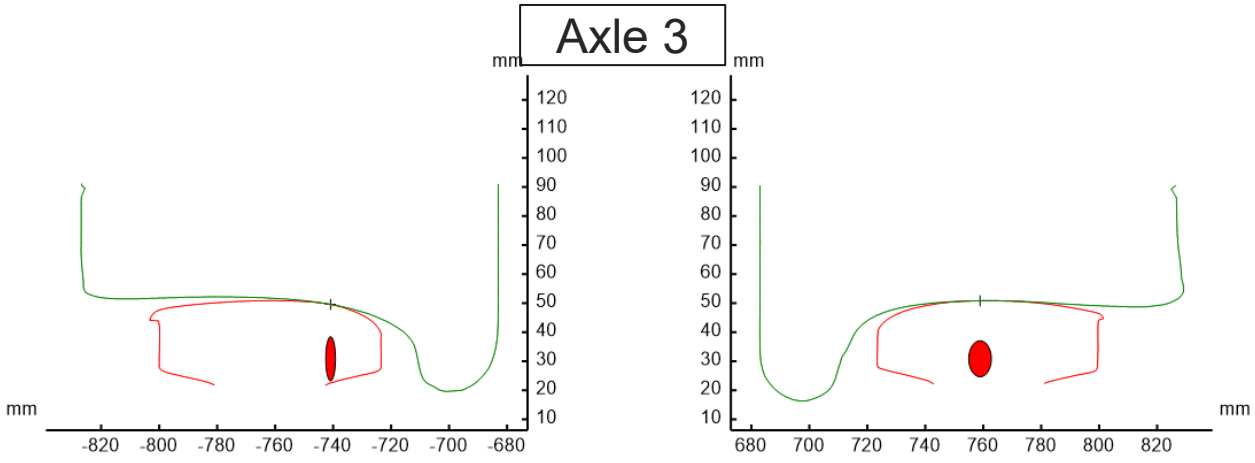
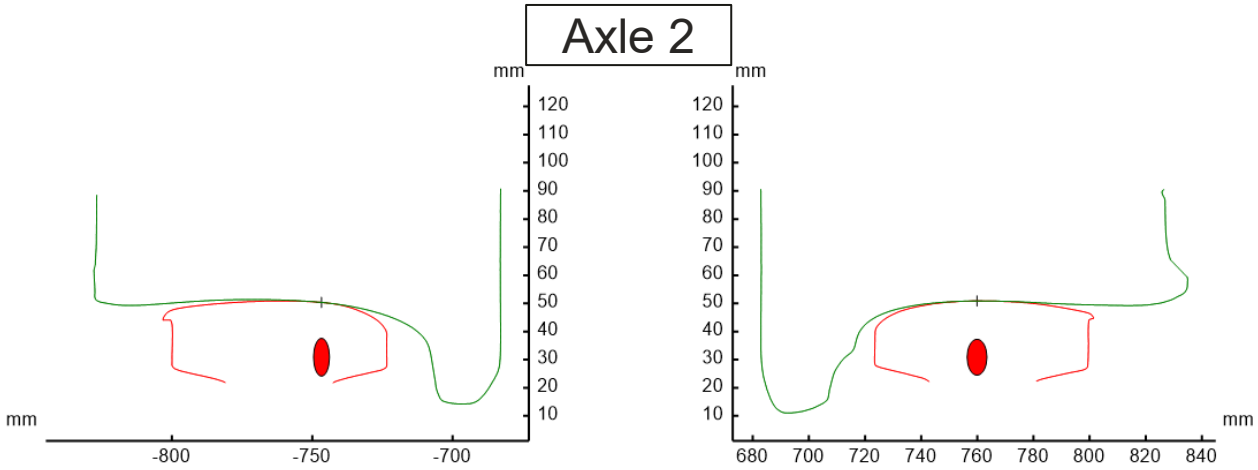
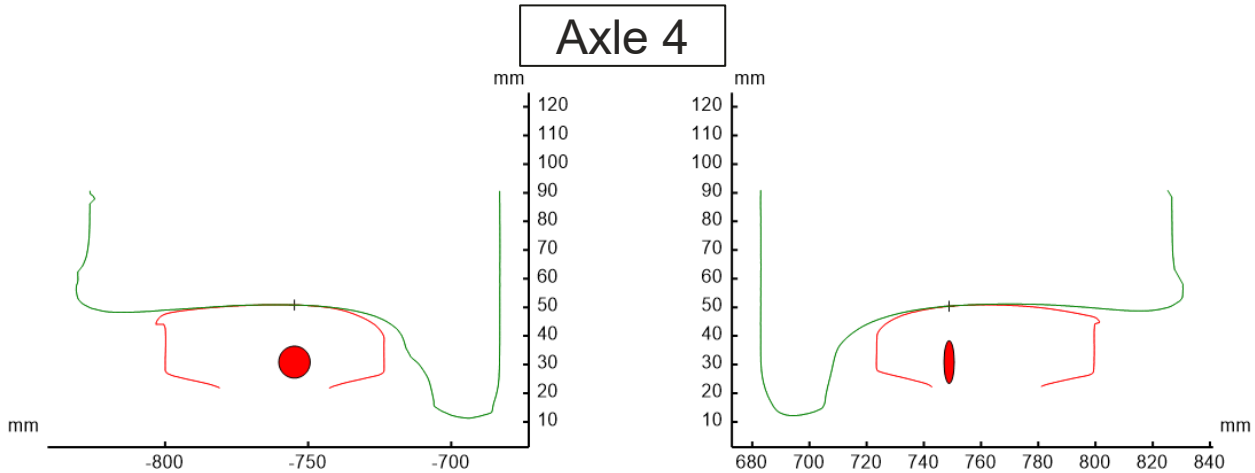
Plot Guide



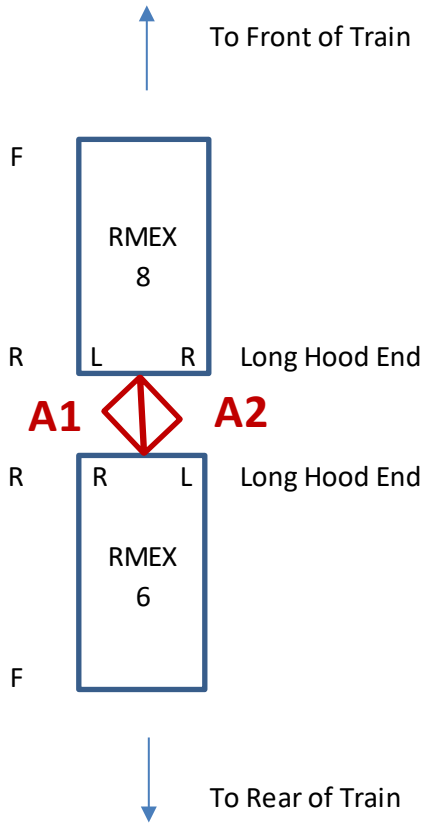






04 Coupler Angle Calculations

Coupler Angle Calculations

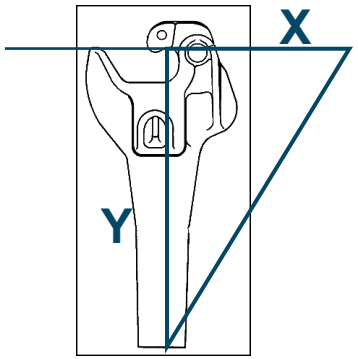


RMEX 08

As Measured – Rear Couplers					Minimum Travel - Front Coupler					Nominal Conditions				
Measurements		Angles			Measurements		Angles			Measurements		Angles		
Left Travel	7.75	Left	0.26	14.96	Left Travel	5.875	Left	0.20	11.45	Left Travel	4	Left	0.14	7.85
Right Travel	7.25	Right	0.24	14.04	Right Travel	8	Right	0.27	15.42	Right Travel	4	Right	0.14	7.85
Total	15		Rad	Deg	Total	13.875		Rad	Deg	Total	8		Rad	Deg
Cplr Length	29				Cplr Length	29				Cplr Length	29			

RMEX 06

As Measured – Rear Couplers					Minimum Travel - Front Coupler					Nominal Conditions				
Measurements		Angles			Measurements		Angles			Measurements		Angles		
Left Travel	7.75	Left	0.26	14.96	Left Travel	7.75	Left	0.26	14.96	Left Travel	4	Left	0.14	7.85
Right Travel	7.5	Right	0.25	14.50	Right Travel	8	Right	0.27	15.42	Right Travel	4	Right	0.14	7.85
Total	15.25		Rad	Deg	Total	15.75		Rad	Deg	Total	8		Rad	Deg
Cplr Length	29				Cplr Length	29				Cplr Length	29			



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TBOGI Overview

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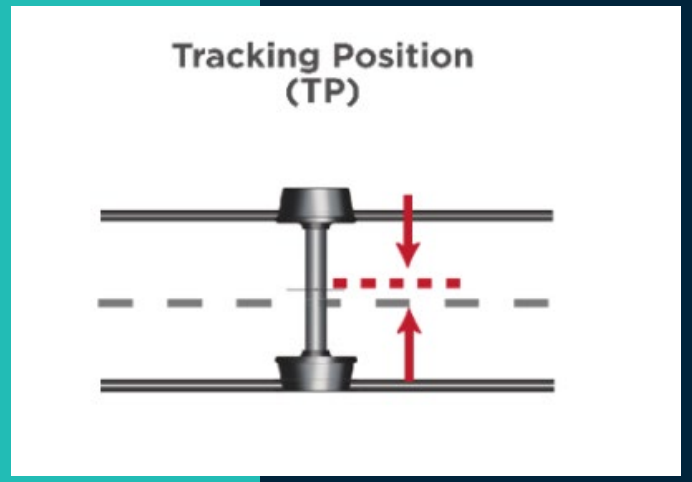
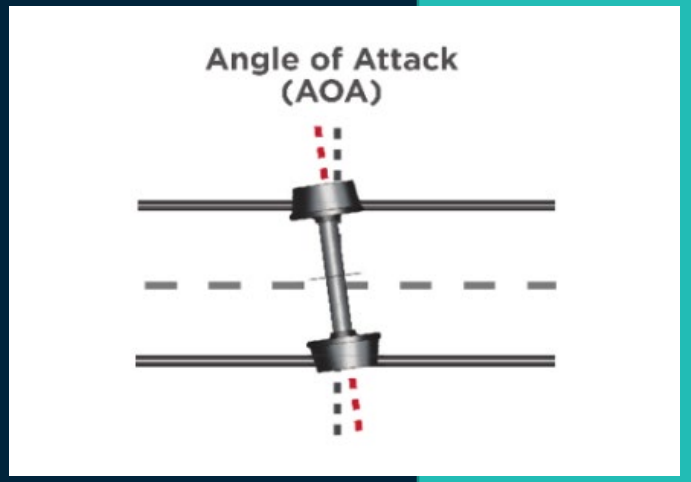
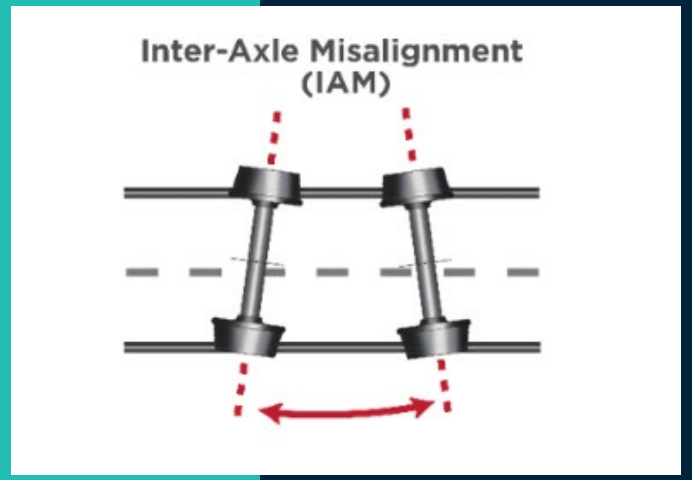
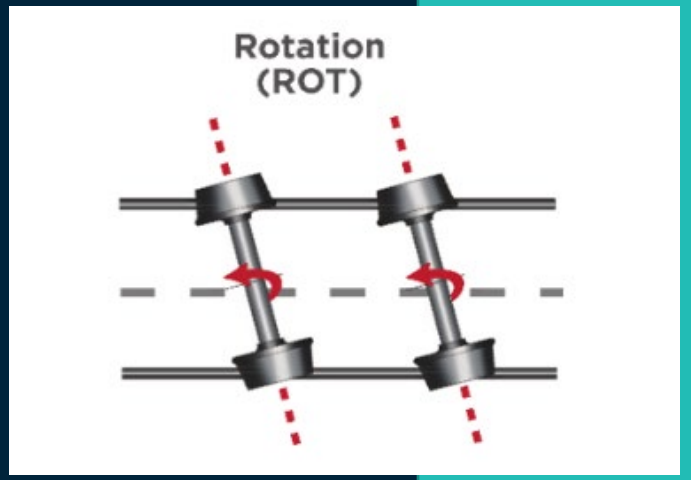
Appendix

TBOGI Definitions









- Tracking Position: Lateral shift distance between the track centerline and the midpoint of the axle.
- Angle of Attack: Angle between the truck radial line and the centerline of the wheel set axle
- Inter-Axle Misalignment: The angle misalignment between two wheel sets of a bogie. Calculated by the difference between the AOA of the leading wheelset minus the AOA of the trailing wheelset.
- Rotation: Angle of the bogie. Defined as the average of the AOA's of the leading and trailing axles.

NORFOLK SOUTHERN

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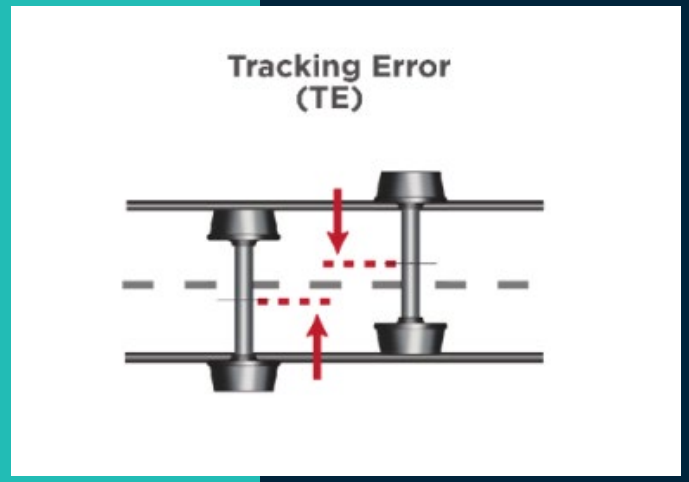
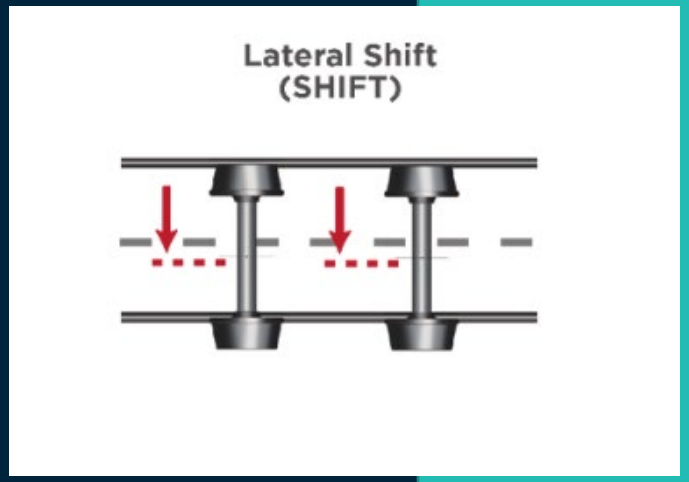
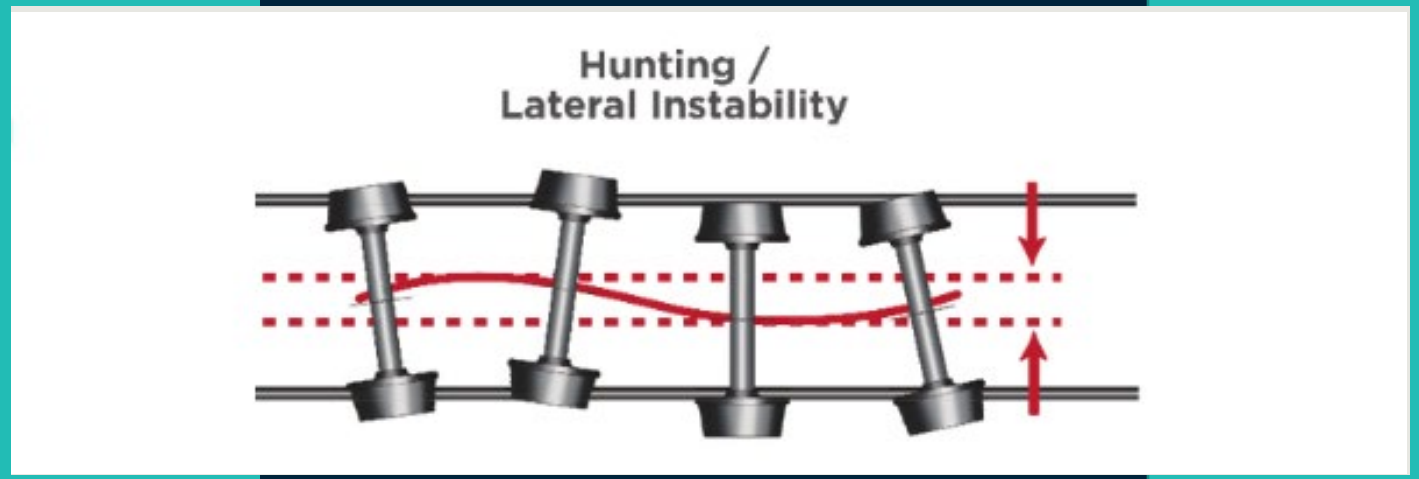
Appendix

TBOGI Definitions







- Tracking Error: The difference in lateral distance between the midpoints of the two axles of a bogie.
- Lateral Shift: Lateral shift of the bogie. Defined as the average of the TP's of the leading and trailing axles.
- Hunting Peak-to-Peak: Peak to peak distance in the amplitude of the hunting motion or the maximum distance travelled by the bogie laterally. Calculated using TP measurements of multiple TBOGI sensors.

NORFOLK SOUTHERN

UP 5574

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Appendix

EXCEPTIONS	
LOCO-AOA	0
LOCO-TP	0
AOA	13
TP	4
IAM	7
ROT	0
TE	3
SHIFT	7
HUNTP	0

SPEEDS	
ENTRY (km/h)	60.8
EXIT (km/h)	62.4
AVERAGE (km/h)	61.9

Lead End F

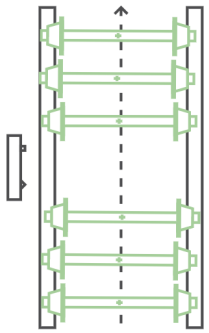

TABLE VIEW

VIEW UP 5574 HISTORY

	AOA (mrad)	TP (mm)	SPEED (km/h)
Axle 7 (Position 1)	-0.3	6.9	60.8
Axle 8 (Position 2)	-0.3	9.6	60.8
Axle 9 (Position 3)	-0.1	4.5	60.8
Axle 10 (Position 4)	-0.4	-2.5	60.8
Axle 11 (Position 5)	-0.5	4.6	60.8
Axle 12 (Position 6)	-0.2	3.9	60.8

Site	Track	Direction	Train Time	Vehicle	Number	Position	Lead End	Bogie	Speed (km/h)	AOA (mrad)	TP (mm)
Flat Rock	1	South	2023-03-07 09:57:00	UP 5574	7	1	F	-	60.8	-0.3	6.9
Flat Rock	1	South	2023-03-07 09:57:00	UP 5574	8	2	F	-	60.8	-0.3	9.6
Flat Rock	1	South	2023-03-07 09:57:00	UP 5574	9	3	F	-	60.8	-0.1	4.5
Flat Rock	1	South	2023-03-07 09:57:00	UP 5574	10	4	F	-	60.8	-0.4	-2.5
Flat Rock	1	South	2023-03-07 09:57:00	UP 5574	11	5	F	-	60.8	-0.5	4.6
Flat Rock	1	South	2023-03-07 09:57:00	UP 5574	12	6	F	-	60.8	-0.2	3.9
Flat Rock	1	South	2023-02-28 10:56:00	UP 5574	7	1	F	-	66.3	-0.2	8.0
Flat Rock	1	South	2023-02-28 10:56:00	UP 5574	8	2	F	-	66.3	0.1	9.2
Flat Rock	1	South	2023-02-28 10:56:00	UP 5574	9	3	F	-	66.3	-0.2	2.3
Flat Rock	1	South	2023-02-28 10:56:00	UP 5574	10	4	F	-	66.3	-0.4	-3.5
Flat Rock	1	South	2023-02-28 10:56:00	UP 5574	11	5	F	-	66.2	-0.1	3.4
Flat Rock	1	South	2023-02-28 10:56:00	UP 5574	12	6	F	-	66.3	-0.1	0.7

UP 9039

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Appendix

EXCEPTIONS	
LOCO-AOA	0
LOCO-TP	0
AOA	13
TP	4
IAM	7
ROT	0
TE	3
SHIFT	7
HUNTP	0

SPEEDS	
ENTRY (km/h)	60.8
EXIT (km/h)	62.4
AVERAGE (km/h)	61.9

Lead End F

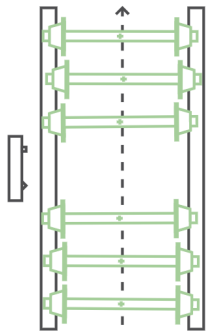

TABLE VIEW

VIEW UP 9039 HISTORY

	AOA (mrad)	TP (mm)	SPEED (km/h)
Axle 13 (Position 1)	-0.1	5.4	60.8
Axle 14 (Position 2)	-0.1	-2.8	60.8
Axle 15 (Position 3)	0.5	6.0	60.8
Axle 16 (Position 4)	0.2	6.8	60.8
Axle 17 (Position 5)	-0.2	2.6	60.7
Axle 18 (Position 6)	-0.4	2.8	60.6

Site	Track	Direction	Train Time	Vehicle	Number	Position	Lead End	Bogie	Speed (km/h)	AOA (mrad)	TP (mm)
Flat Rock	1	South	2023-03-07 09:57:00	UP 9039	13	1	F	-	60.8	-0.1	5.4
Flat Rock	1	South	2023-03-07 09:57:00	UP 9039	14	2	F	-	60.8	-0.1	-2.8
Flat Rock	1	South	2023-03-07 09:57:00	UP 9039	15	3	F	-	60.8	0.5	6.0
Flat Rock	1	South	2023-03-07 09:57:00	UP 9039	16	4	F	-	60.8	0.2	6.8
Flat Rock	1	South	2023-03-07 09:57:00	UP 9039	17	5	F	-	60.7	-0.2	2.6
Flat Rock	1	South	2023-03-07 09:57:00	UP 9039	18	6	F	-	60.6	-0.4	2.8
Flat Rock	1	North	2023-03-04 07:08:00	UP 9039	13	6	R	-	61.5	0.5	0.3
Flat Rock	1	North	2023-03-04 07:08:00	UP 9039	14	5	R	-	61.4	0.1	2.6
Flat Rock	1	North	2023-03-04 07:08:00	UP 9039	15	4	R	-	61.4	-0.3	-2.2
Flat Rock	1	North	2023-03-04 07:08:00	UP 9039	16	3	R	-	61.5	0.3	0.2
Flat Rock	1	North	2023-03-04 07:08:00	UP 9039	17	2	R	-	61.5	0.3	-1.4
Flat Rock	1	North	2023-03-04 07:08:00	UP 9039	18	1	R	-	61.3	0.5	-1.3

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Appendix

NS 9485

EXCEPTIONS	
LOCO-AOA	0
LOCO-TP	4
AOA	4
TP	0
IAM	0
ROT	0
TE	0
SHIFT	4
HUNTP	0

SPEEDS	
ENTRY (km/h)	42.0
EXIT (km/h)	32.7
AVERAGE (km/h)	41.9

Lead End F

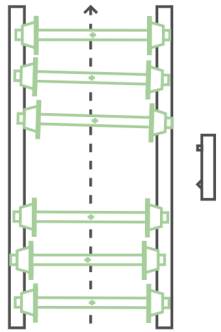

TABLE VIEW

VIEW NS 9485 HISTORY

	AOA (mrad)	TP (mm)	SPEED (km/h)
Axle 7 (Position 1)	0.1	5.1	42.1
Axle 8 (Position 2)	1.5	2.5	42.1
Axle 9 (Position 3)	1.6	10.1	42.0
Axle 10 (Position 4)	0.3	0.5	42.2
Axle 11 (Position 5)	0.0	-7.2	42.2
Axle 12 (Position 6)	0.2	3.4	42.2

Site	Track	Direction	Train Time	Vehicle	Number	Position	Lead End	Bogie	Speed (km/h)	AOA (mrad)	TP (mm)
Marion	1	East	2023-02-11 17:55:00	NS 9485	7	1	F	-	42.1	0.1	5.1
Marion	1	East	2023-02-11 17:55:00	NS 9485	8	2	F	-	42.1	1.5	2.5
Marion	1	East	2023-02-11 17:55:00	NS 9485	9	3	F	-	42.0	1.6	10.1
Marion	1	East	2023-02-11 17:55:00	NS 9485	10	4	F	-	42.2	0.3	0.5
Marion	1	East	2023-02-11 17:55:00	NS 9485	11	5	F	-	42.2	0.0	-7.2
Marion	1	East	2023-02-11 17:55:00	NS 9485	12	6	F	-	42.2	0.2	3.4
Marion	1	West	2023-02-11 02:37:00	NS 9485	7	6	R	-	61.2	-0.8	-3.5
Marion	1	West	2023-02-11 02:37:00	NS 9485	8	5	R	-	61.2	-0.5	-6.1
Marion	1	West	2023-02-11 02:37:00	NS 9485	9	4	R	-	61.3	-0.7	-9.7
Marion	1	West	2023-02-11 02:37:00	NS 9485	10	3	R	-	61.2	-0.3	1.6
Marion	1	West	2023-02-11 02:37:00	NS 9485	11	2	R	-	61.4	0.3	1.9
Marion	1	West	2023-02-11 02:37:00	NS 9485	12	1	R	-	61.2	0.3	-2.7

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Appendix

NS 4408

EXCEPTIONS		SPEEDS	
LOCO-AOA	0	ENTRY (km/h)	66.7
LOCO-TP	0		
AOA	2	EXIT (km/h)	54.4
TP	0		
IAM	0	AVERAGE (km/h)	59.0
ROT	0		
TE	0		
SHIFT	1		
HUNTP	0		

Lead End F

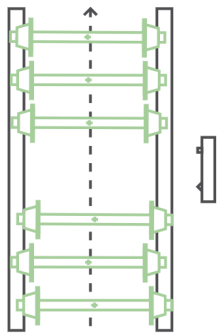

TABLE VIEW

VIEW NS 4408 HISTORY

	AOA (mrad)	TP (mm)	SPEED (km/h)
Axle 7 (Position 1)	0.3	-6.6	66.6
Axle 8 (Position 2)	0.1	-4.8	66.5
Axle 9 (Position 3)	0.2	-2.6	66.5
Axle 10 (Position 4)	0.3	10.4	66.4
Axle 11 (Position 5)	0.1	-4.9	66.2
Axle 12 (Position 6)	0.0	9.5	66.2

Site	Track	Direction	Train Time	Vehicle	Number	Position	Lead End	Bogie	Speed (km/h)	AOA (mrad)	TP (mm)
Marion	1	East	2023-01-23 11:58:00	NS 4408	505	1	F	-	50.0	-0.5	-4.3
Marion	1	East	2023-01-23 11:58:00	NS 4408	506	2	F	-	50.0	-0.3	-4.7
Marion	1	East	2023-01-23 11:58:00	NS 4408	507	3	F	-	50.0	-0.3	-4.1
Marion	1	East	2023-01-23 11:58:00	NS 4408	508	4	F	-	49.9	0.0	10.2
Marion	1	East	2023-01-23 11:58:00	NS 4408	509	5	F	-	50.0	1.2	4.2
Marion	1	East	2023-01-23 11:58:00	NS 4408	510	6	F	-	49.9	0.1	9.3
Marion	1	East	2022-11-14 00:28:00	NS 4408	1	1	F	-	71.4	-0.2	-3.0
Marion	1	East	2022-11-14 00:28:00	NS 4408	2	2	F	-	71.6	-0.9	-3.2
Marion	1	East	2022-11-14 00:28:00	NS 4408	3	3	F	-	71.6	-0.3	-3.4
Marion	1	East	2022-11-14 00:28:00	NS 4408	4	4	F	-	71.8	-0.5	9.7
Marion	1	East	2022-11-14 00:28:00	NS 4408	5	5	F	-	71.6	0.1	3.2
Marion	1	East	2022-11-14 00:28:00	NS 4408	6	6	F	-	71.4	0.6	9.4

RMEX 06

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Appendix

EXCEPTIONS	
LOCO-AOA	4
LOCO-TP	3
AOA	33
TP	3
IAM	13
ROT	2
TE	0
SHIFT	5
HUNTP	0

SPEEDS	
ENTRY (km/h)	52.7
EXIT (km/h)	60.1
AVERAGE (km/h)	54.7

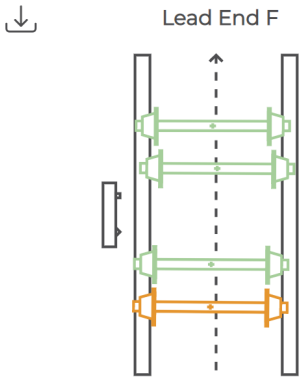

TABLE VIEW

VIEW RMEX 6 HISTORY

	AOA (mrad)	TP (mm)	SPEED (km/h)
Axle 7 (Position 1)	-0.1	7.9	52.8
Axle 8 (Position 2)	-0.3	-2.7	52.7
Axle 9 (Position 3)	-0.3	11.7	52.7
Axle 10 (Position 4)	-0.5	13.7	52.9

Site	Track	Direction	Train Time	Vehicle	Number	Position	Lead End	Bogie	Speed (km/h)	AOA (mrad)	TP (mm)
Flat Rock	1	South	2023-02-26 06:34:00	RMEX 6	7	1	F	-	52.8	-0.1	7.9
Flat Rock	1	South	2023-02-26 06:34:00	RMEX 6	8	2	F	-	52.7	-0.3	-2.7
Flat Rock	1	South	2023-02-26 06:34:00	RMEX 6	9	3	F	-	52.7	-0.3	11.7
Flat Rock	1	South	2023-02-26 06:34:00	RMEX 6	10	4	F	-	52.9	-0.5	13.7

RMEX 08

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Appendix

EXCEPTIONS	
LOCO-AOA	4
LOCO-TP	3
AOA	33
TP	3
IAM	13
ROT	2
TE	0
SHIFT	5
HUNTP	0

SPEEDS	
ENTRY (km/h)	52.7
EXIT (km/h)	60.1
AVERAGE (km/h)	54.7

Lead End R

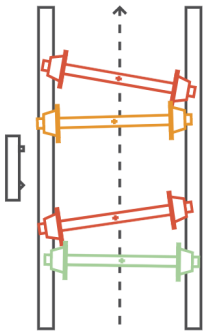

TABLE VIEW

VIEW RMEX 8 HISTORY

	AOA (mrad)	TP (mm)	SPEED (km/h)
Axle 11 (Position 4)	-9.5	2.5	52.8
Axle 12 (Position 3)	1.5	12.9	52.9
Axle 13 (Position 2)	7.9	10.2	53.1
Axle 14 (Position 1)	-0.8	-5.0	52.8

Site	Track	Direction	Train Time	Vehicle	Number	Position	Lead End	Bogie	Speed (km/h)	AOA (mrad)	TP (mm)
Flat Rock	1	South	2023-02-26 06:34:00	RMEX 8	11	4	R	-	52.8	-9.5	2.5
Flat Rock	1	South	2023-02-26 06:34:00	RMEX 8	12	3	R	-	52.9	1.5	12.9
Flat Rock	1	South	2023-02-26 06:34:00	RMEX 8	13	2	R	-	53.1	7.9	10.2
Flat Rock	1	South	2023-02-26 06:34:00	RMEX 8	14	1	R	-	52.8	-0.8	-5.0

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Additional Wheel/Rail Interaction Plots

NORFOLK SOUTHERN

Wheel/Rail Interaction Plot Guide

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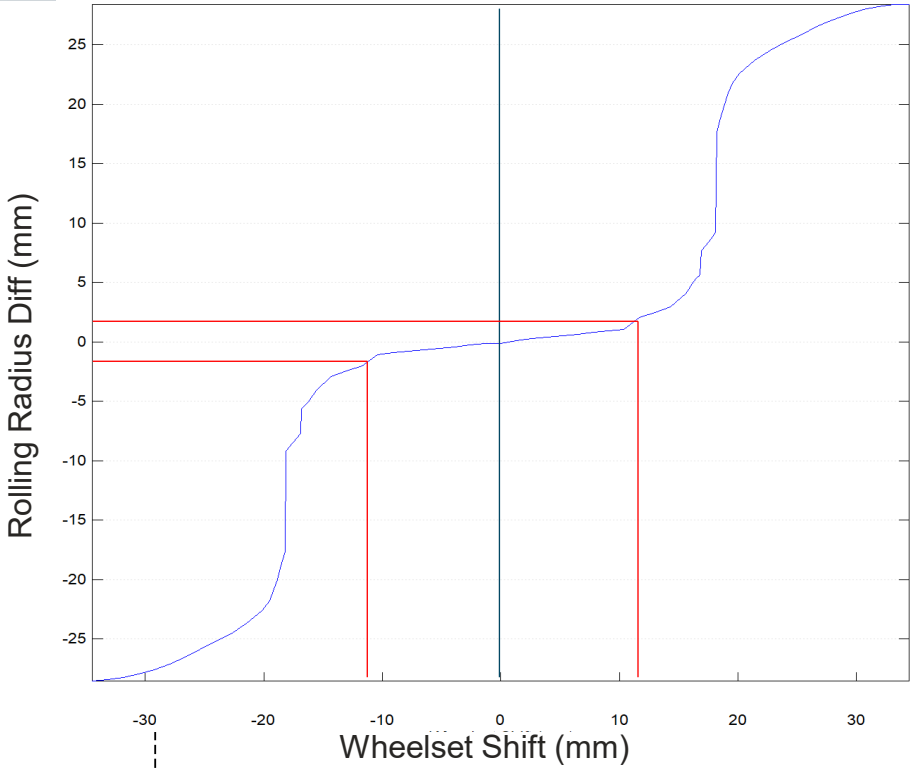
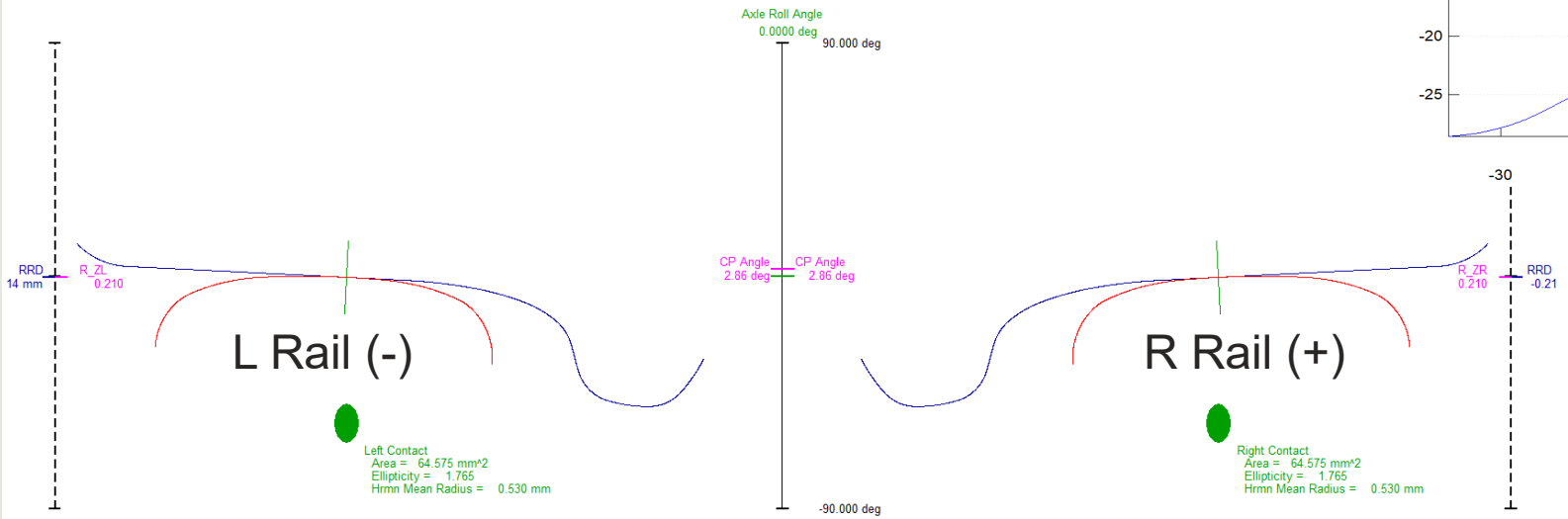
- Rolling Radius Differential =$\Delta r = \frac{G \times r}{R}$
  - Gage G = 57.0”
  - Curvature R = (1.33º to 4.0º) = 4784.3 to 1432.7 ft
  - Wheel Radius r = 43/2 = 21.5”
  - Δr = 0.54 mm (1.33º) to 1.81 mm (4.0º)





RMEX 6 – Wheel/Rail Interaction

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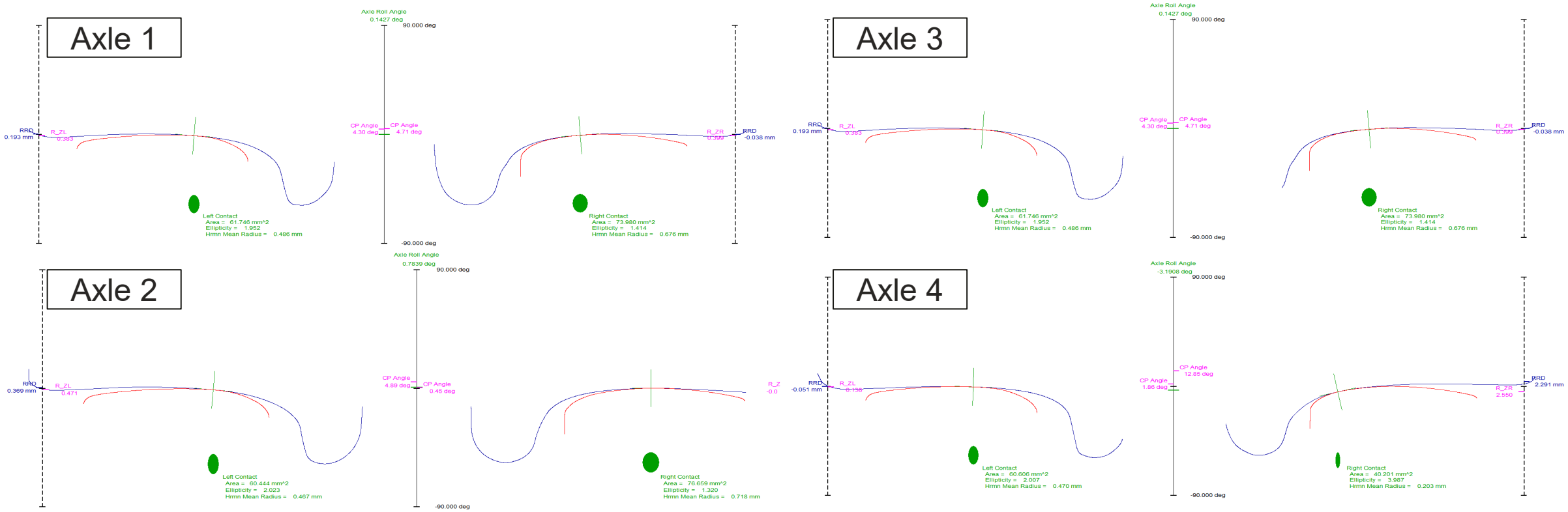
Plot Guide



RMEX 6 – Rolling Radius Differential

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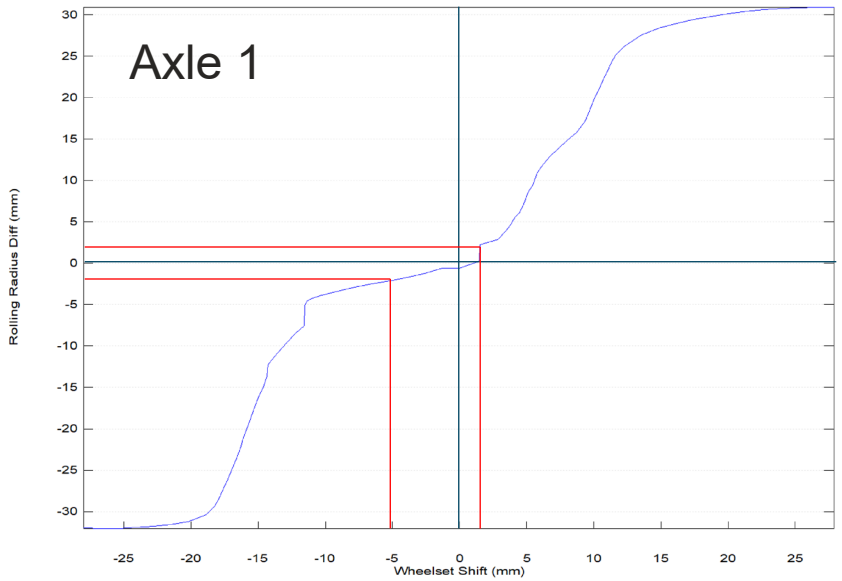

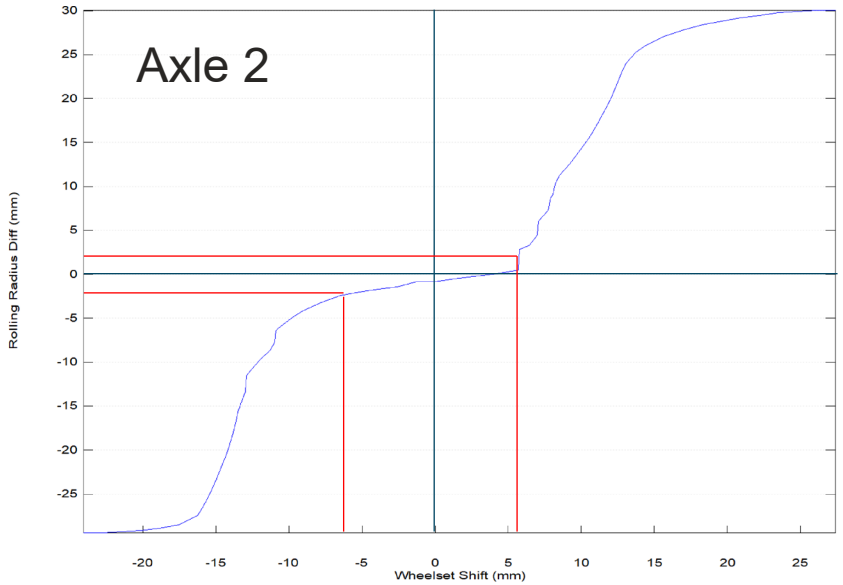

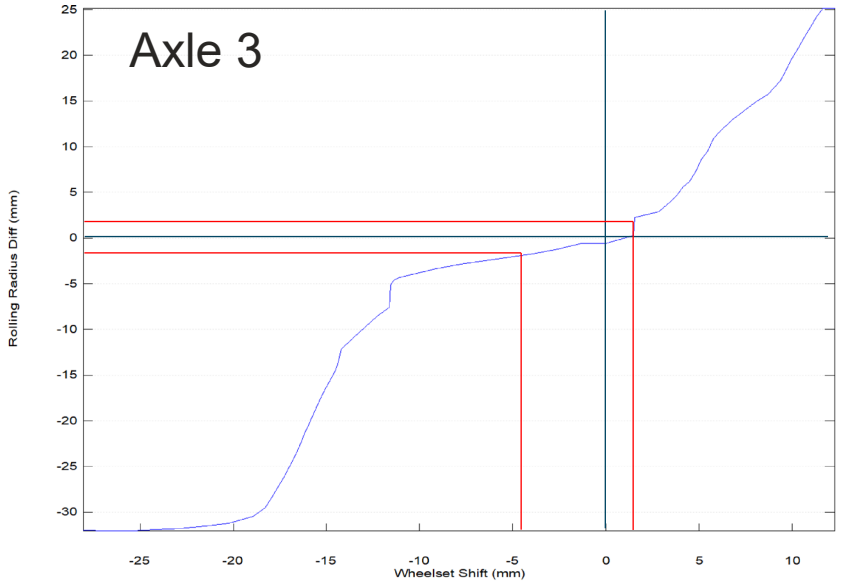

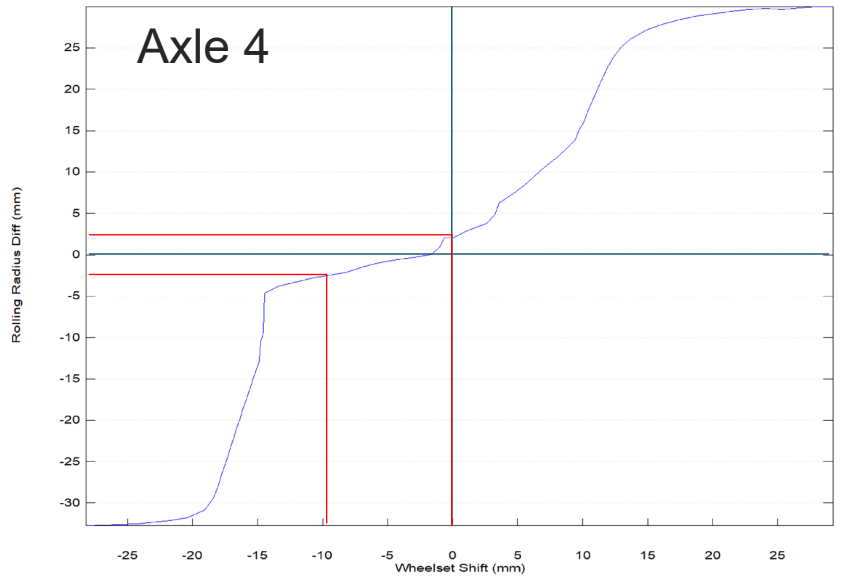

NORFOLK SOUTHERN

RMEX 8 – Wheel/Rail Interaction

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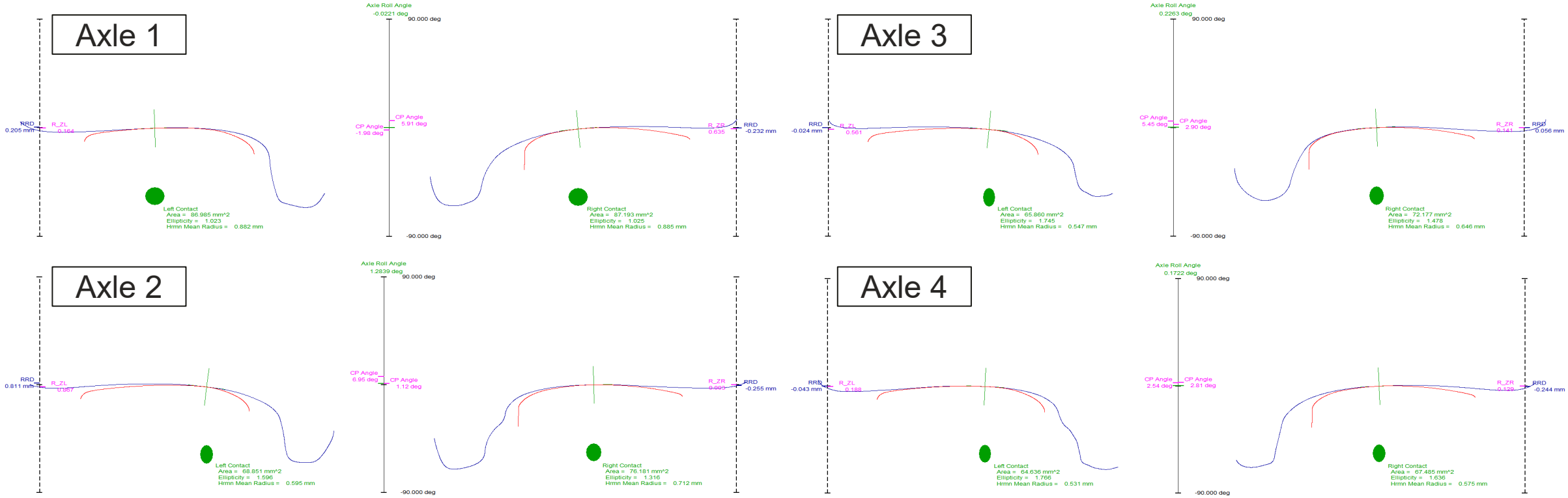
Plot Guide



RMEX 8 – Rolling Radius Differential

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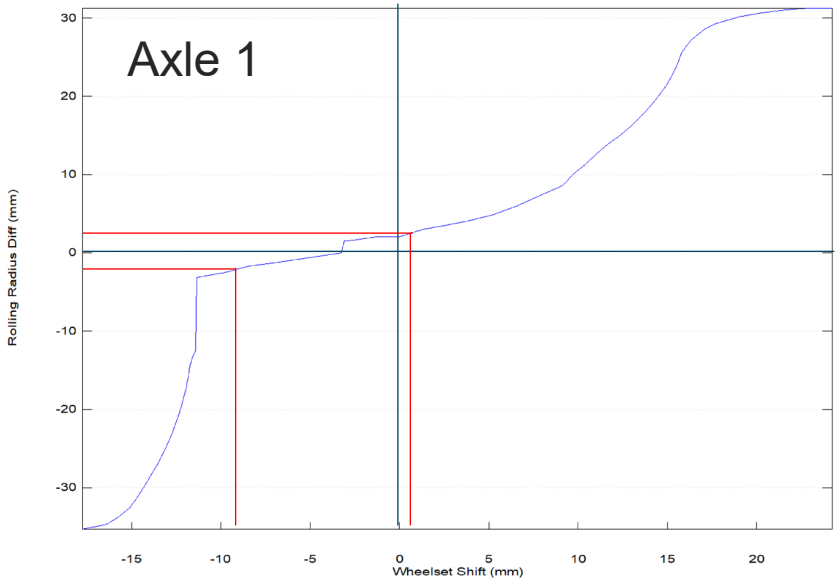
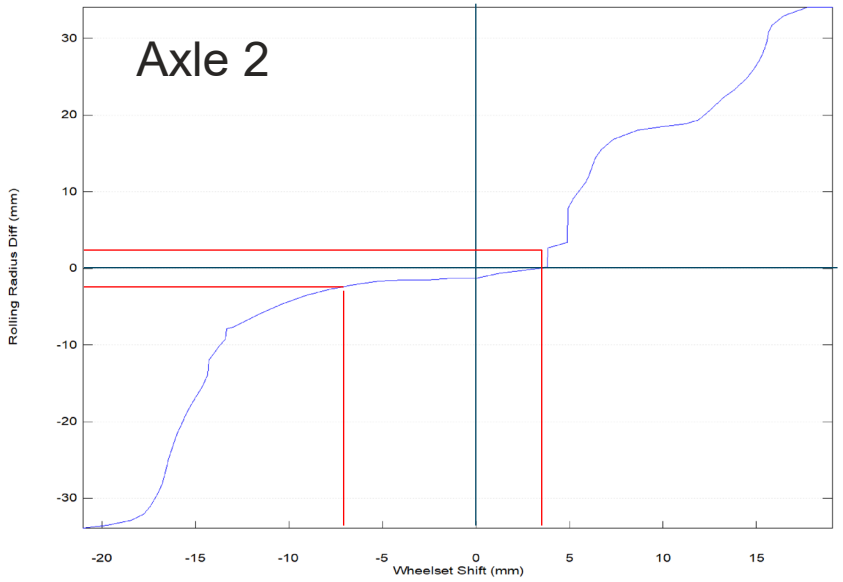
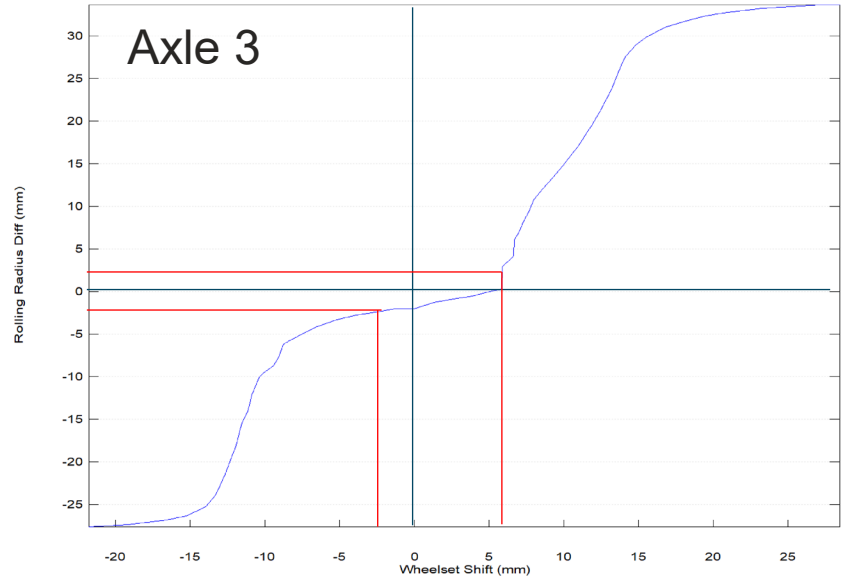
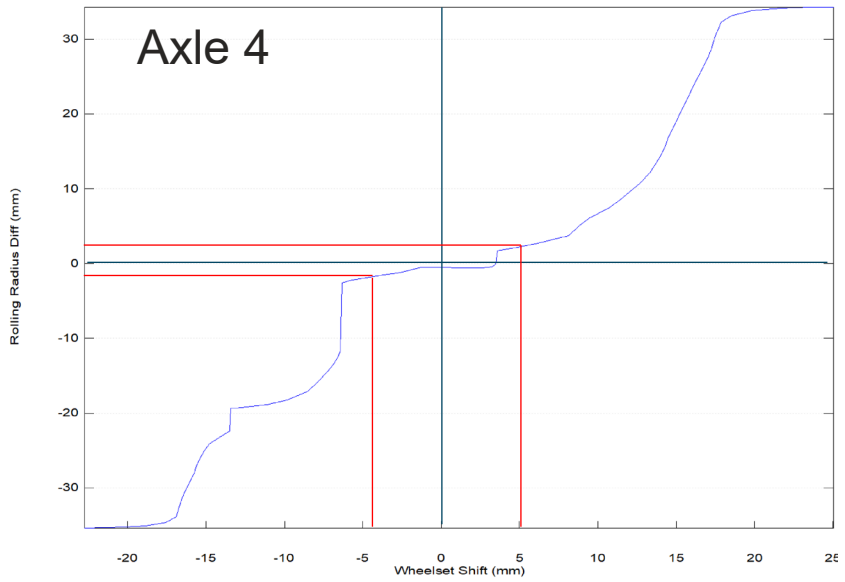
Plot Guide









NS 4408 – Wheel/Rail Interaction

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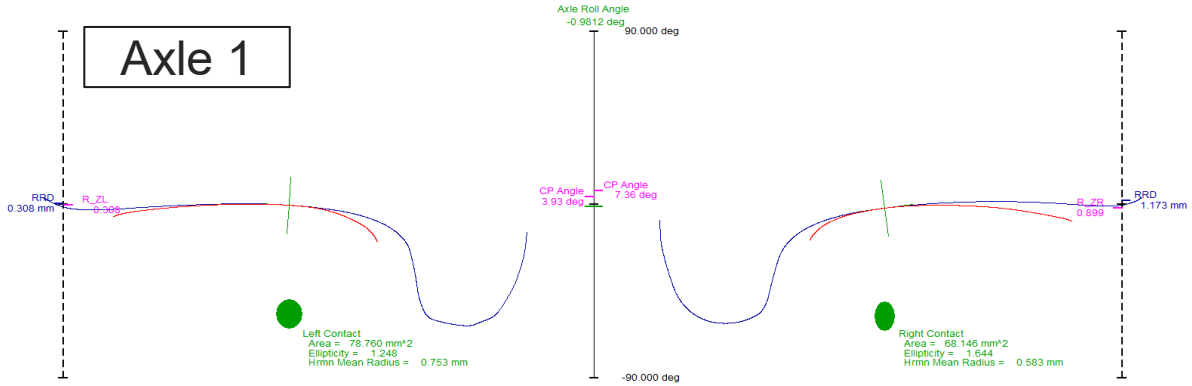
Appendix
Plot Guide

Axle 1



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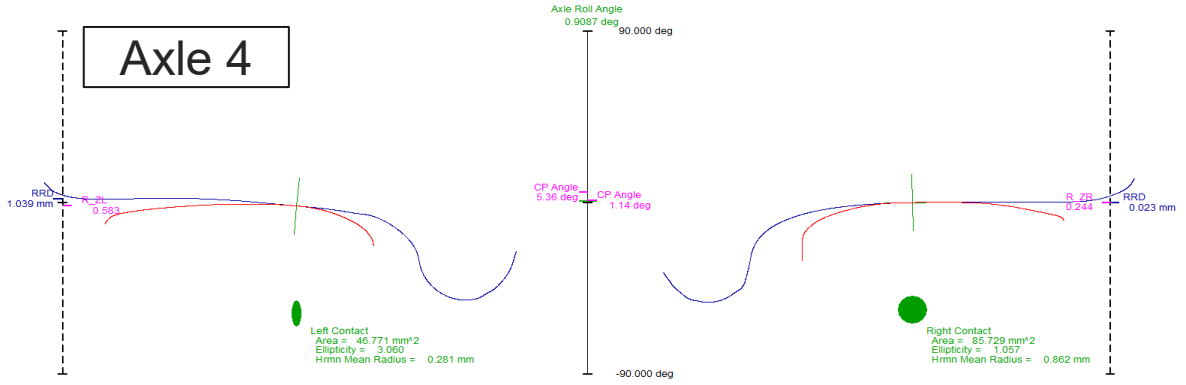
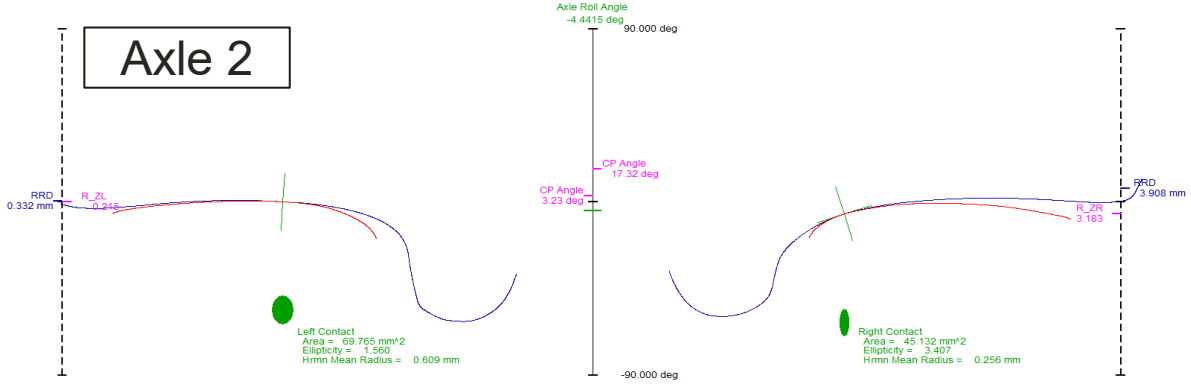
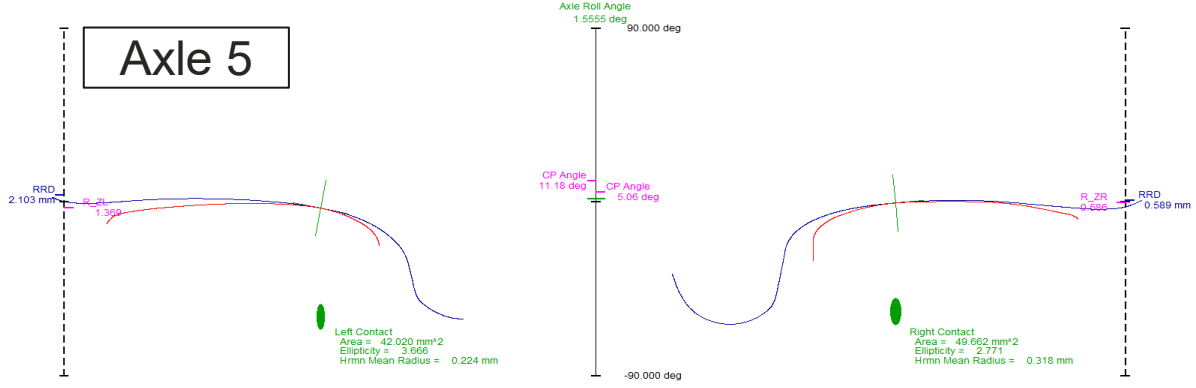


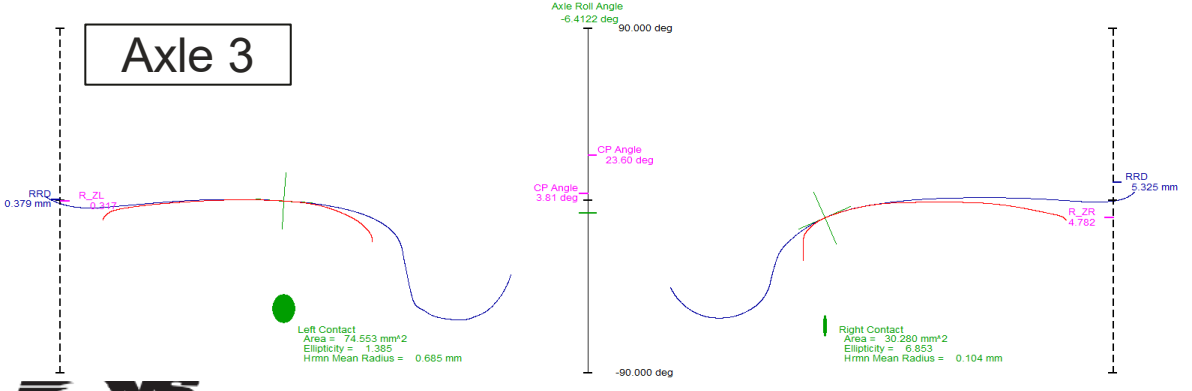
Axle 2



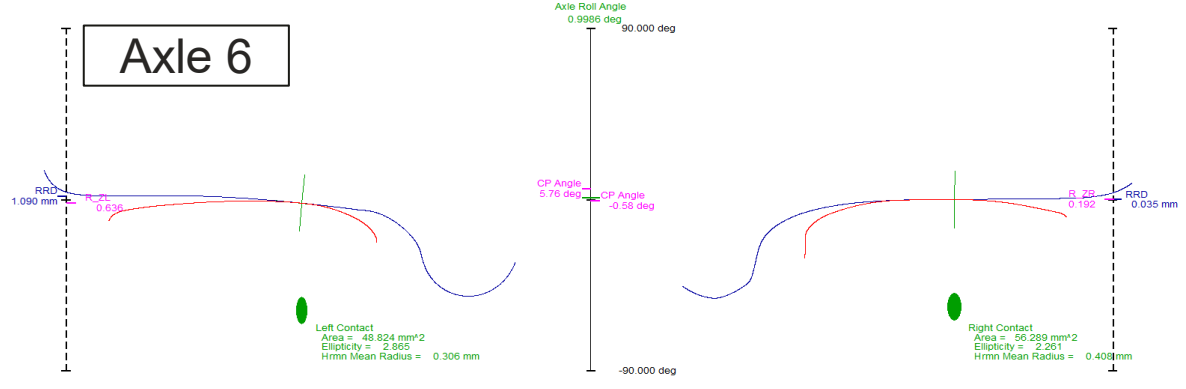
Axle 5



Axle 3



Axle 6



NORFOLK SOUTHERN

NS 4408 – Rolling Radius Differential

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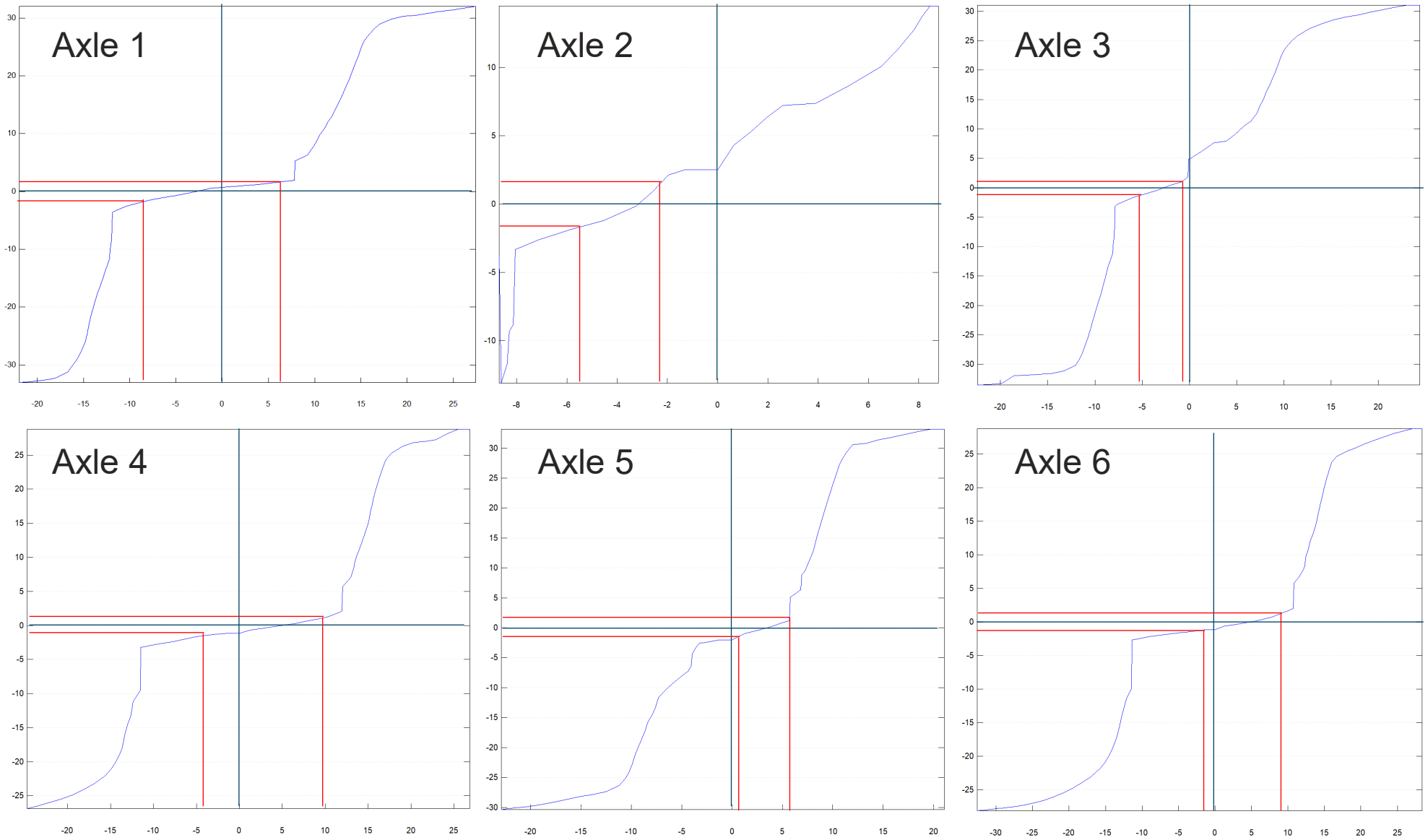
Appendix
Plot Guide



NS 9485 – Wheel/Rail Interaction

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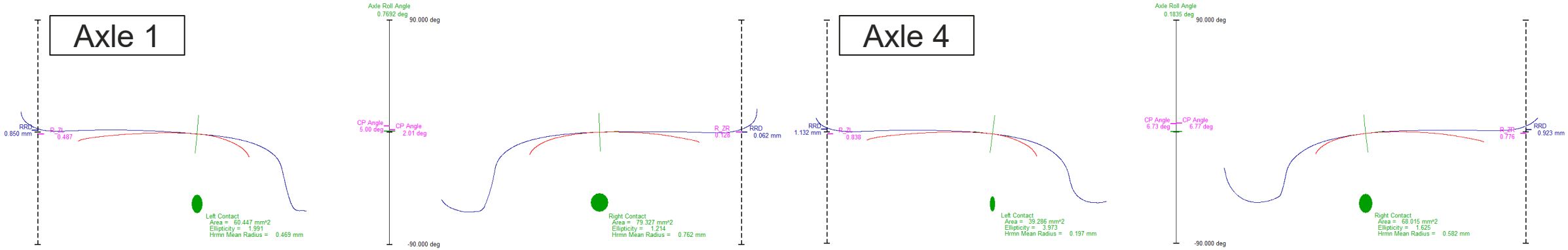
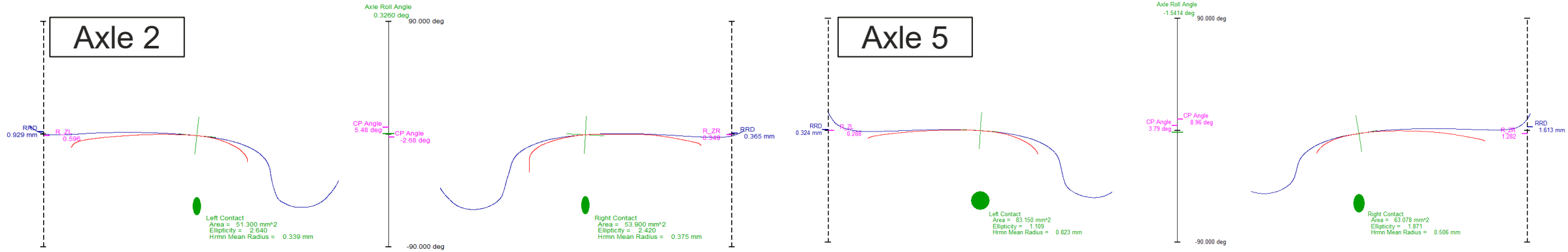
Appendix
Plot Guide

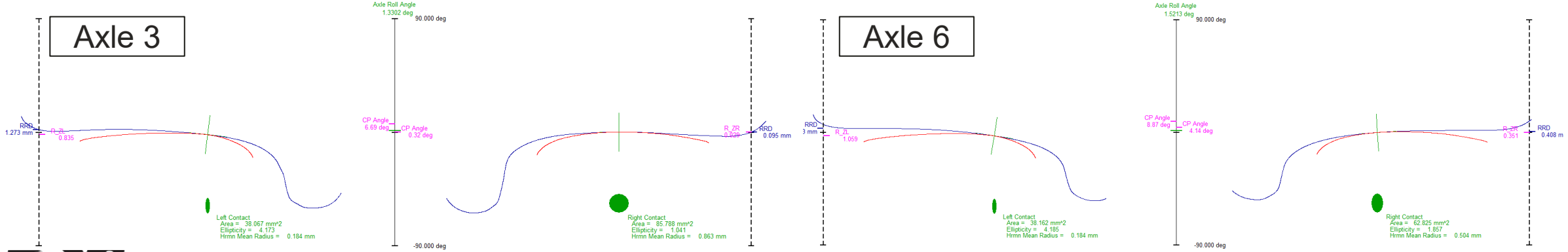
Axle 1



Axle 2



Axle 3



Axle 4

Axle 5

Axle 6

NORFOLK SOUTHERN

NS 9485 – Rolling Radius Differential

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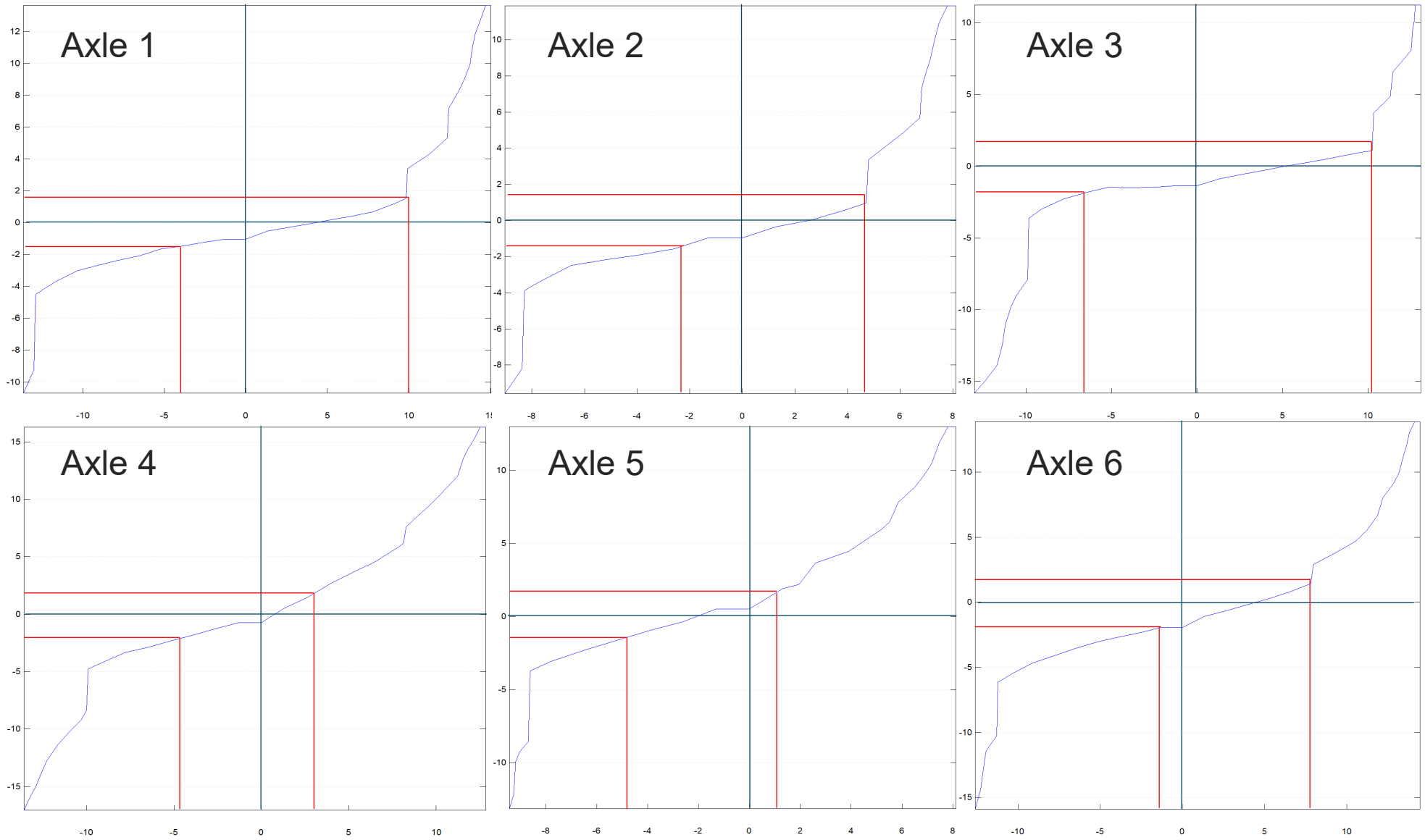
Appendix
Plot Guide



UP 5574– Wheel/Rail Interaction

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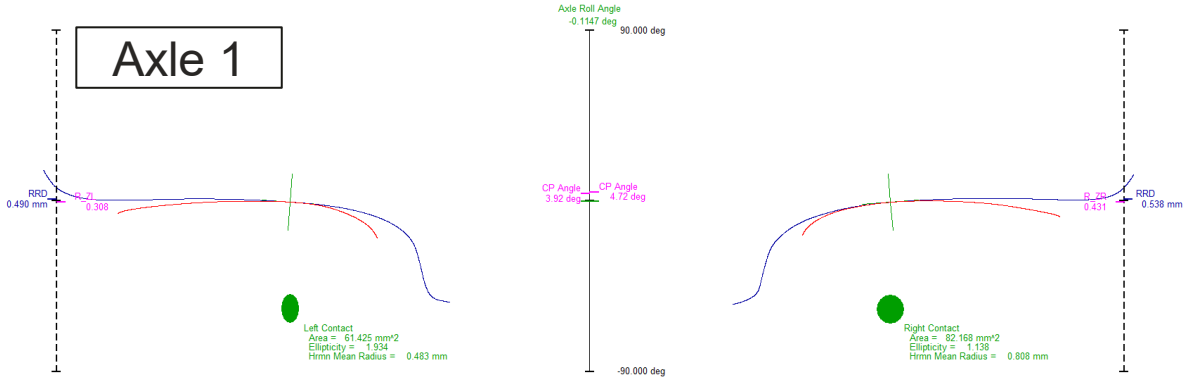
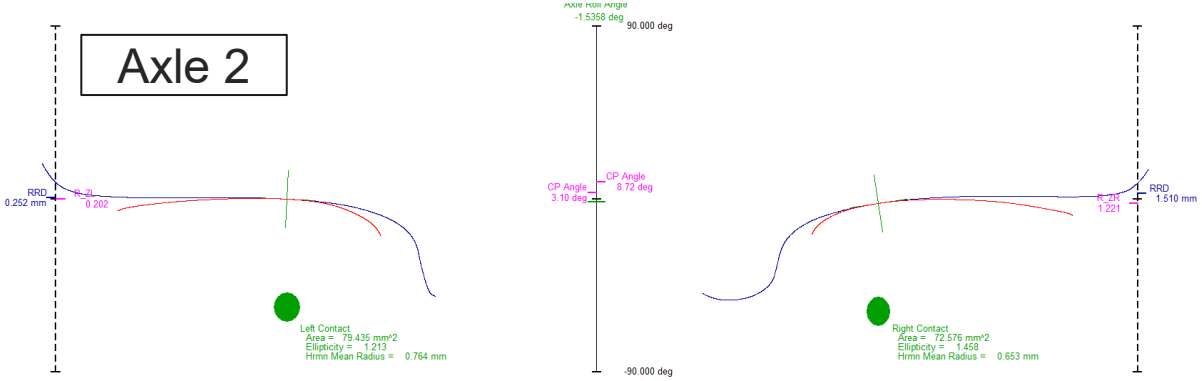
Appendix
Plot Guide

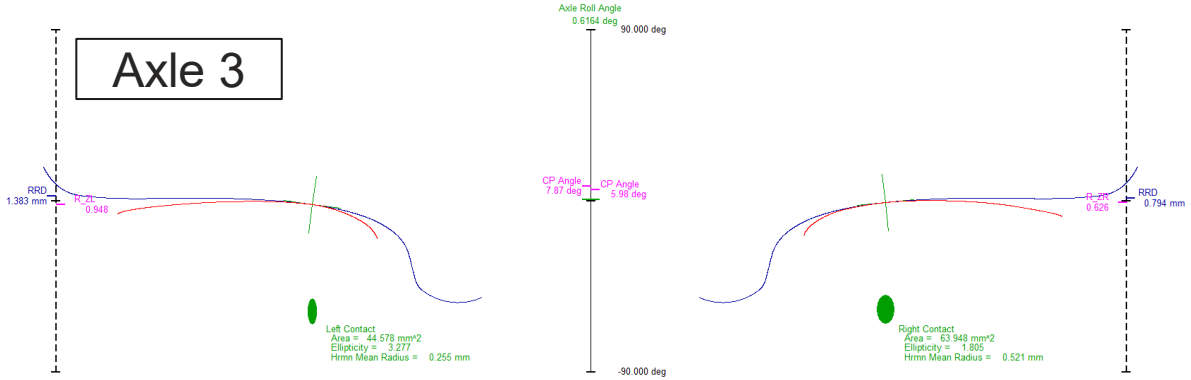
Axle 1



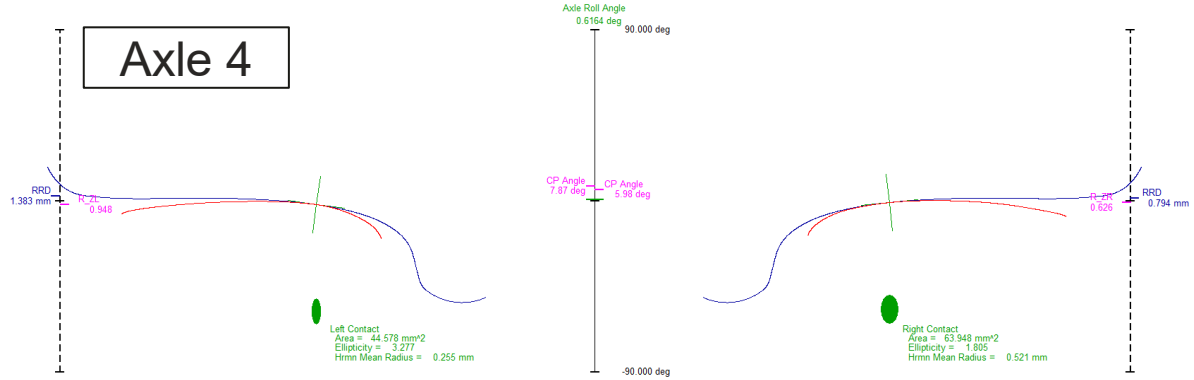
Axle 2



Axle 3



Axle 4



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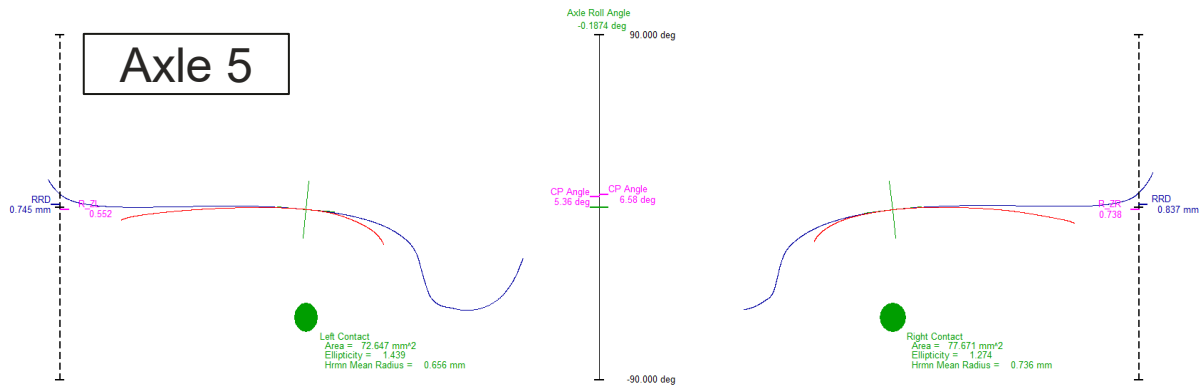

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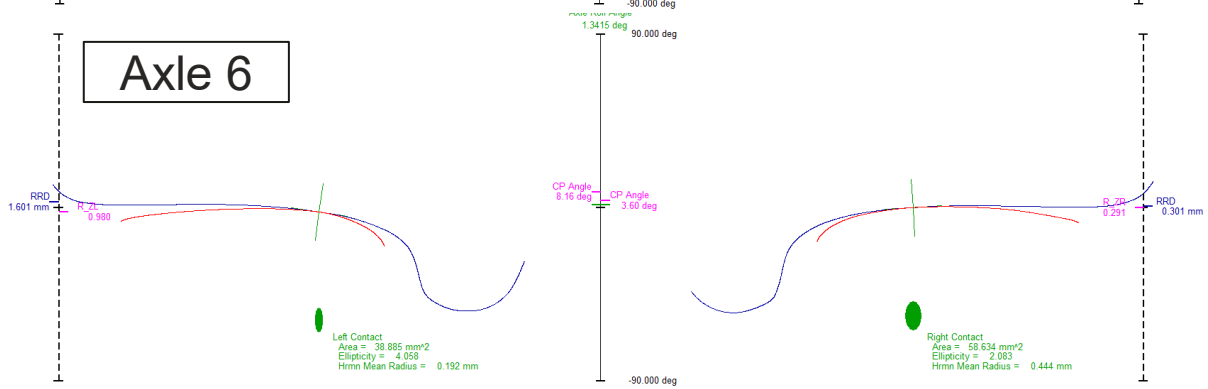
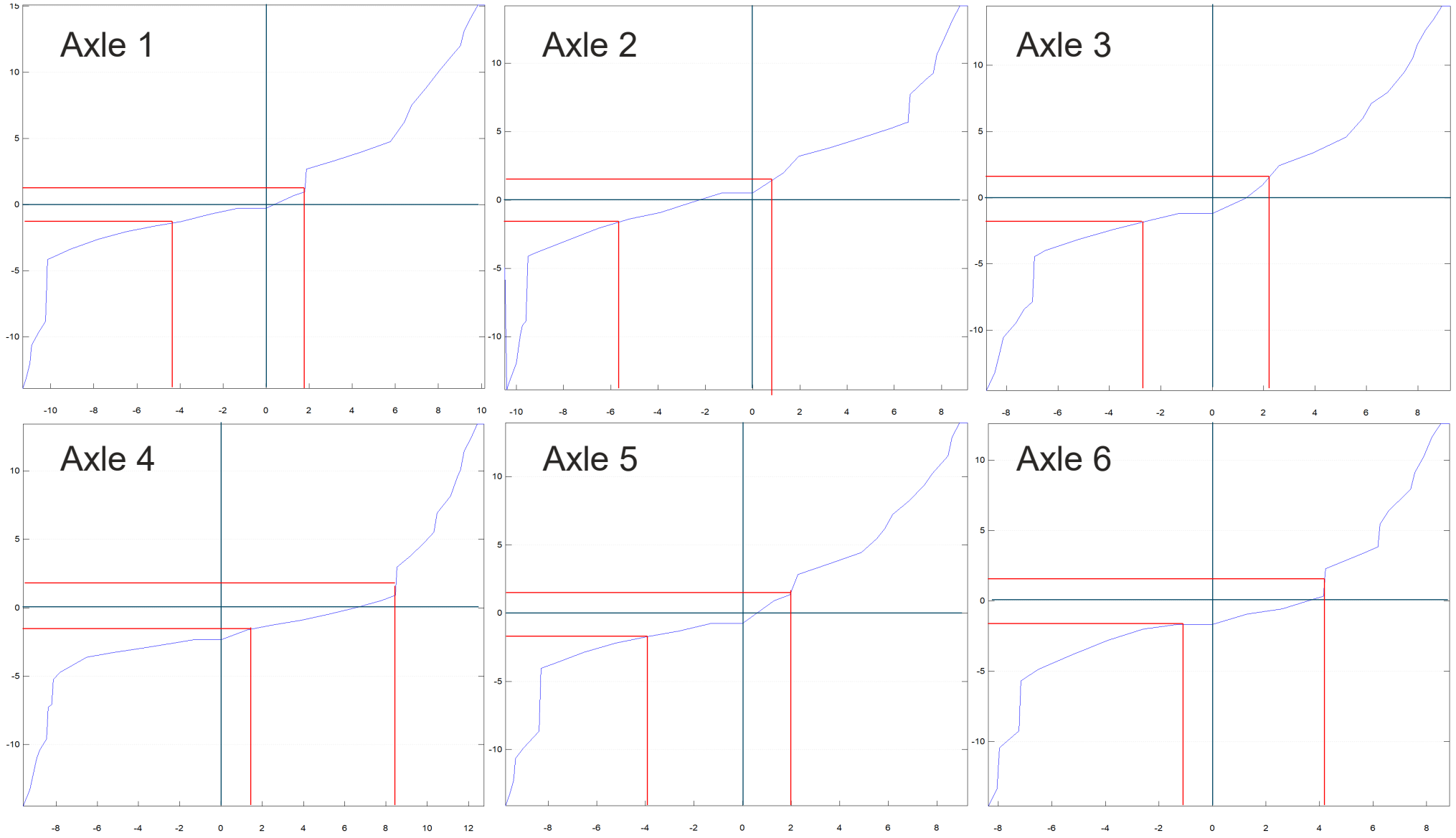


NORFOLK SOUTHERN

UP 5574 – Rolling Radius Differential

DRAFT

Appendix
Plot Guide



UP 9039– Wheel/Rail Interaction

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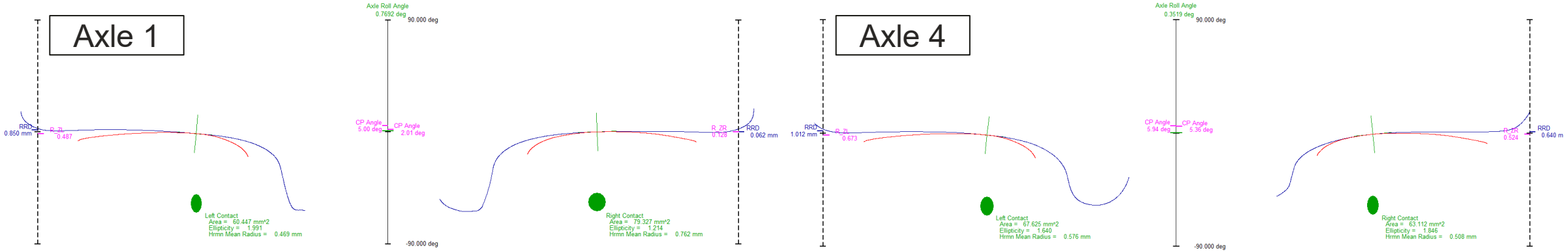
Appendix
Plot Guide

Axle 1



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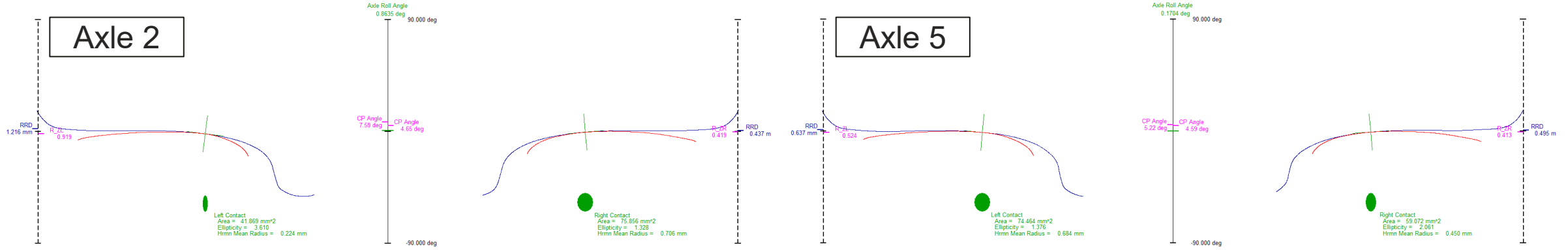

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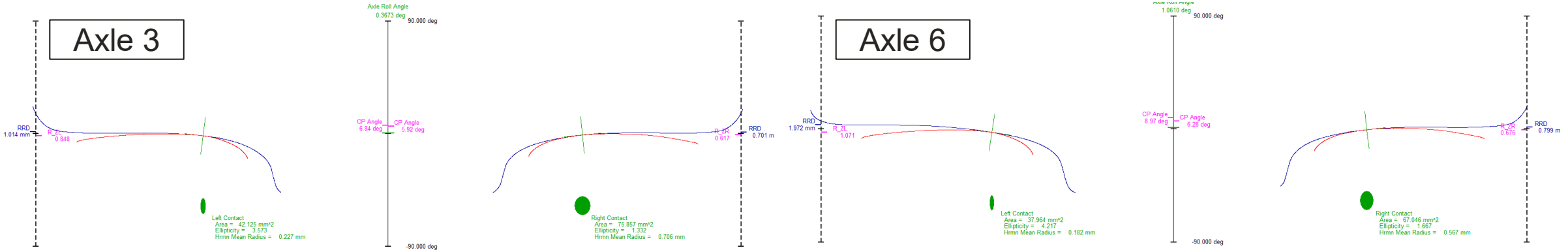

Axle 4

Axle 5

Axle 6

NORFOLK SOUTHERN

UP 9039 – Rolling Radius Differential

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Appendix
Plot Guide