31ST ANNUAL
Association of American Railroads
RESEARCH REVIEW

ASSOCIATION OF AMERICAN RAILROADS

MxV RAIL

AAR RESEARCH REVIEW
April 28-30, 2026
Pueblo, CO

Celebrating 50 Years of FAST®

FACILITY FOR ACCELERATED SERVICE TESTING
MxV RAIL
FAST® 50th Anniversary
1976-2026

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31ST ANNUAL Association of American Railroads RESEARCH REVIEW

FAST 50th Anniversary 1976-2026 Facility for Accelerated Service Testing MxV Rail

Agenda | Plenary Sessions

Wednesday, April 29, 2026

Plenary Session 1 (AM) | Fortino Ballroom A/B

Safety Briefing | Greeting	Scott Cummings, MxV Rail
Welcome	Miles Lucero, Pueblo County Commissioner
Keynote Address	Rand Ghayad, Chief Economist & SVP, AAR
Keynote Address	Mark Patterson, Associate Administrator, FRA
FAST® 50th Anniversary	Scott Cummings
Track Stability Research	Stephen Wilk and Yi Wang, MxV Rail
Q&A	

Plenary Session 2 (PM) | Fortino Ballroom A/B

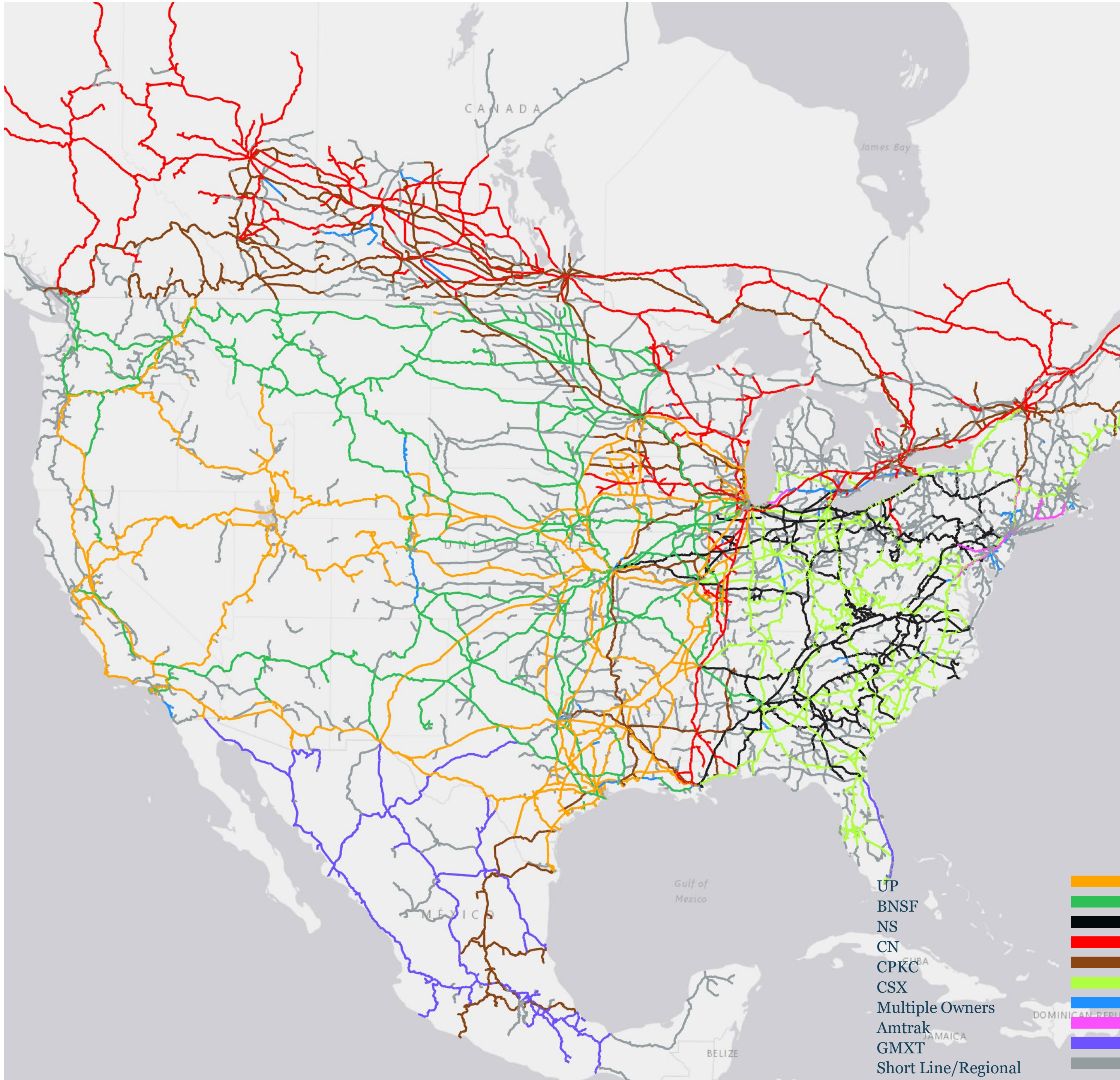
Friction Product Interaction with RCF	Ulrich Spangenberg, MxV Rail
Turnout Derailment Prevention	Corey Pasta, MxV Rail
Restricted Speed Enforcement	Thomas Nast, MxV Rail
Q&A	
Closure and Track Walk Information	Scott Cummings

Freight Rail at the Center of the Economy

Rand Ghayad
Chief Economist

April 29, 2026

ASSOCIATION OF AMERICAN RAILROADS | POLICY & ECONOMICS



Why Rail Data is So Informative About the Economy

The Foundation Behind Every Rail Insight We Deliver

2M+
freight cars & containers

13.8M+
Movements & events

450+
commodity categories

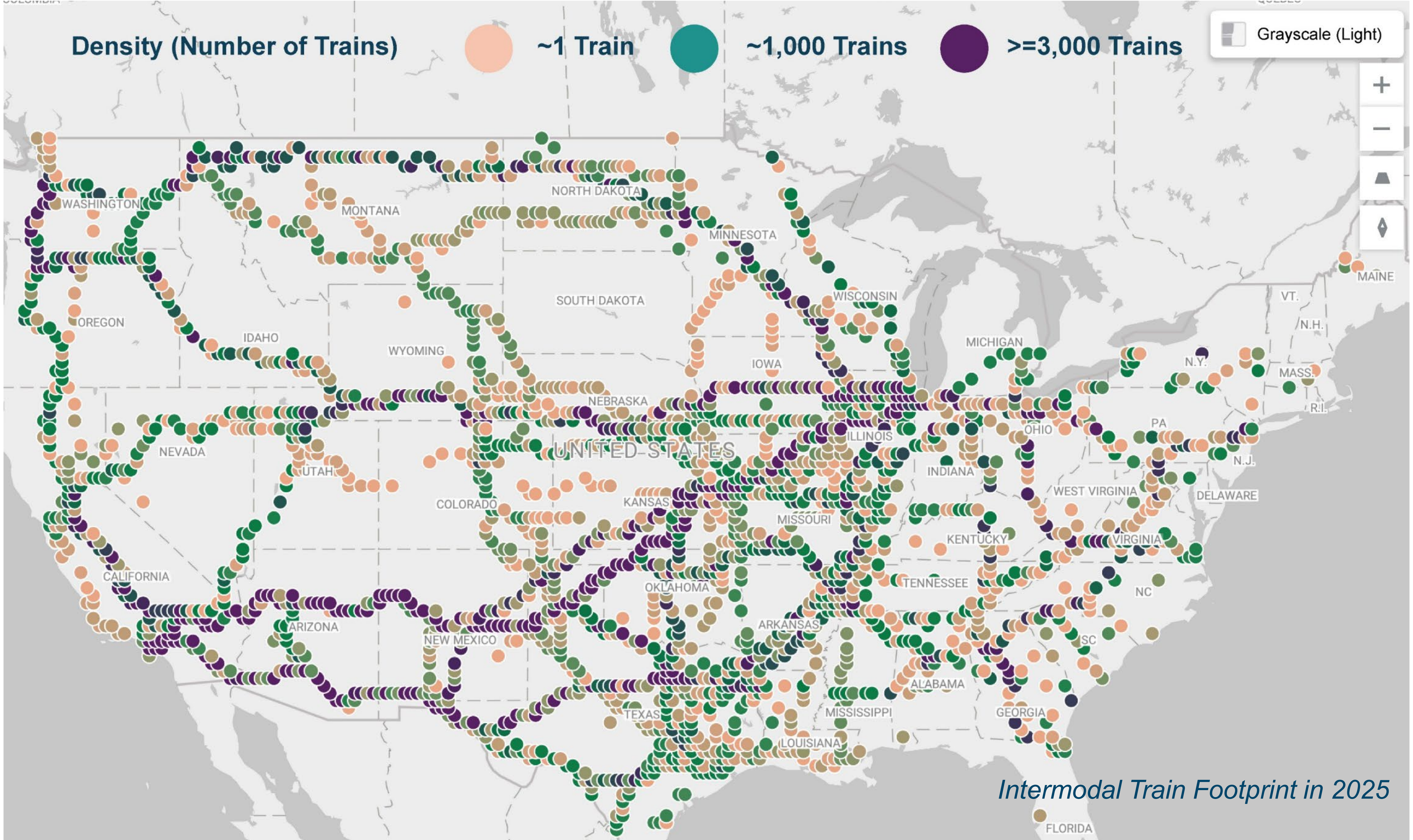
20+ years
of consistent time series

Full Coverage Across **North America**

Reading the Economy Through Rail

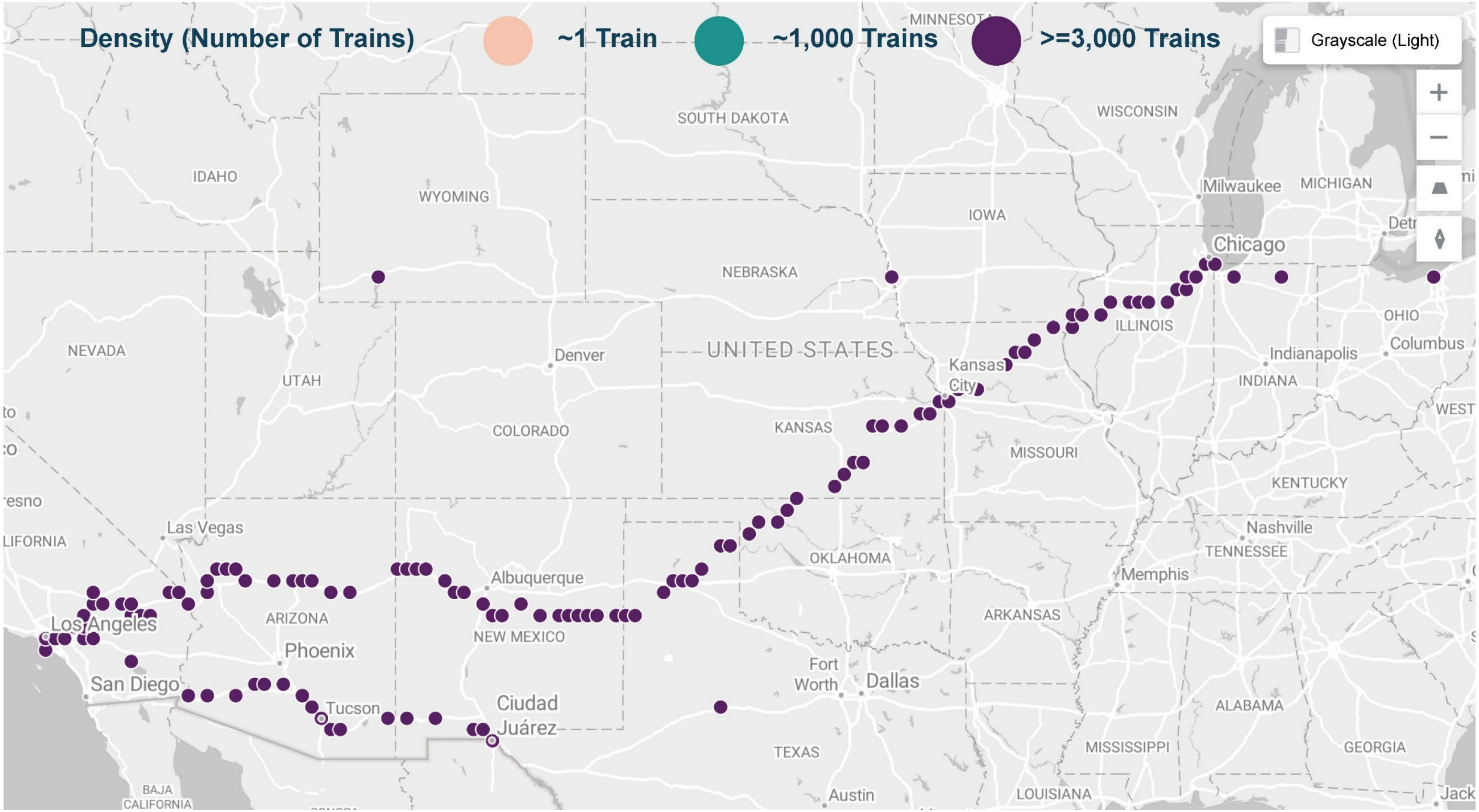
Where firms adjust	What we see in rail	What it tells us
Production & inputs	Carloads by commodity	Where industrial demand is strengthening or softening
Trade & routing	Intermodal & port flows	How trade patterns and supply chains are shifting
Inventory position	Dwell, velocity, turns	Whether the system is tightening or clearing
Network load	Throughput, congestion	Where capacity pressure is building

What the Economy Looks Like in Motion



Intermodal Train Footprint in 2025

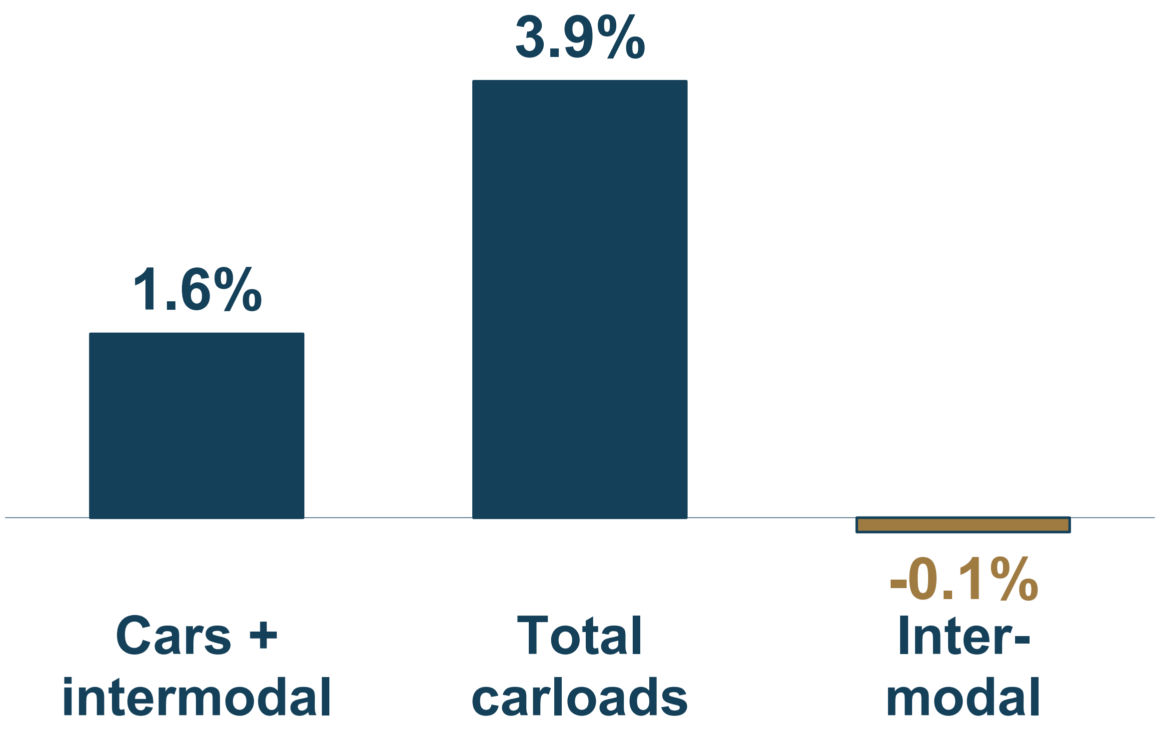
The Arteries of the Network



Current State of Rail Traffic

- Early 2026: volumes modestly higher overall; divergence by segment
- Carloads strengthening; intermodal down
- Commodity mix is reshuffling beneath stable toplines
- Read-through: adjustment and rotation, not broad-based contraction

% change YTD 2026 vs. 2025*

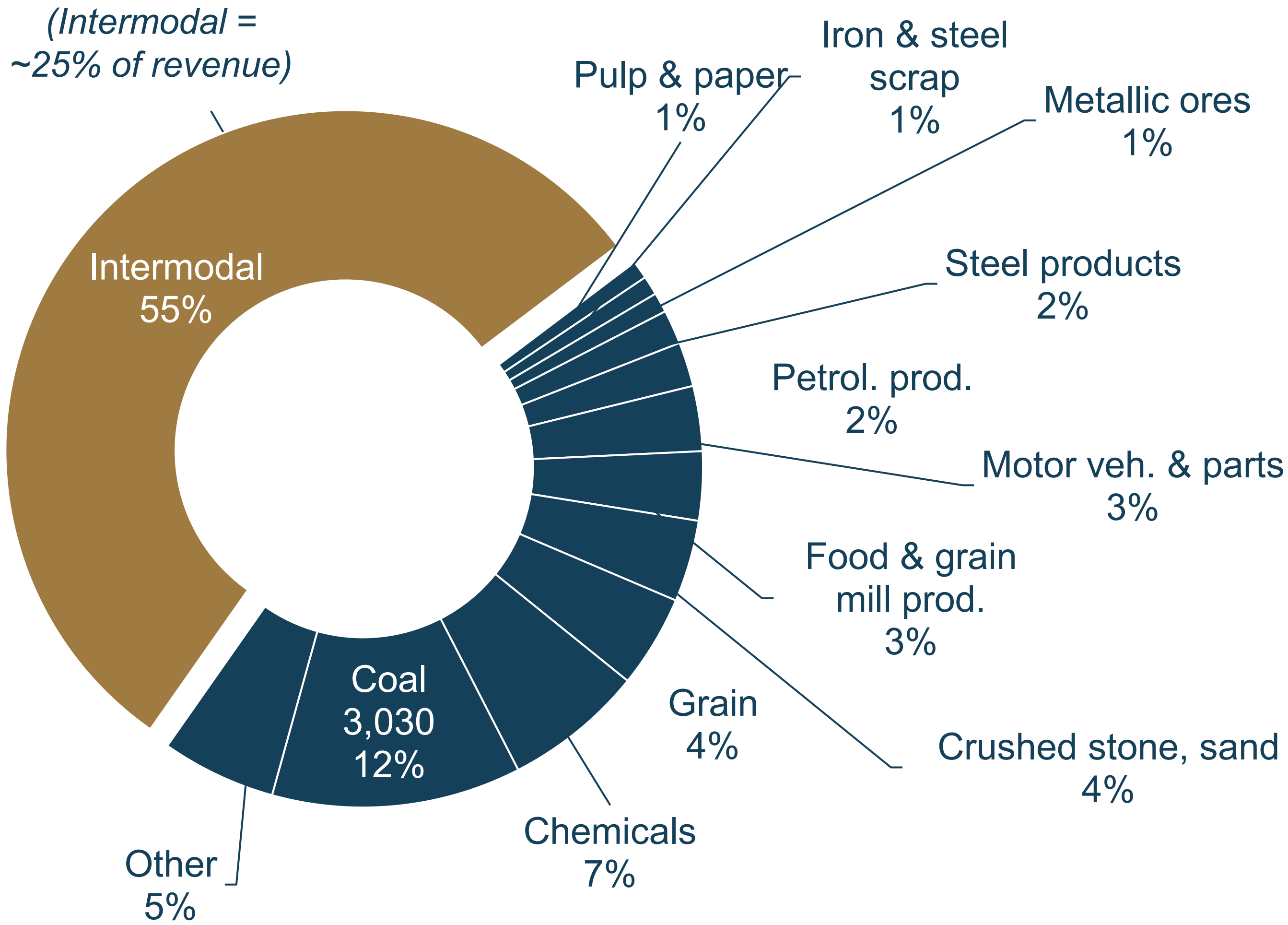


*through week 15

Mix Matters

- Stability at the topline masks reallocation underneath
- Intermodal is the majority of units; carloads carry "the physical backbone"
- Today's signal is *mix shift* (energy, industrial, agriculture, consumer)
- Resilience comes from breadth—but planning must be mix-aware

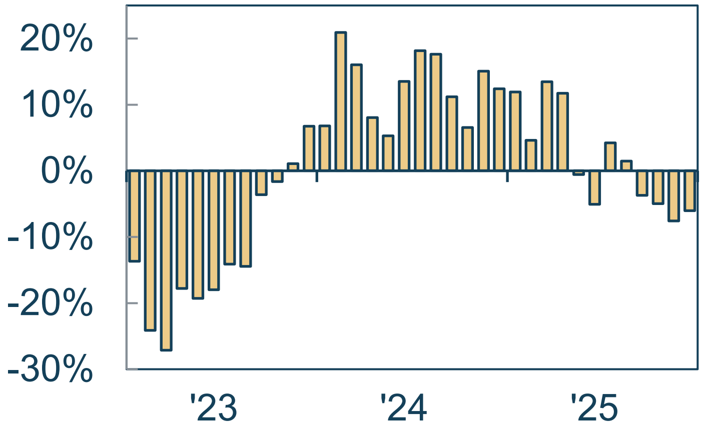
U.S. Rail Traffic in 2025 - % of Total

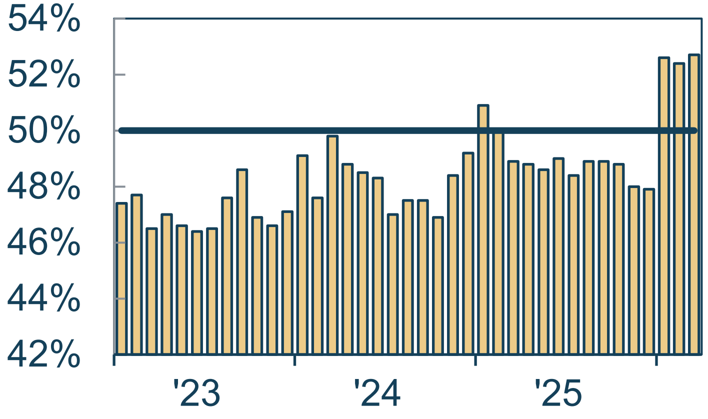


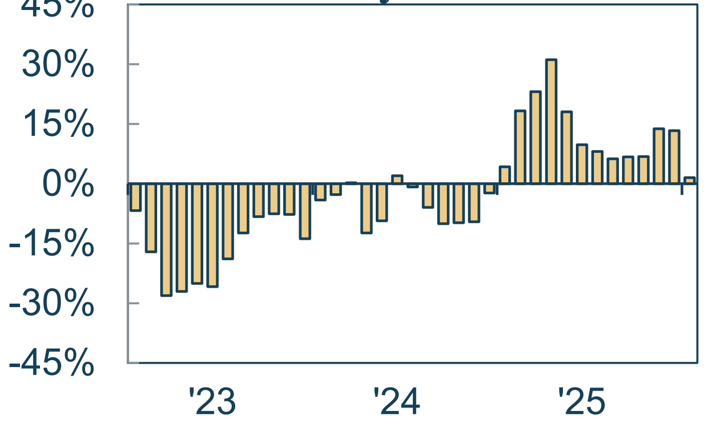
What's Driving Rail Right Now

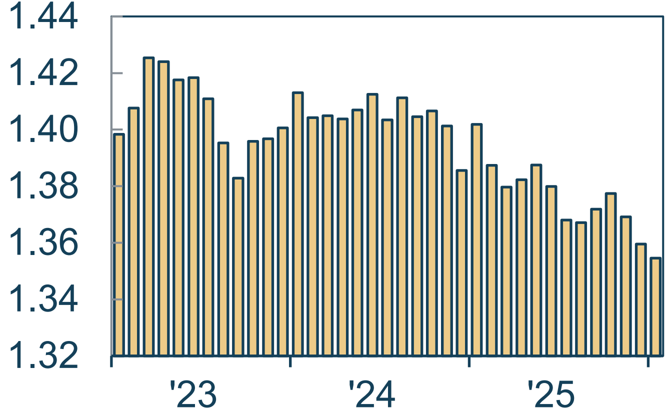
1. Inventory normalization
2. Industrial activity
3. Trade & intermodal dynamics
4. Energy & weather noise

Multiple forces → one confusing headline


Y/Y Change U.S. Port Activity

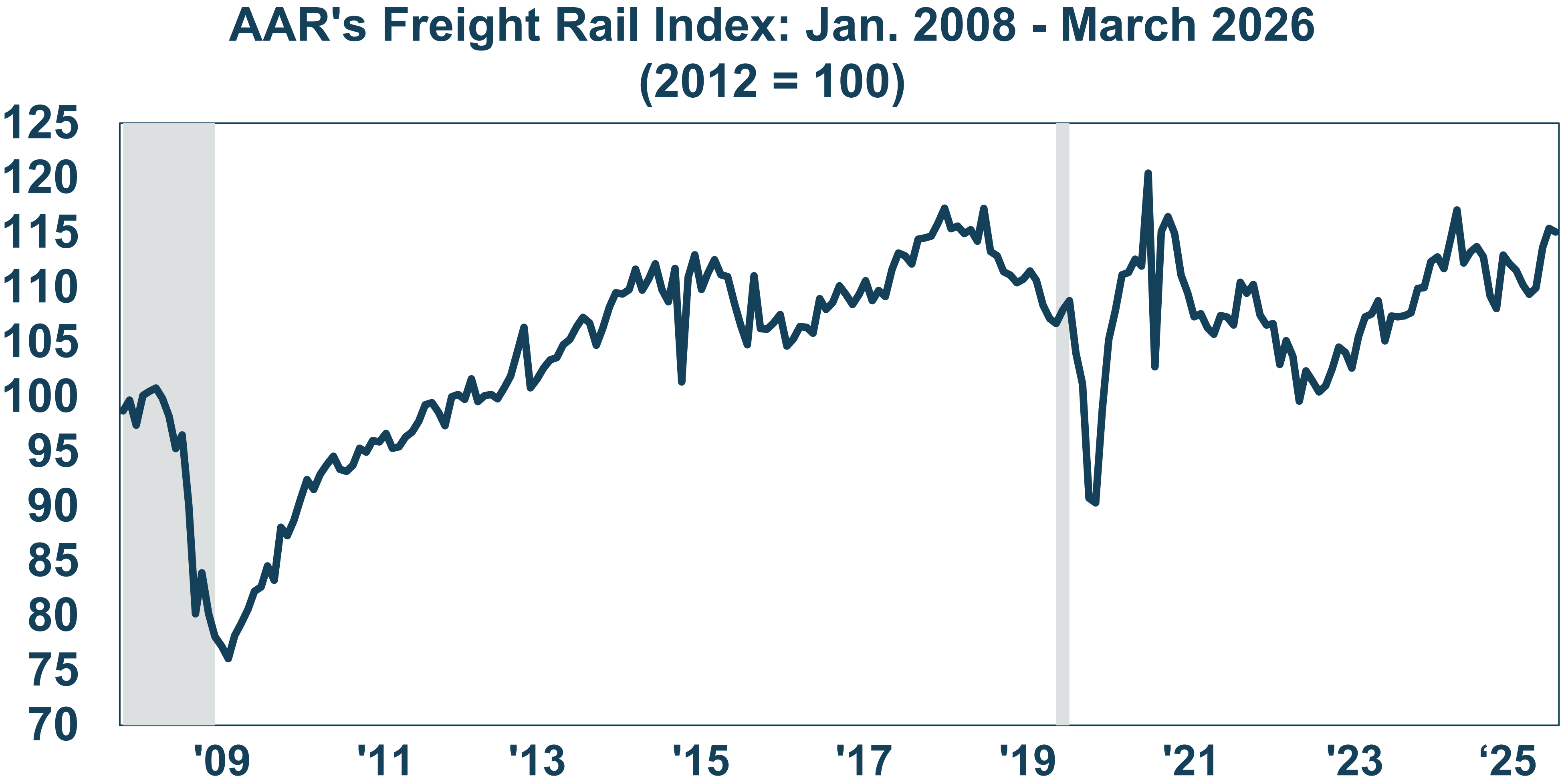

Manufacturing PMI® (>50% = expansion)


Y/Y Change U.S. Electricity From Coal


Inventory-Sales Ratio – All Sectors Combined

Freight Rail Index (FRI): What is Demand Actually Doing - Net of Structural Noise

AAR | P&E POLICY AND ECONOMICS



Data are based on seasonally adjusted U.S. intermodal originations plus carloads excluding coal and grain. Data do not include the U.S. operations of CN, CPKC, and GMXT.

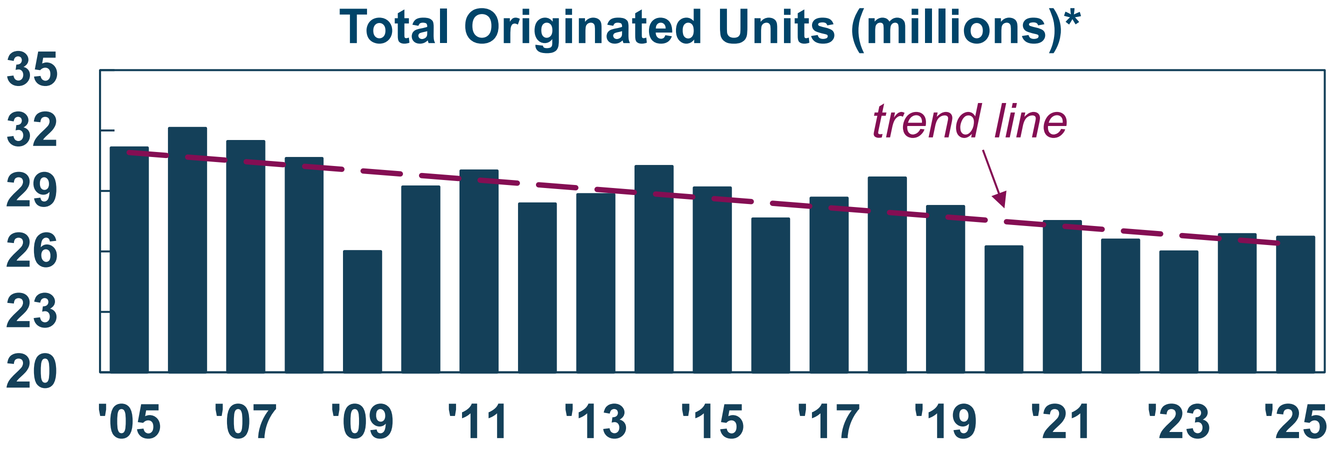
Why “*Rail is Declining*" is the Wrong Story

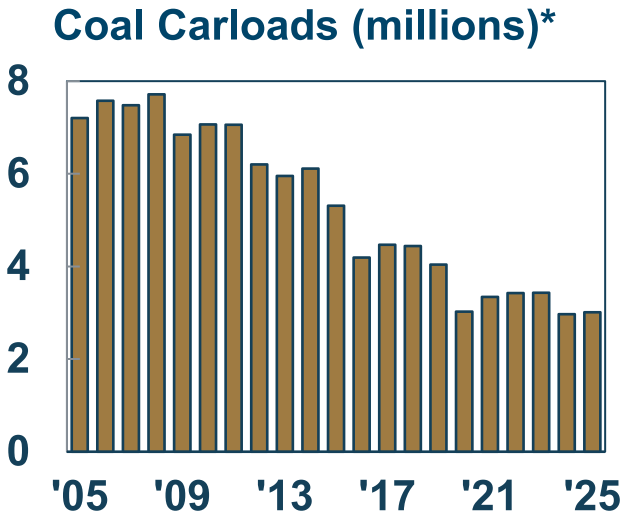
- Long-run trend is down — but the composition is the story
- Coal explains a large share of the secular decline in units
- Ex-coal: far more stable trend; closer to "flat-to-cyclical"

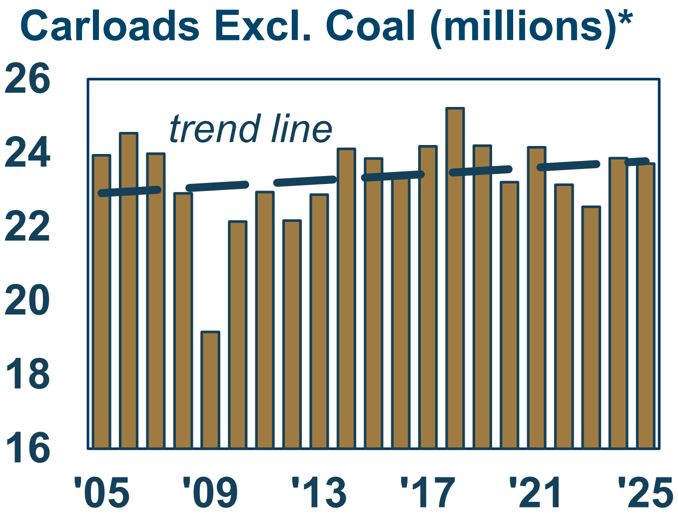
% U.S. Electricity Generation

	2000	2010	2020	2025
Coal	**52%**	**45%**	**19%**	**17%**
Natural gas	16%	24%	41%	41%
Nuclear	20%	20%	20%	18%
Renewables	2%	4%	12%	19%
Hydro	7%	6%	7%	5%

Source: EIA


Total Originated Units (millions)*


Coal Carloads (millions)*


Carloads Excl. Coal (millions)*

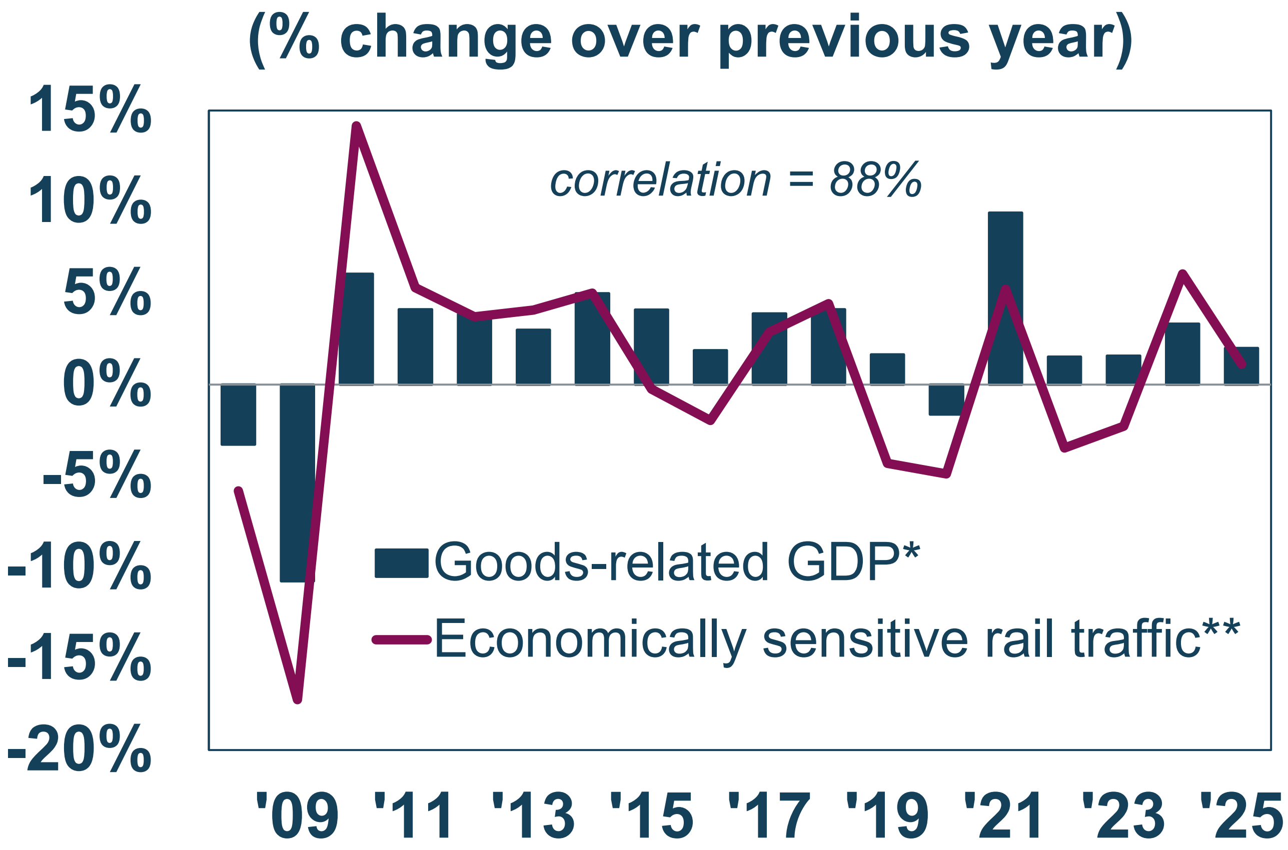
**Figures are for Class I railroads.*

What's Structural vs. What's Cyclical

- Structural:
  - Coal secular decline (energy transition)
  - Supply chain reconfiguration / reshoring
- Cyclical:
  - Intermodal surge (pandemic) → normalization
  - Inventory swings → freight adjustments
- **Policy should solve structural problems—not chase cyclical noise**

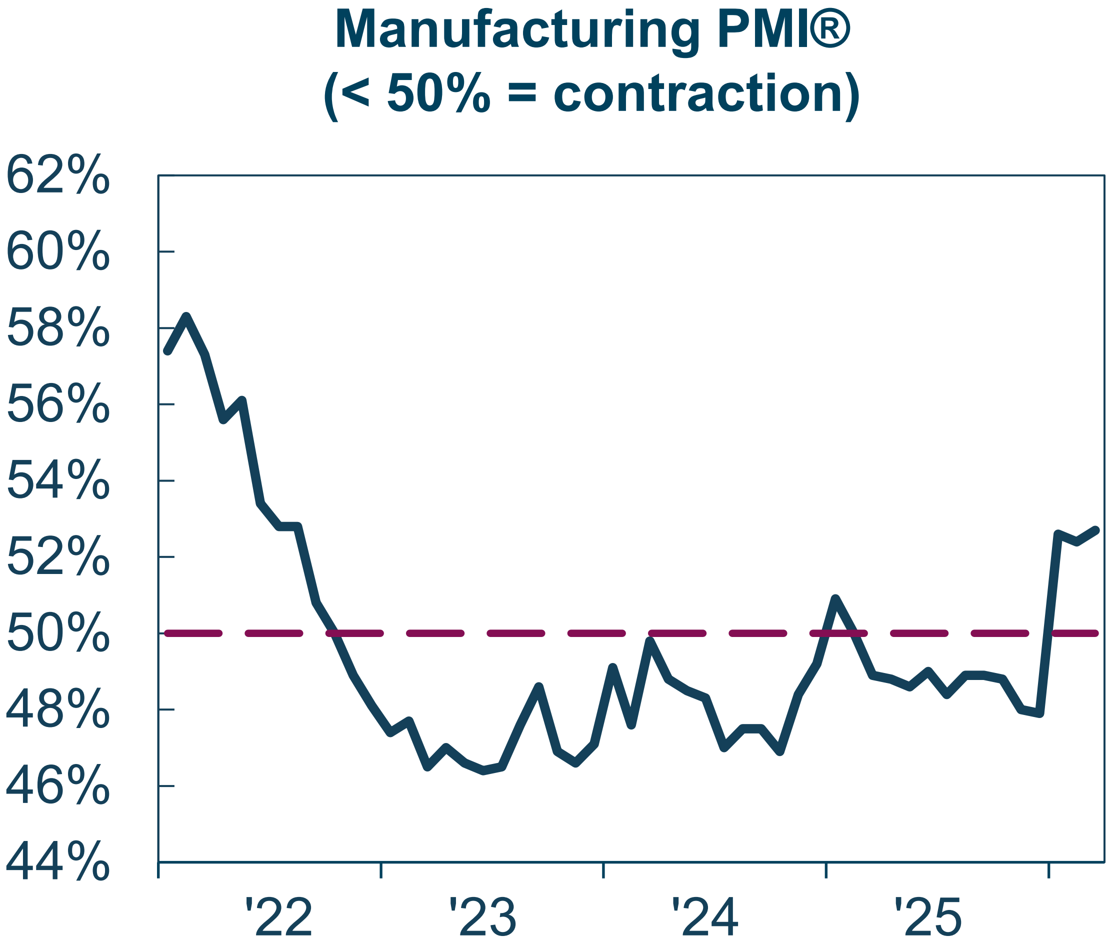
Why Rail Often Feels 'Out of Sync' With Headlines

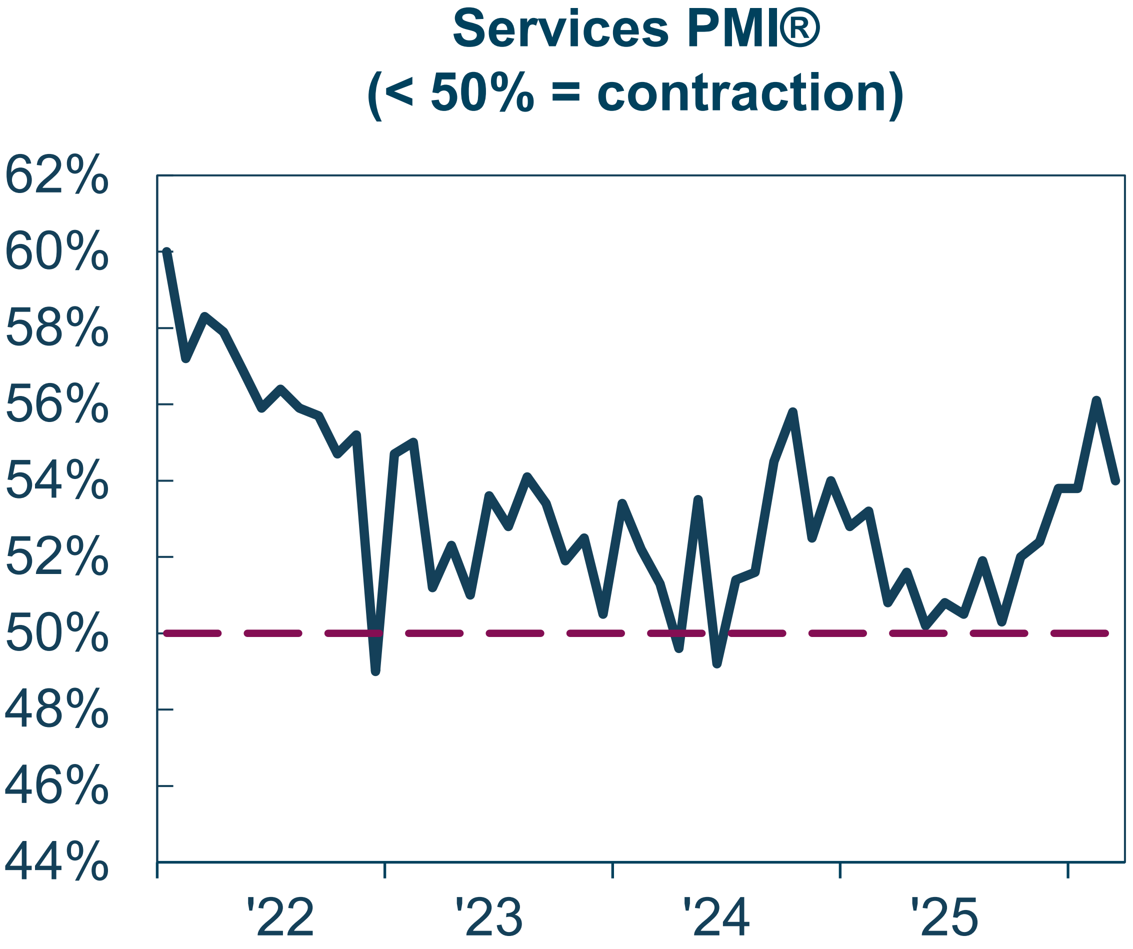
- Rail best tracks the goods economy — not overall GDP
- Rail tracks the goods economy more closely than "services-heavy" overall GDP headlines
- Rail is a production-side signal: inputs, intermediate goods, trade in goods
- Implication: rail can feel weak even when headline GDP looks fine—and vice versa



*Total originated U.S. carloads and intermodal units. Rail traffic excludes the U.S. operations of Canadian and Mexican railroads. Source: BEA, AAR

Manufacturing Is Turning—That Matters for Rail





Source: Institute for Supply Management®

Railroads Enable Foreign Trade

International Trade as a Share of U.S. Rail Traffic in 2023

	Rail Total	Trade Share	Trade % of Total
Units (millions)*	29.8	11.3	38%
Revenue ($ bil)	$80.1	$29.8	37%
Tons (millions)	1,628	544	33%

*carloads, containers, and trailers

Source: Association of American Railroads

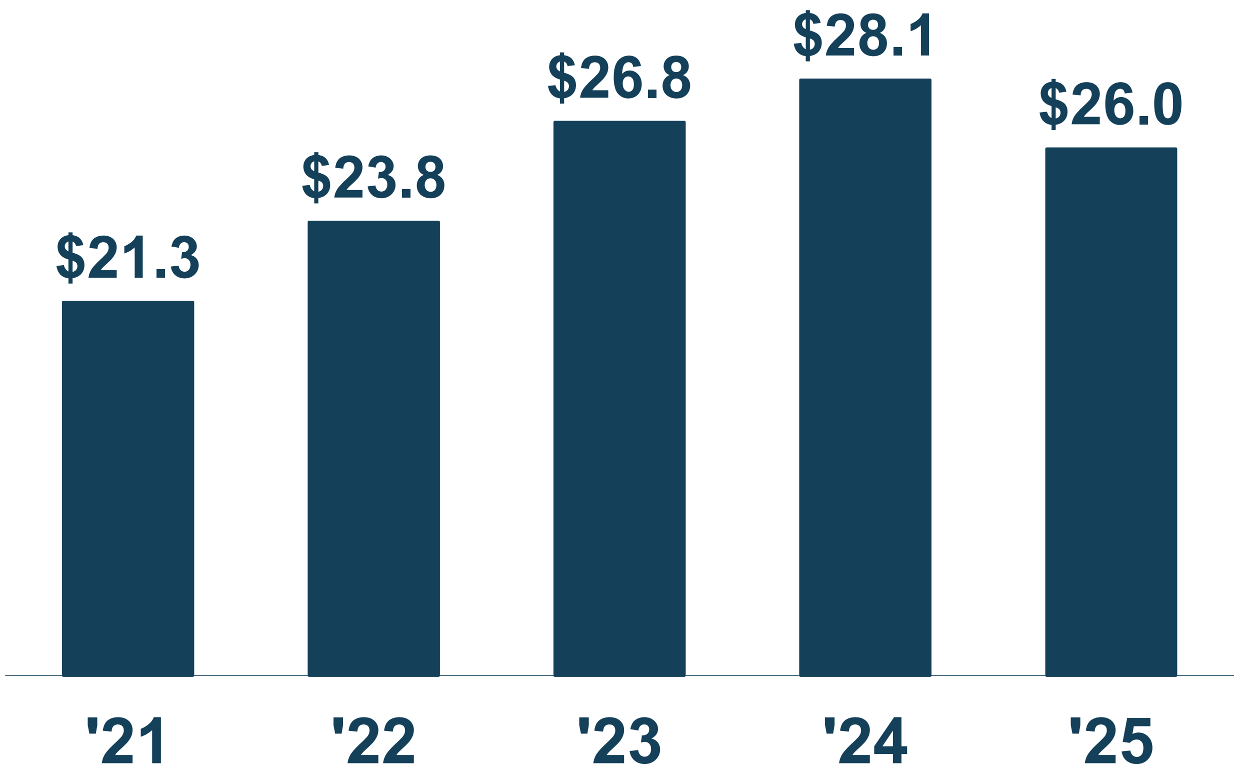
The System Behind the Signal

- 6 Class I, ~620 non-Class I RRs
- >135,000 route-miles
- ~40% of long-distance ton-miles
- ~$85 billion annual revenue
- ~28,000 locomotives
- ~1.6 million railcars
- ~3.3 billion gallons of fuel
- ~140,000 employees
- ~28 million carloads and intermodal units transported

Rail is Self-Funded National Infrastructure

- Investment is sustained:
  - $25B+ capex + maintenance per year
  - capital spending = ~16% of revenue last 5 years
- Long asset cycles require long planning horizons
- Capacity + safety + resilience are investment outcomes

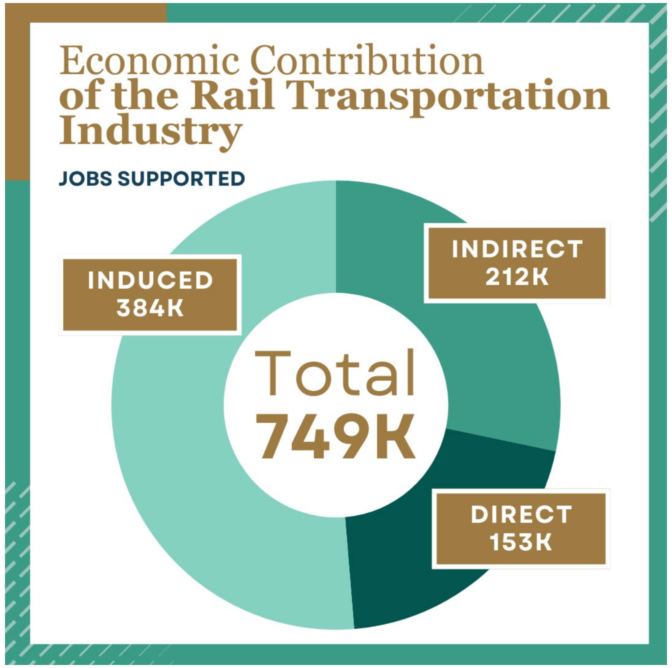
Reinvesting in the Rail Network*
($ billions)



*Capital spending + maintenance expenses, Class I railroads. Source: AAR

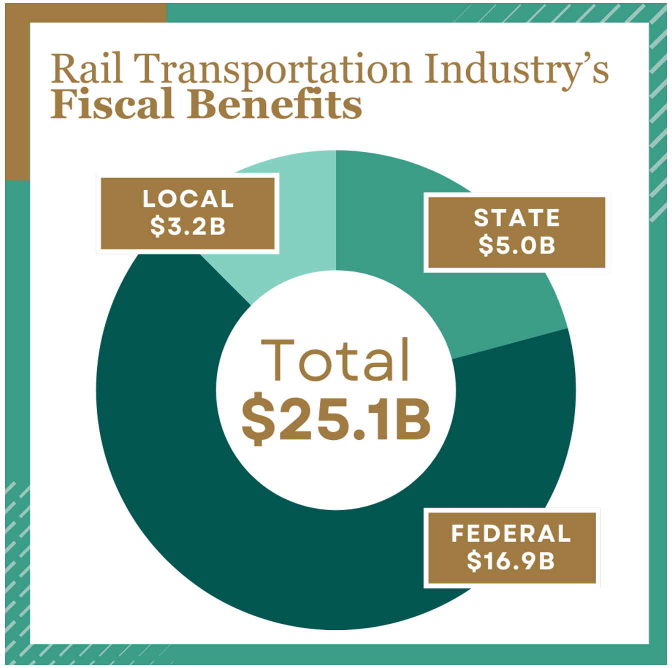
Rail's Economic Role is Larger Than It Looks

- **$233.4B** total economic output
- **~750K** jobs supported (153K direct)
- **$25.1B** in federal/state/local tax revenue

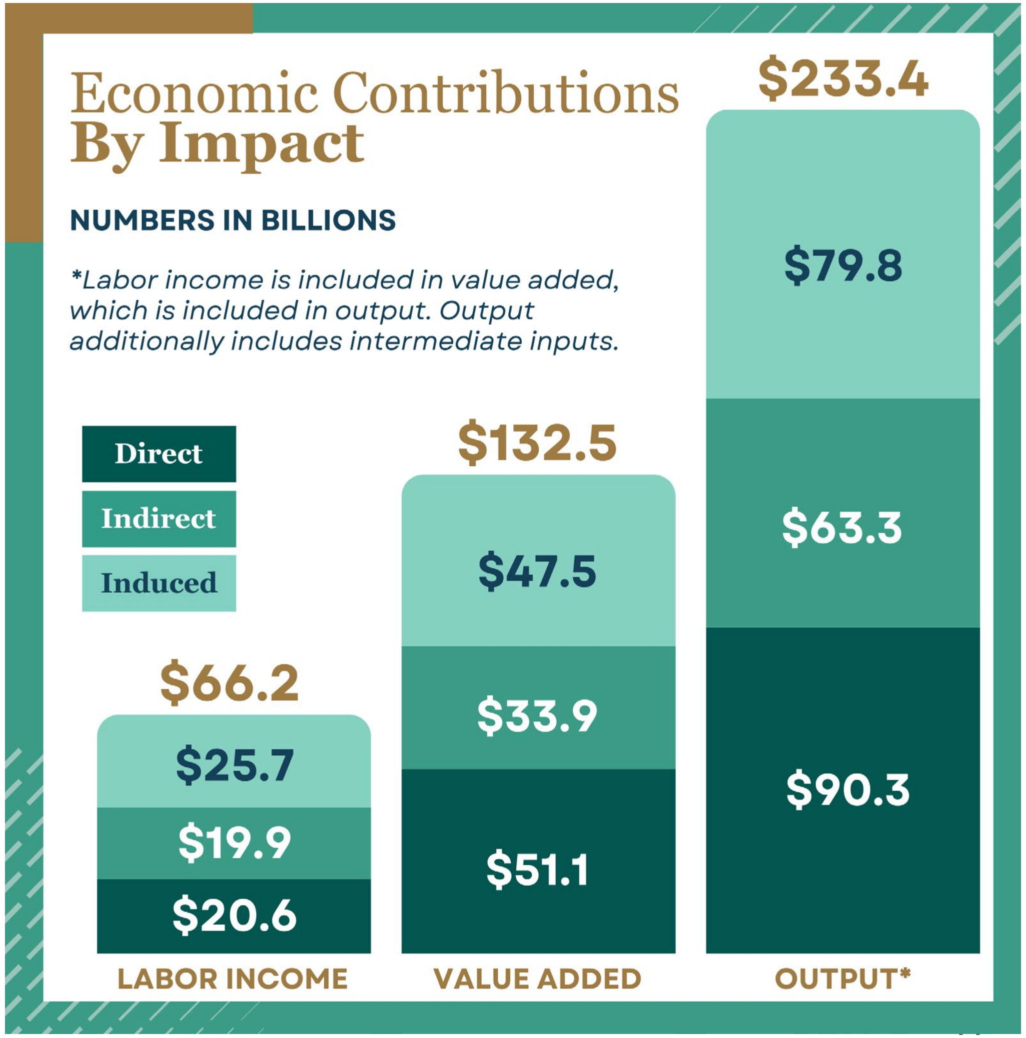


Economic Contribution **of the Rail Transportation Industry**

JOBS SUPPORTED



Rail Transportation Industry's **Fiscal Benefits**



Economic Contributions **By Impact**

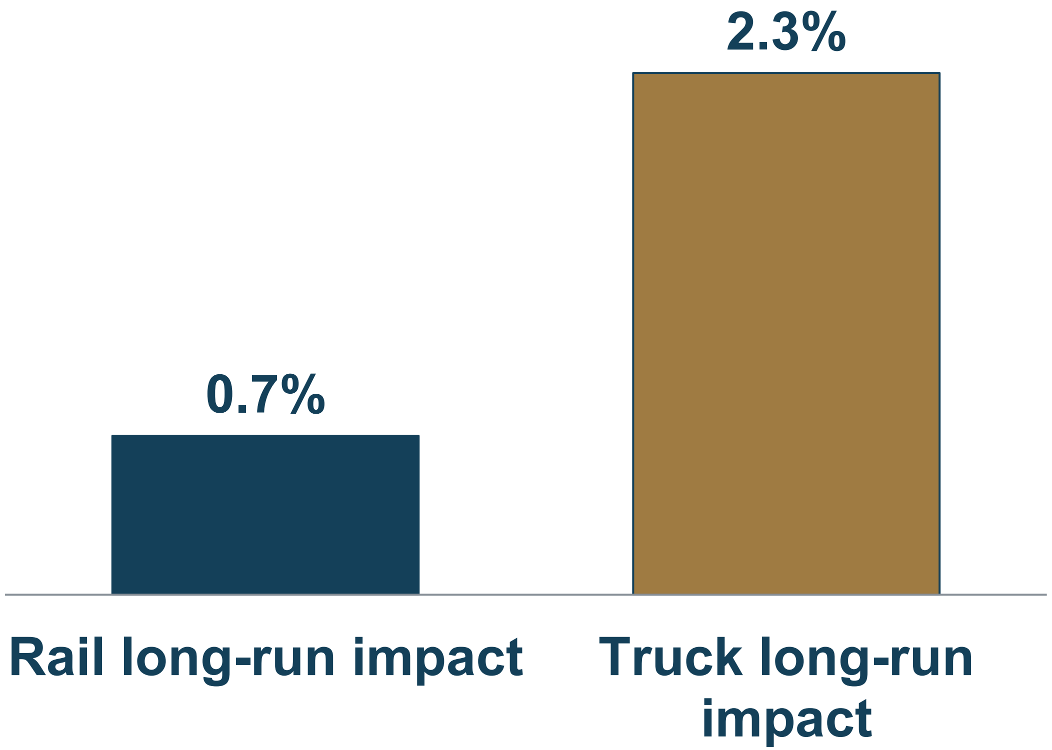
NUMBERS IN BILLIONS

**Labor income is included in value added, which is included in output. Output additionally includes intermediate inputs.*

Freight Rail Dampens Inflation

- AAR research: rail is a "built-in stabilizer" in logistics costs
- Pass-through comparisons:
  - 10% trucking cost inflation → ~2.3% goods inflation
  - 10% rail cost inflation → 0.7% goods inflation
- Truck cost shocks hit consumer prices faster; rail shocks are smaller and fade faster

Rail as an Affordability Enhancer*

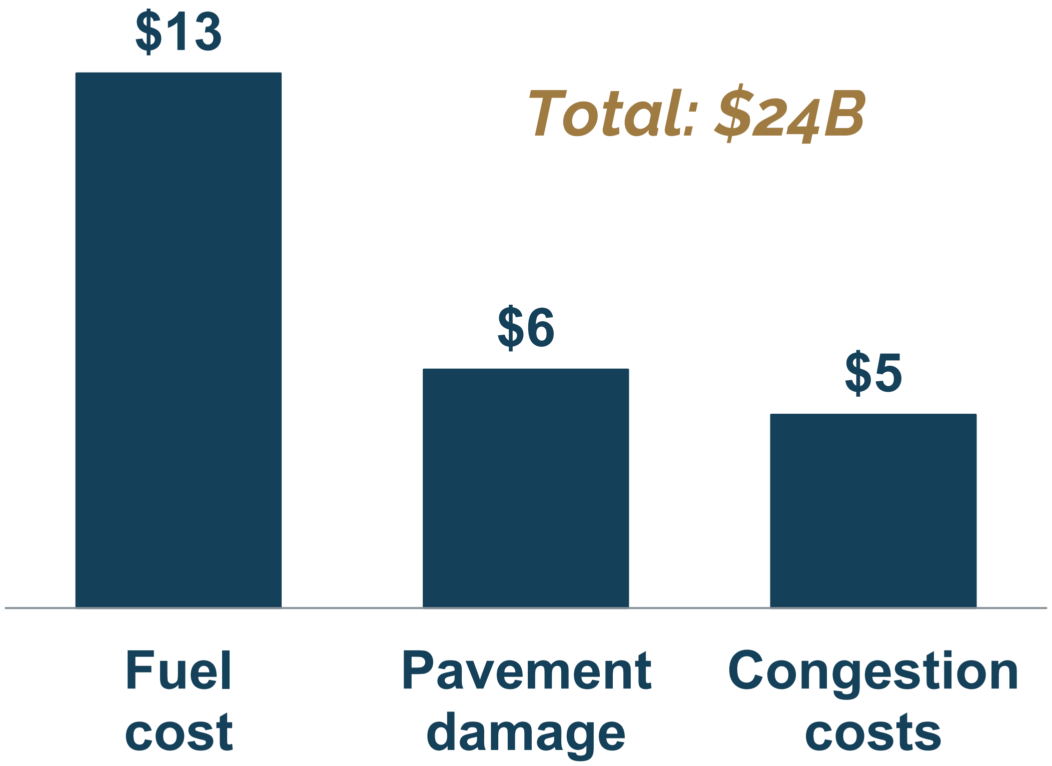


*Estimated pass-through effect of a 10% increase in freight rate growth on goods inflation as measured by CPI goods commodities.

Significant Public Benefits From Rail

- Rail is ~3-4x more fuel-efficient than trucking
  - One train = hundreds of trucks
  - Reduced highway congestion
  - Less pressure to spend $ on highways
- Hypothetical shift of 20% of long-haul heavy-truck freight:
  - ~$13B in fuel savings
  - ~$11B reduced congestion + pavement wear annually

Public Benefits Associated With Moving Truck Traffic to Rail ($ billions)*



**Estimated savings from diverting 20% of long-haul truck freight to rail*

Policy Choices Show Up as Capacity Constraints—or Resilience

- The next decade is defined by volatility and policy interaction
- Policy doesn’t just regulate rail — it shapes system outcomes:
  - Investment → capacity and reliability
  - Operations → network velocity and fluidity
  - Incentives → long-term resilience
- Core tension: Regulation can protect outcomes — or unintentionally constrain capacity
- Implication: Align safety, service, competition, and capacity around system performance

Safety is a System Outcome

- Goal = zero accidents
- 2025 = record lows for derailment rate, equipment-caused accident rate, Class I employee injury rate
- Safety is a system: engineering + operations + training + investment + technology
- Safety improvement requires a regulatory system that values innovation

Changes in Railroad Accident and Injury Rates

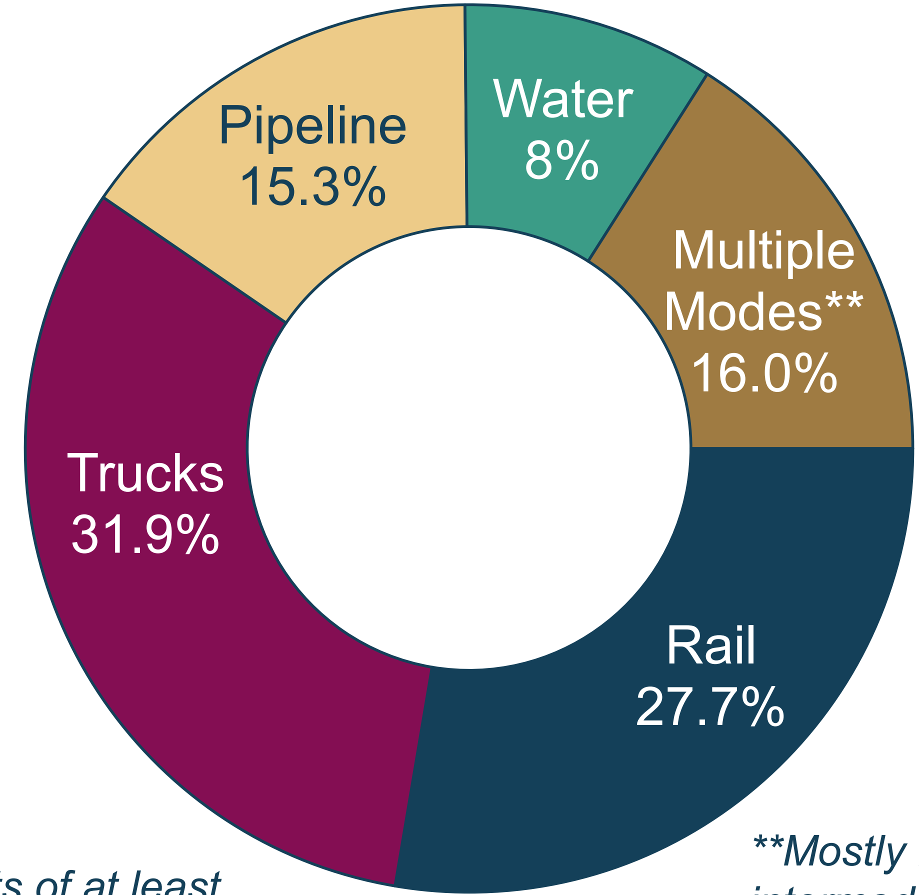
	2005-2025
Total train accidents	-40%
Collisions	-67%
Derailments	-46%
Track-caused	-53%
Equipment-caused	-40%
Human factors-caused	-41%
Mainline accidents	-37%
Employee injuries	-30%
Grade crossings	-4%
Hazmat incidents	-80%

2025 is preliminary. Source: FRA, AAR

Lots of Freight Out There for Rail to Capture

- Reallocation across sectors continues
- Key drivers of demand: industrial activity, trade flows, inventory cycles, energy markets
- Greater value on fluidity and reliability leading to resiliency and adaptability
- Bottom line: demand will be shaped by where the goods economy is shifting

Long-Distance U.S. Freight Ton-Miles by Mode



*Shipments of at least 500 miles. Source: BTS

**Mostly rail intermodal.

Thank You

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Back to Plenary Agenda

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FAST® 50th Anniversary

1976-2026

FACILITY FOR ACCELERATED SERVICE TESTING

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1976-2026

- 5.5 billion gross tons accumulated
- 300,000 loaded train passes
- 140 MGT in a typical year

- Heavy axle loads in North America (286,000 lbs GRL)
- Evaluate new products and systems in a safe, controlled, accelerated manner

Back to Plenary Agenda

Track Stability Research

Stephen Wilk and Yi Wang

Principal Investigator II

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Track Buckle Prevention

- **Thermal misalignments/track buckles can be highly disruptive during summer months**
- **Combined effort between track and vehicle perspectives**
- **Long-term goals:**
  - Improve rail neutral temperature (RNT) management
  - Improve track buckle strength and identify high-risk scenarios
  - Optimize speed restriction policies

Track Buckle from 2022 MxV Rail/BNSF Test

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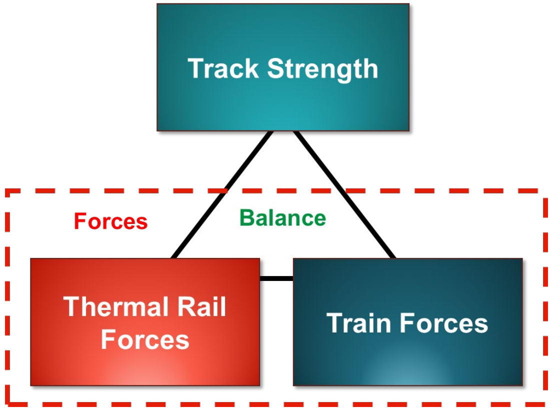
Outline

1 Background



Track Strength

Forces

Balance

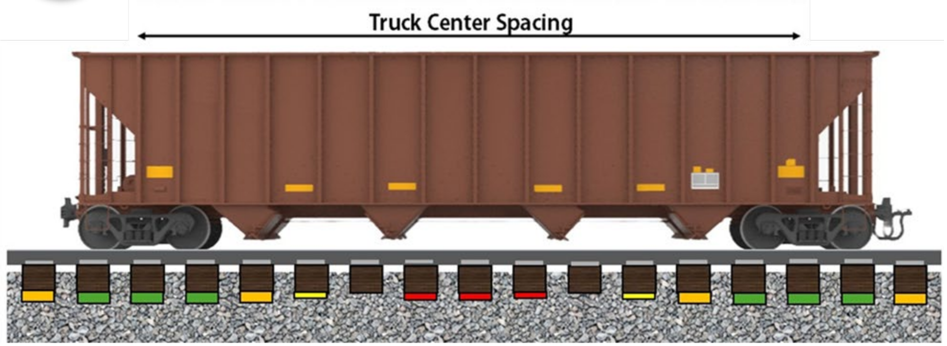
Thermal Rail Forces

Train Forces

2 Longitudinal Vehicle Forces

3 Track Uplift Testing

4 Track Uplift Modeling



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Topic 1: Background

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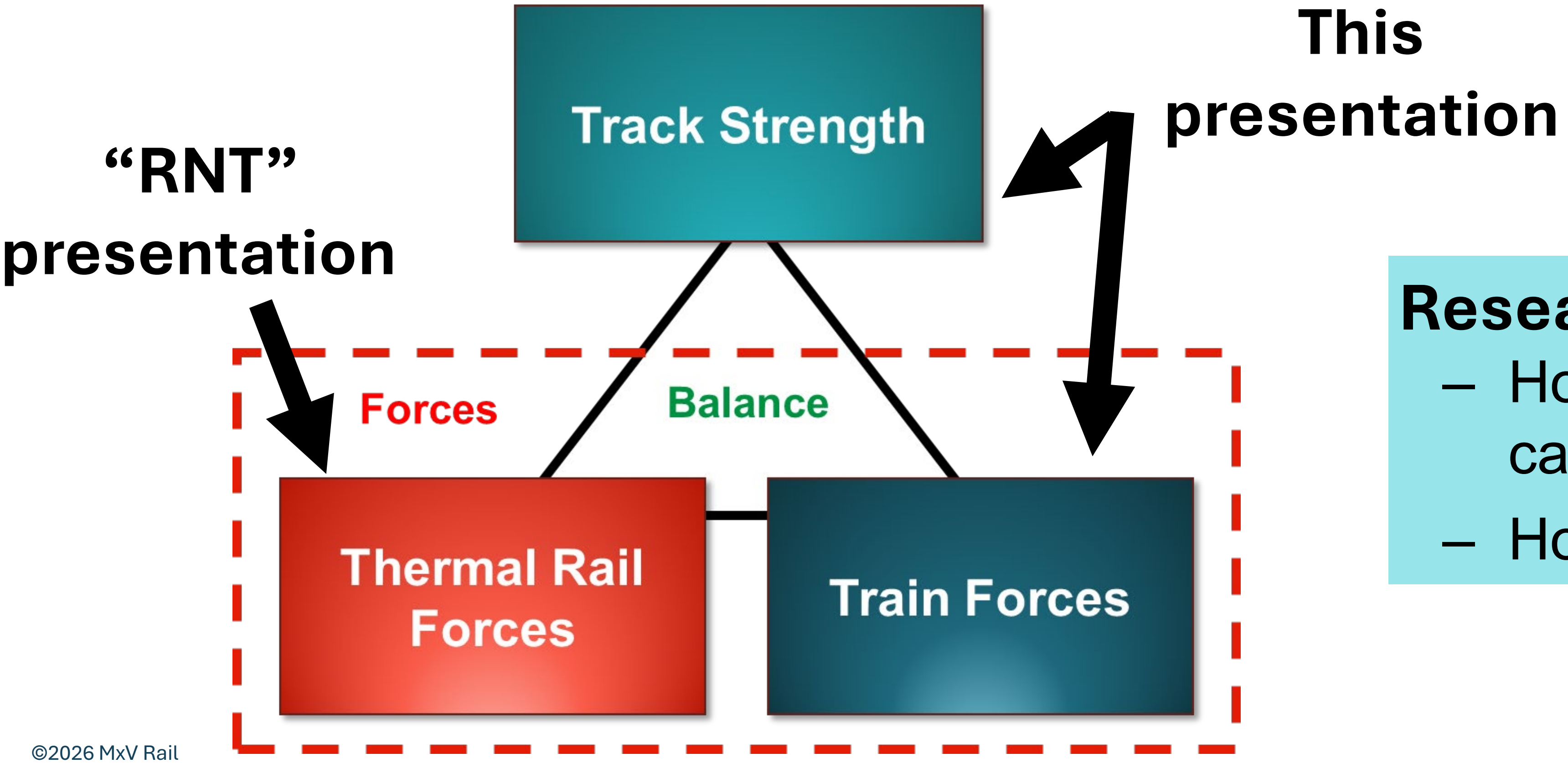
Thermal Forces and Track Stability

$$\boxed{Track\ Strength > Forces\ (Thermal\ and\ Train)}$$



Research Items:

- How do we measure each category?
- How do they interact?

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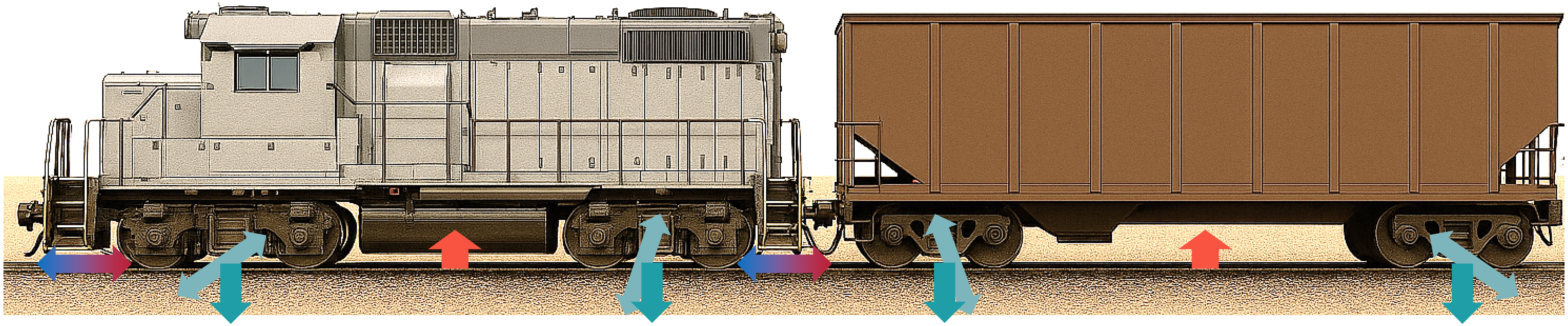
Vehicle Effects



- Longitudinal
- Uplift

2025

- Lateral Forces
- Vibrations/other

2026

- Full-scale buckle tests

2027 and beyond

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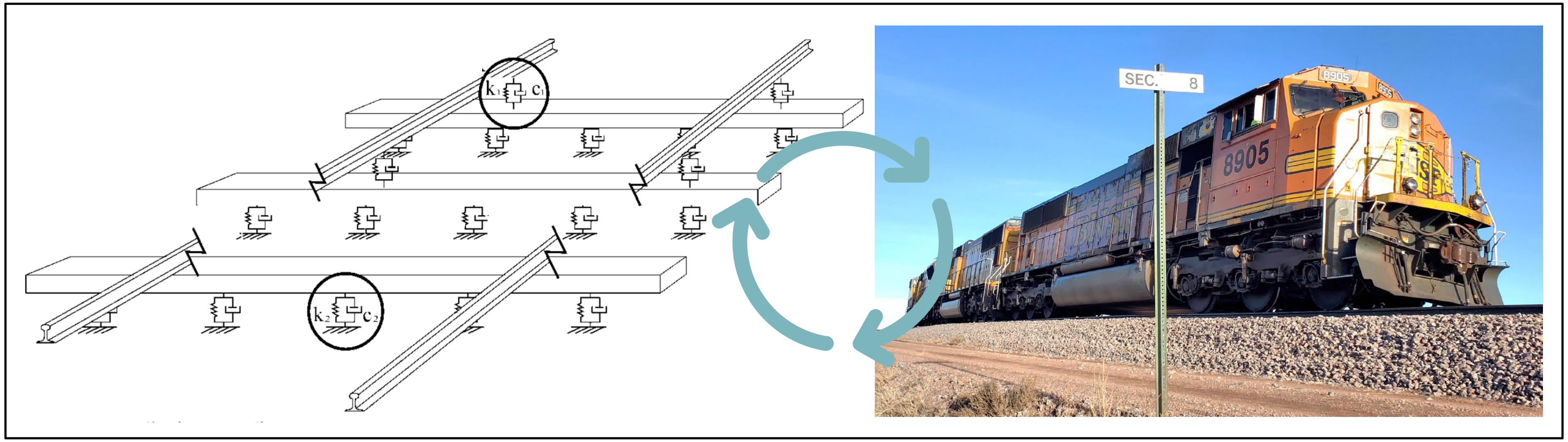
Field Tests and Modeling

- Need more field tests to better understand mechanisms and calibrate numerical models
- Full-scale track buckle test planned in the future
- Collaborations with other institutions to access the latest in various types of relevant models



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Topic 2: Longitudinal Force from Locomotive Traction

TD25-017: “Longitudinal Rail Forces from Locomotive Traction”

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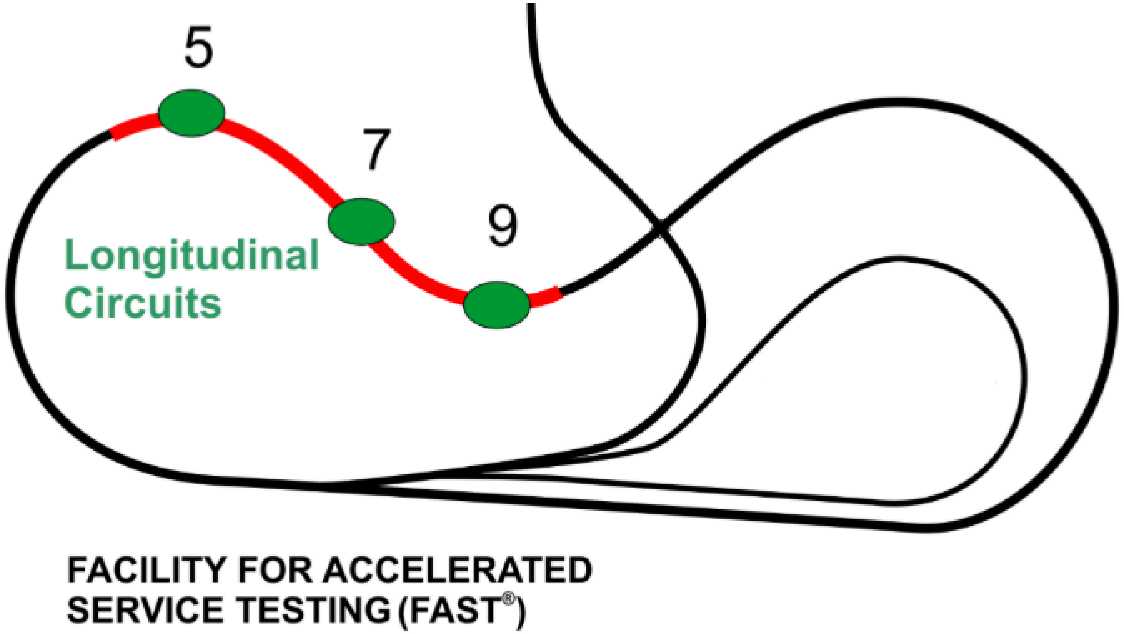
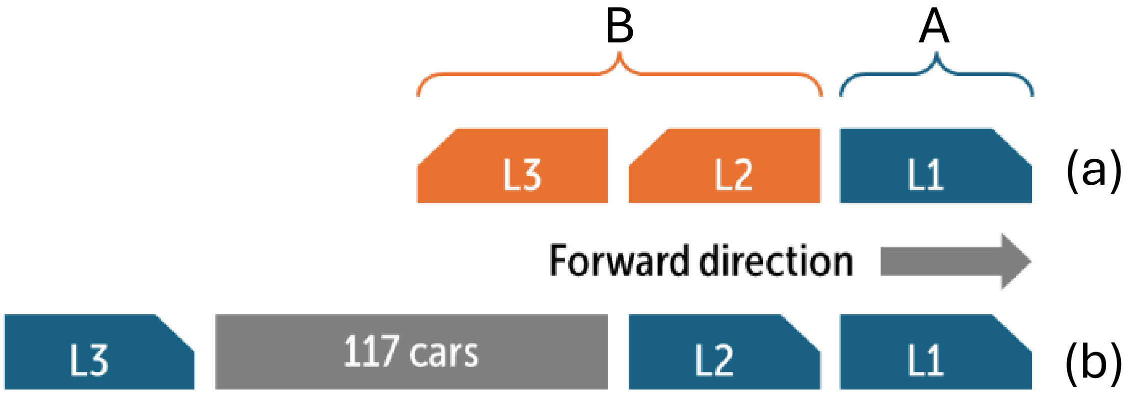
Longitudinal Forces

- **Two parts with (a) dedicated locomotive consist and (b) Facility for Accelerated Service Testing (FAST®) train**
  - For (a), locomotives consist A ran in throttle and consist B ran in dynamic braking through Sections 5 to 9 in both directions
  - FAST consist (b) operated normally counterclockwise (Section 9 to 5)
- **Truck Performance Detectors (TPD) in all three sections**





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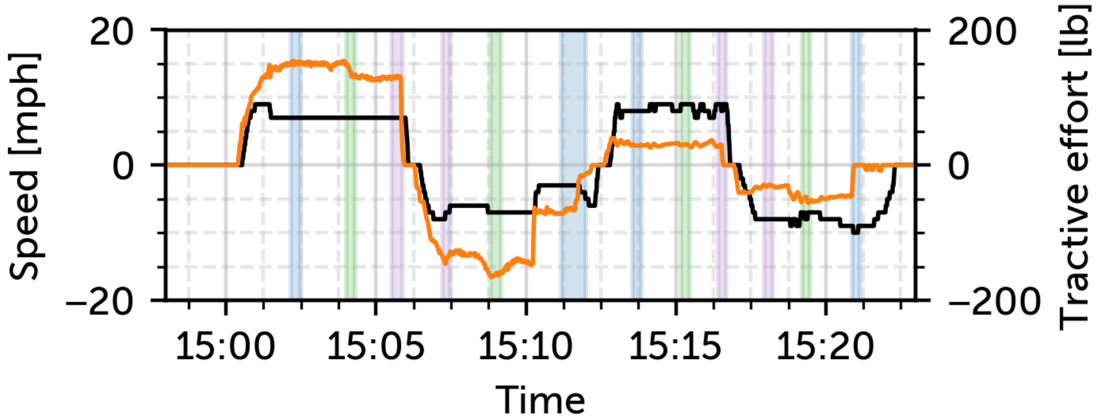
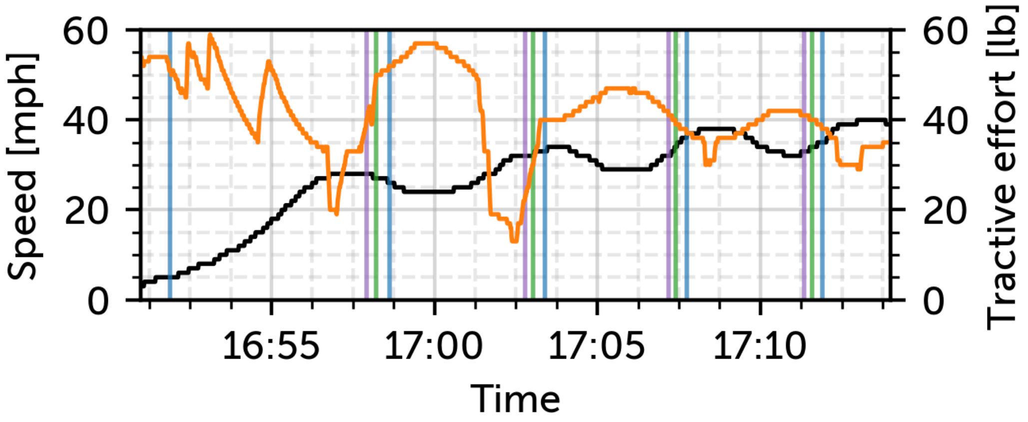
Longitudinal Forces

- **Dedicated locomotive consist**
  - Various maximum tractive efforts (TE), dynamic braking efforts (DB), and speeds
  - TE or DB leading
- **FAST train**
  - Low TE in general



(a) Locomotives only

Shaded areas: test consist passing through TPD



(b) FAST consist

Colored lines: head-end passing through TPD

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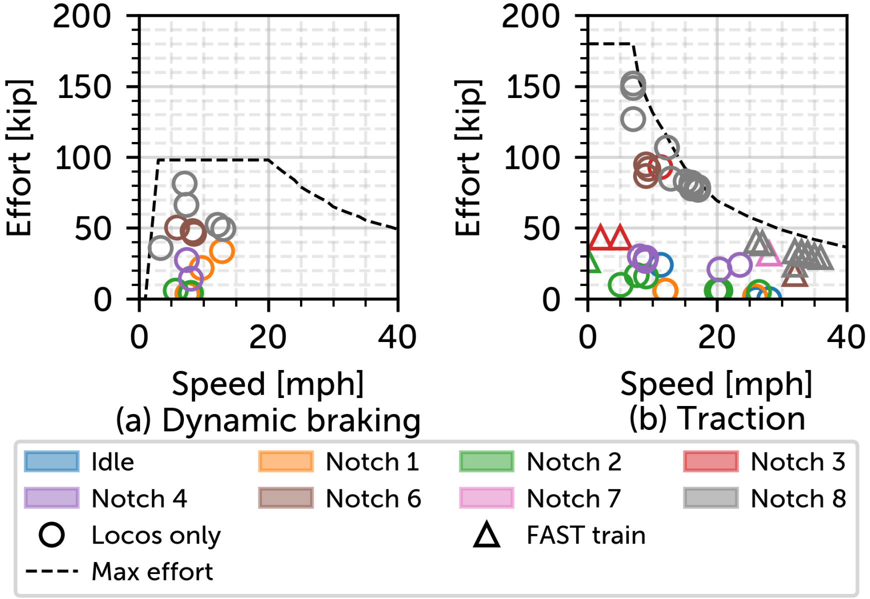
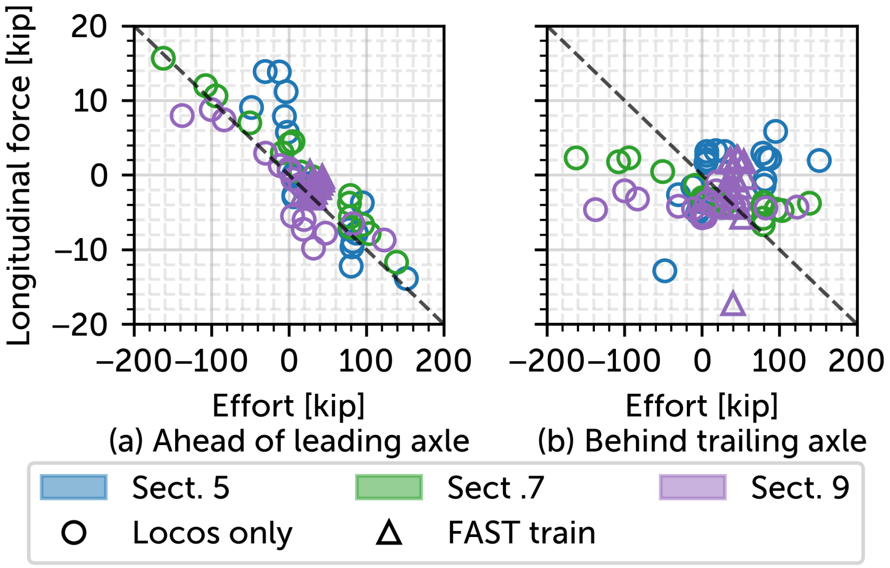
Longitudinal Forces

- **Maximum traction forces generated approximately 150 kips**
- **More consist results ahead of the leading axle vs. behind the trailing axle**
- **On average, 10% of locomotive traction is transferred to the rail as longitudinal force**
  - ~0.5°F equivalent rail temperature increase per kip longitudinal rail force



(a) Dynamic braking

(b) Traction



(a) Ahead of leading axle

(b) Behind trailing axle

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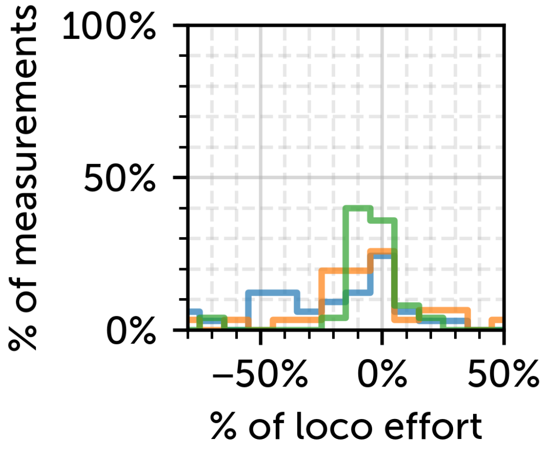
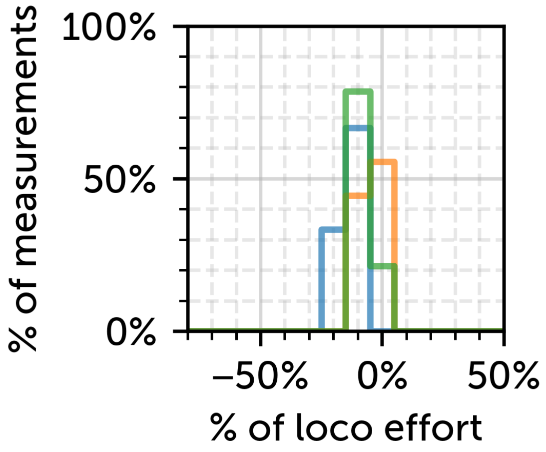
Longitudinal Forces

- **Results are more consistent in high traction than low traction**
- **Vertical load changes individual rail forces considerably**



(a) Effort ≤ 50, ahead



(b) Effort > 50, ahead

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Topic 3: Track Uplift (Field Test)

TD26-001: “Track Uplift Tests at FAST®”

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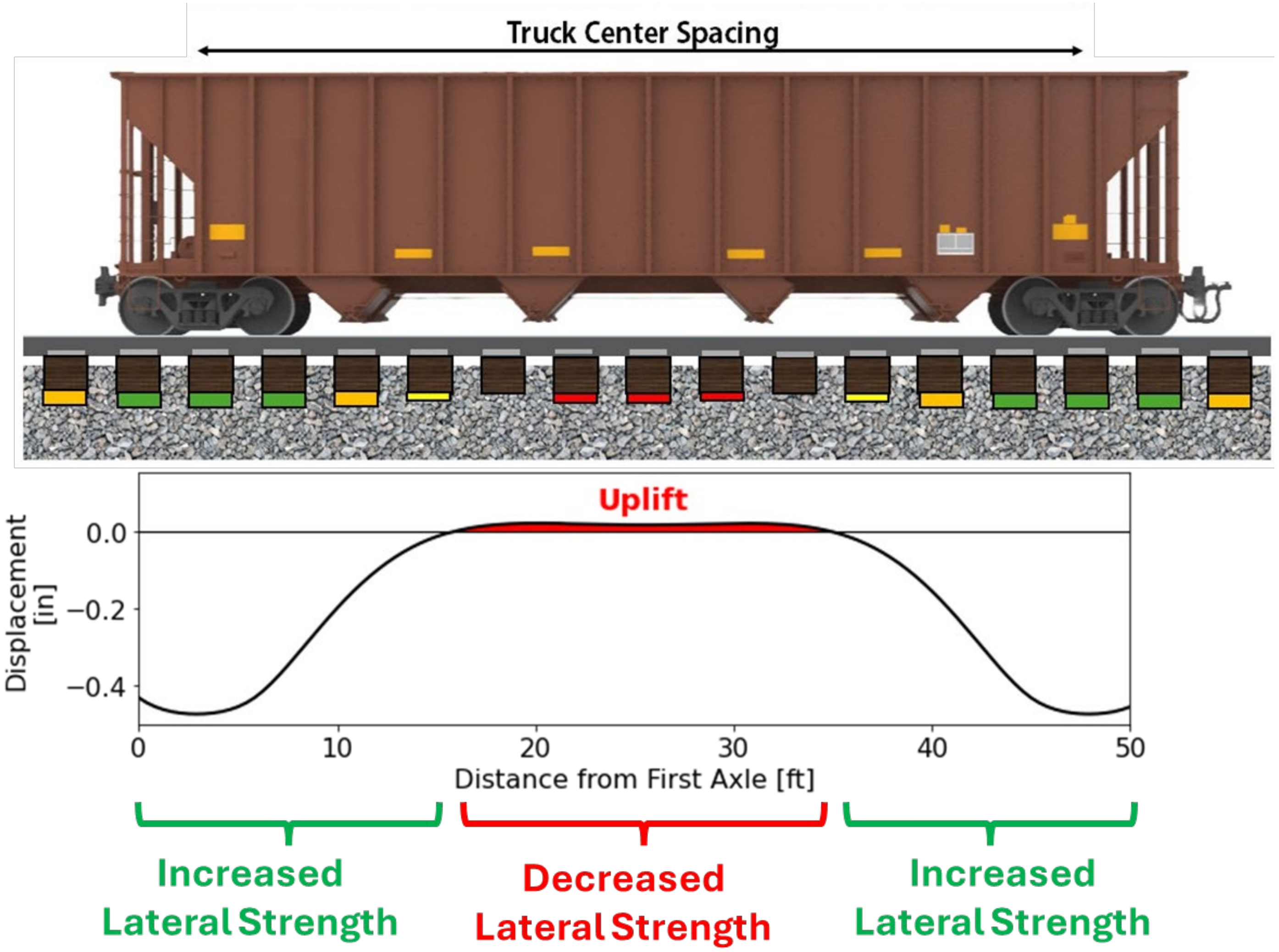
Track Uplift



- **Uplift one of multiple potential vehicle forces**
- **Rail bending can produce an uplift region in the center of the carbody**
- **Creates "weak spot"**
- **Testing in 1980s* showed effect for weaker track with low RNT**
- **Rail bending simulated using Beam on Elastic Foundation (BOEF) theory**

**Kish, A (FRA,1990)*

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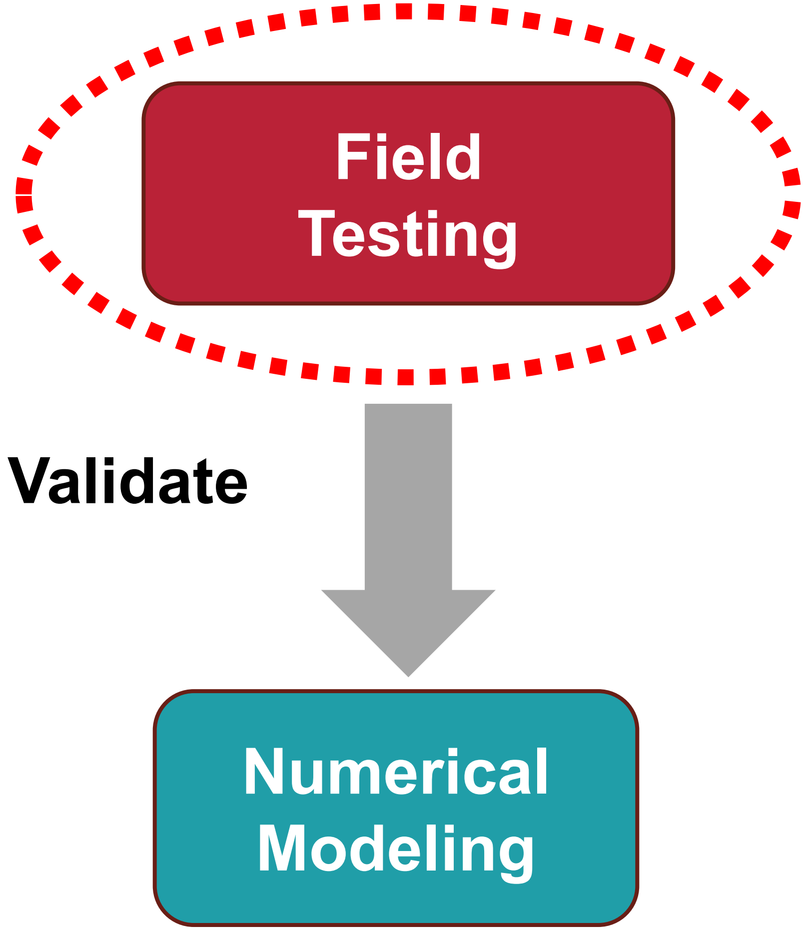
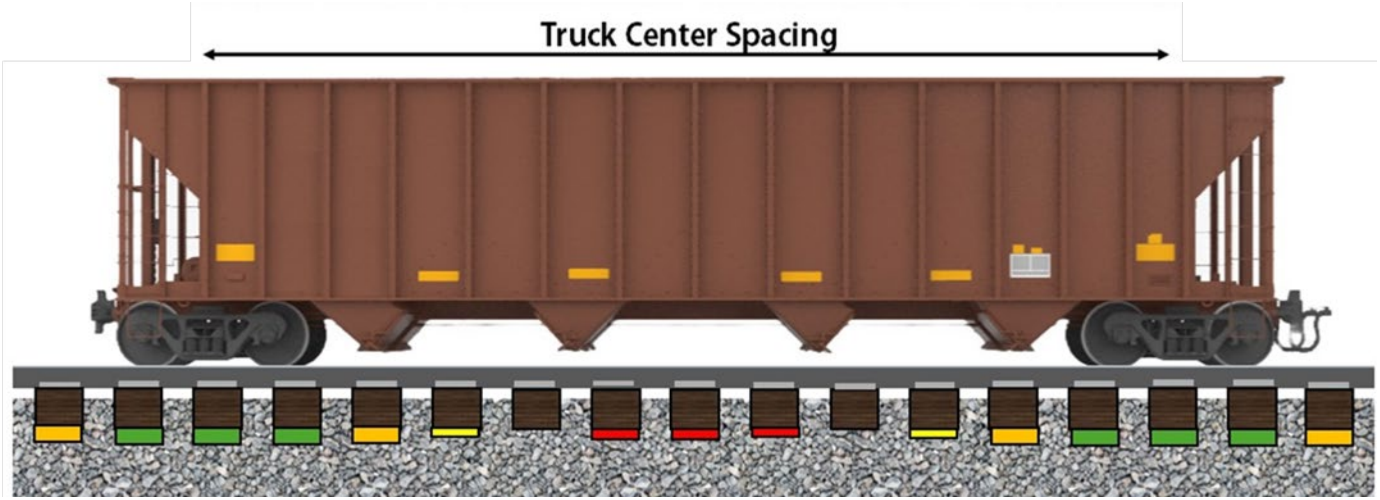
Test Objectives



Field Testing

Validate

Numerical Modeling



Included	Not Included
Axle load	Fastener type
Truck center Spacing	Vehicle speed
Track Modulus	Surface Profile

Questions

Does uplift occur and match theory?
Effect of train type and speed?
Effect of track conditions?

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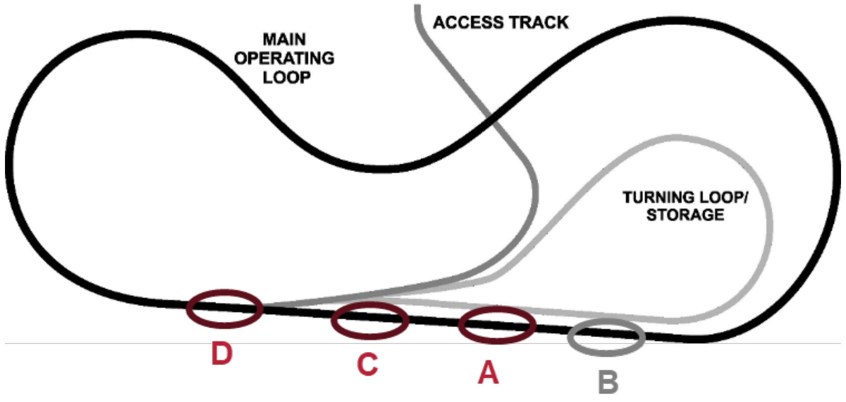
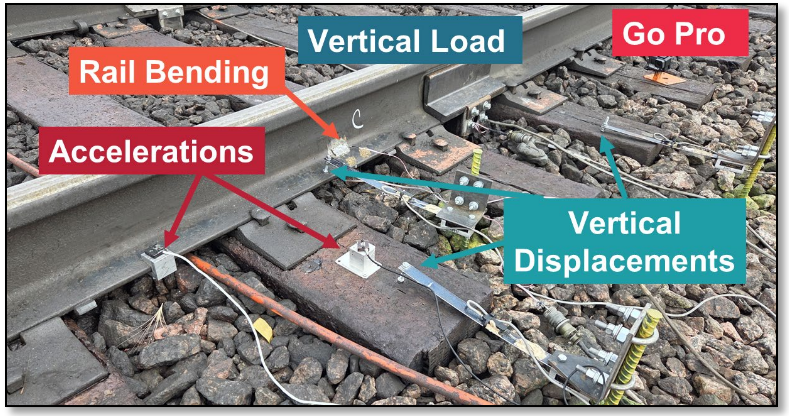
Location, Instrumentation, and Consist

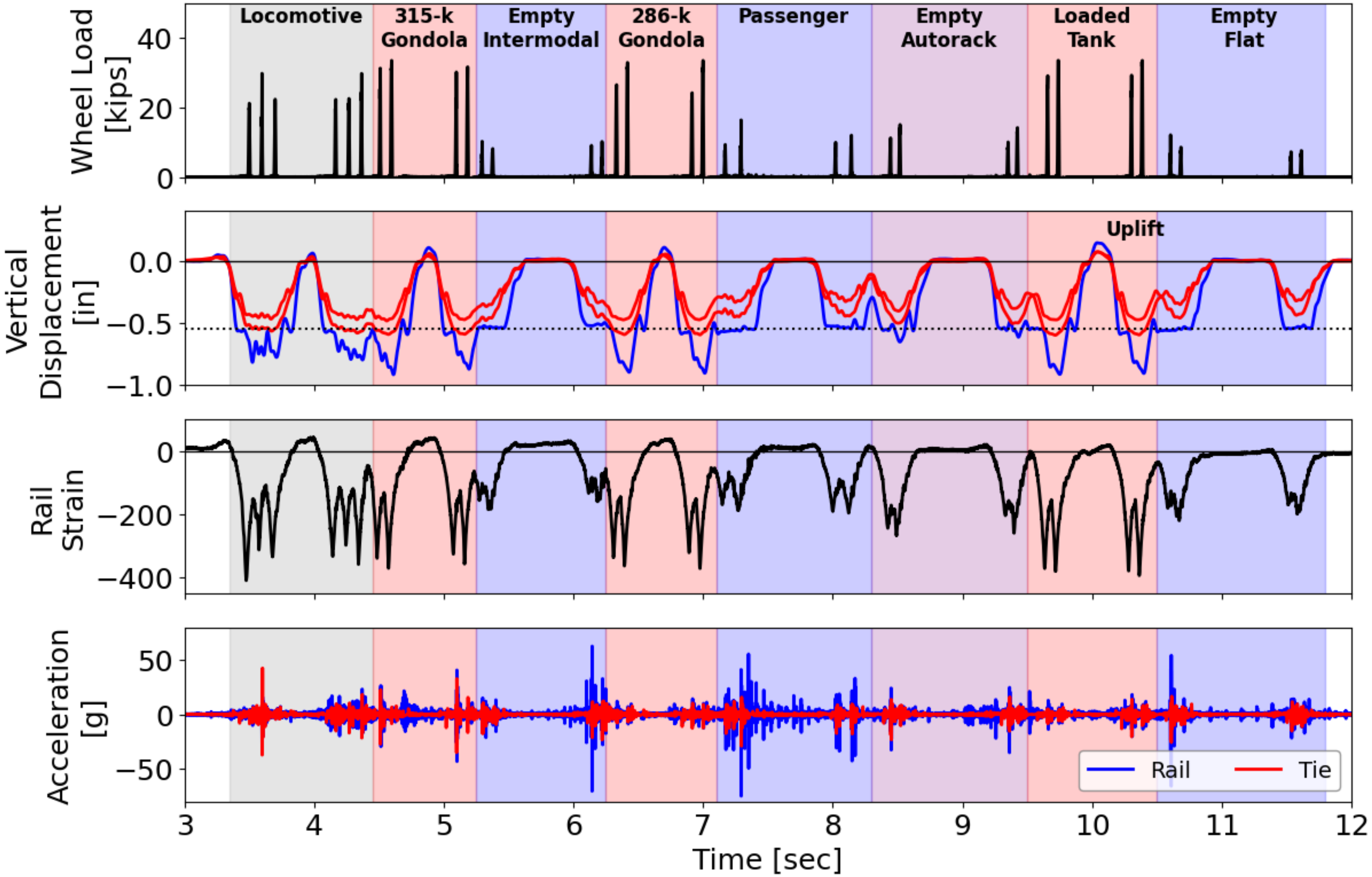
Facility for Accelerated Service Testing (FAST®) Loop



Location	Tie Type	Surface Condition
A	Wood	Good
B	Concrete	Good
C	Wood	Pumping
D	Wood	Pumping



Time History and Videos



Location A: Good Support (50 mph)

Location C: Poor Support (40 mph)

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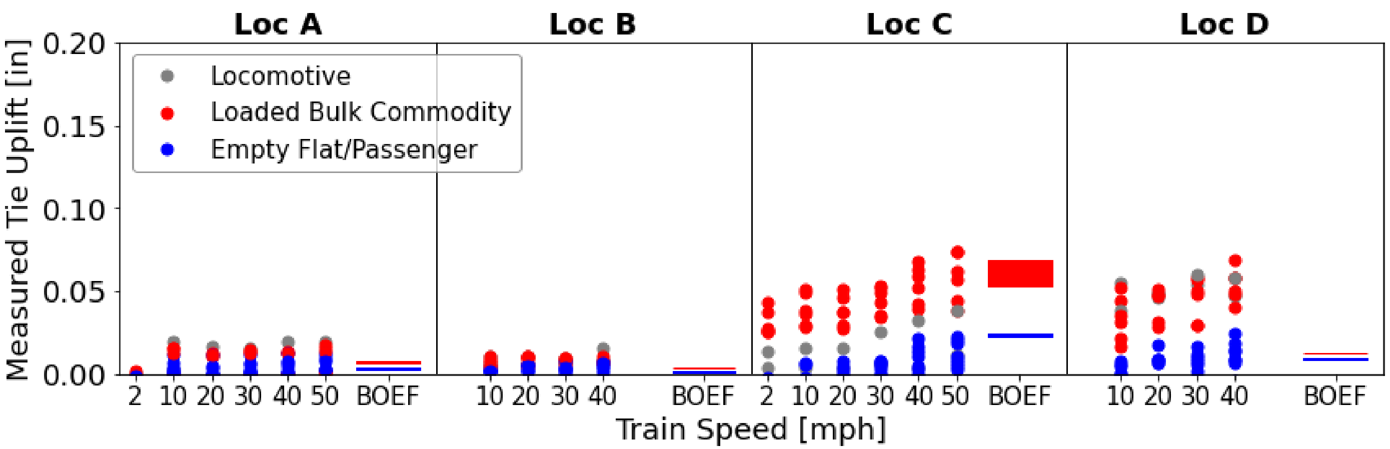
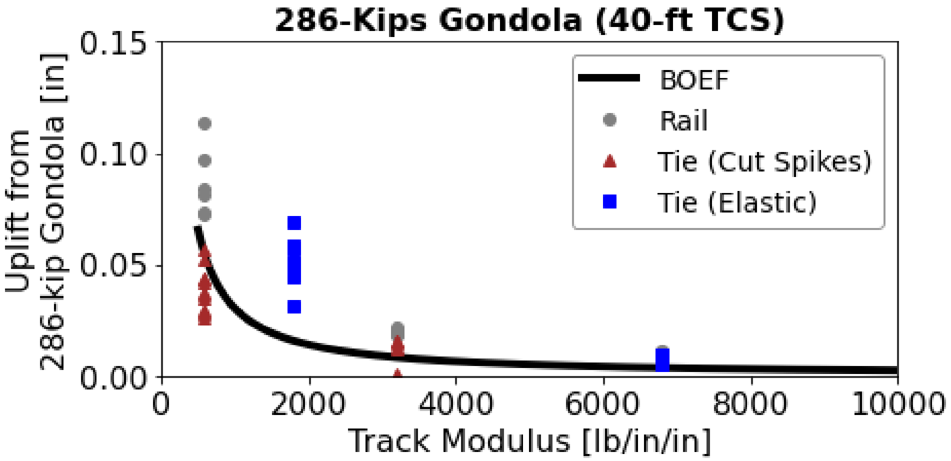
High-Level Findings





Validation

- **Field data generally matches BOEF trends**
  - Better match for wood ties with cut spikes than ties with elastic fasteners

Most Uplift

- Loaded bulk commodity cars
- Soft track (track modulus < 2000 lb/in/in or 0.25-in displacement)
- Speed influence on softer track

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Topic 4: Track Uplift (Modeling)

TD26-002: “Vehicle Influence on Track Buckle Strength: Track Uplift”

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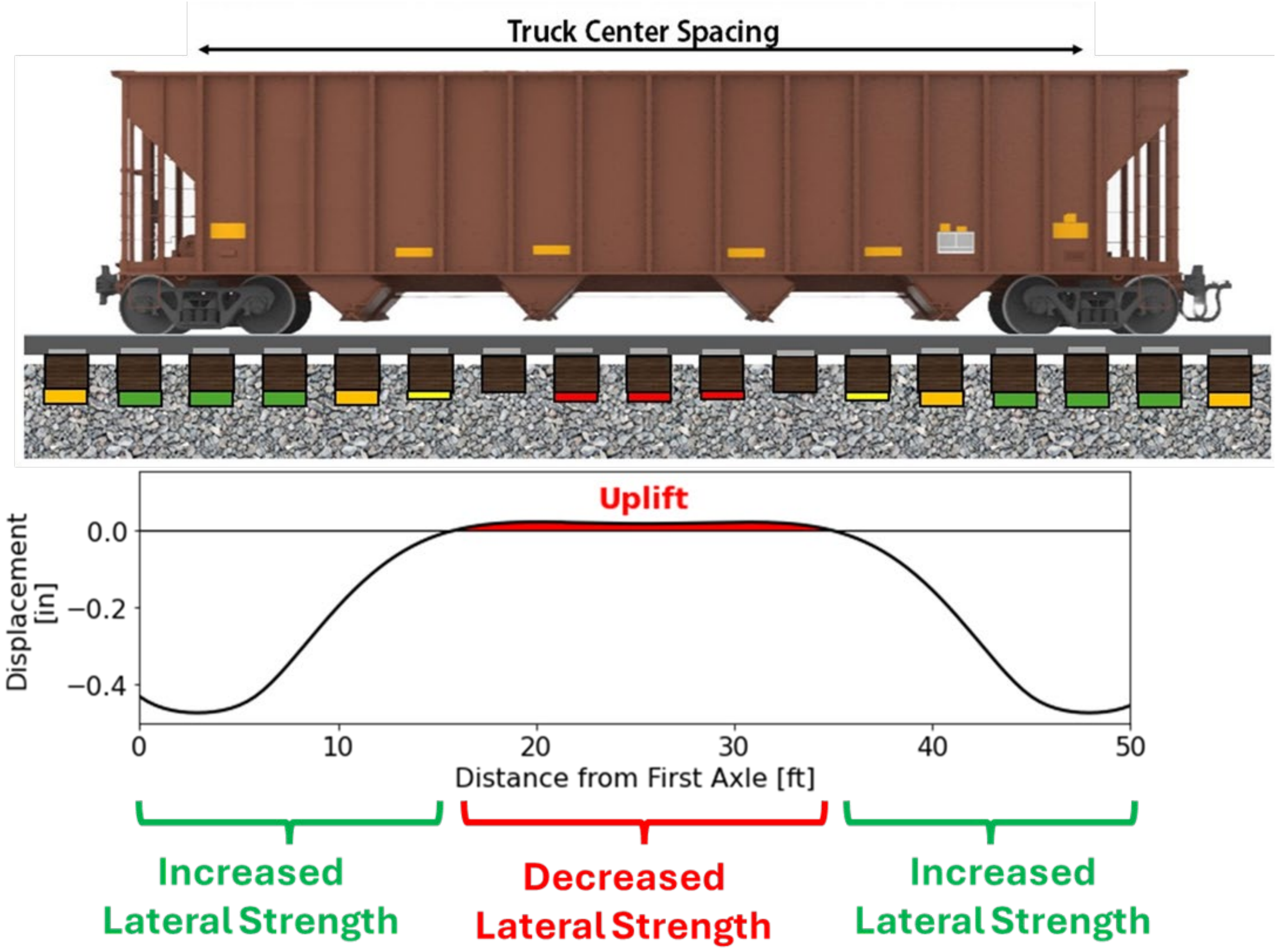
AAR/TAMU Model and Uplift

Field Testing

Use BOEF to input lateral track strength of each tie along track

Numerical Modeling



AAR/Texas A&M University (AAR/TAMU) model is an AAR-funded finite element method track buckle model

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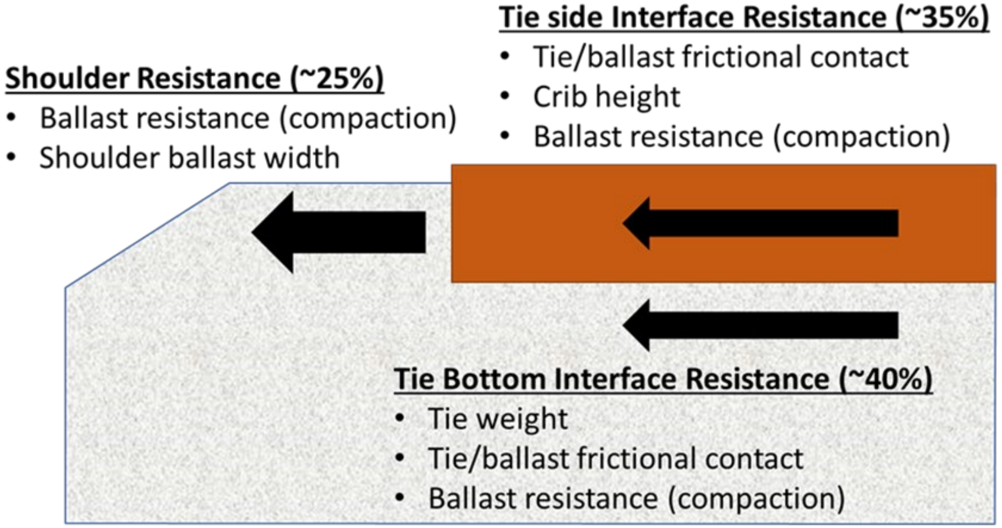
Model Inputs/Outputs

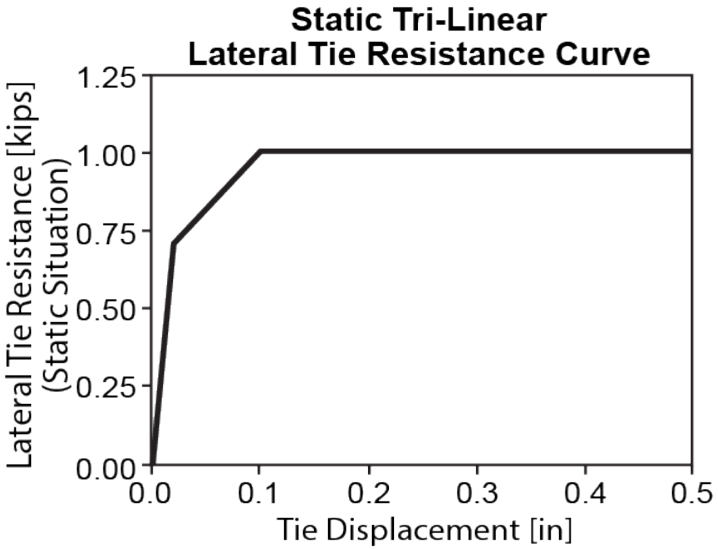
- **Interested in progressive buckle growth under vehicle**



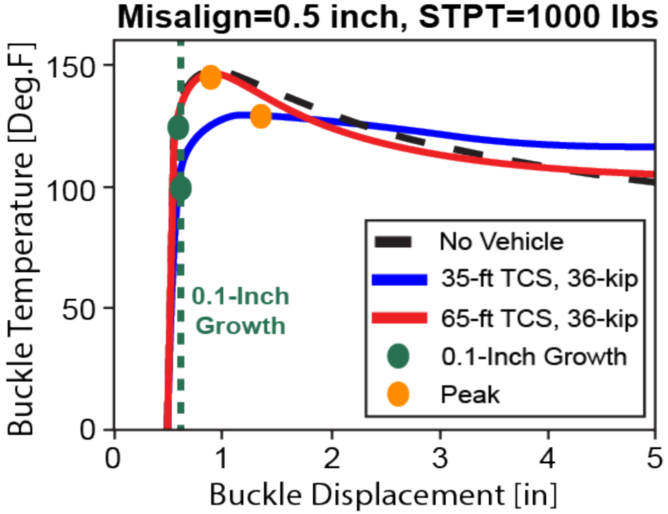
Shoulder Resistance (~25%)
- Ballast resistance (compaction)
- Shoulder ballast width

Tie side Interface Resistance (~35%)
- Tie/ballast frictional contact
- Crib height
- Ballast resistance (compaction)

Tie Bottom Interface Resistance (~40%)
- Tie weight
- Tie/ballast frictional contact
- Ballast resistance (compaction)



Static Tri-Linear Lateral Tie Resistance Curve



Misalign=0.5 inch, STPT=1000 lbs

1.25-inch Misalignment

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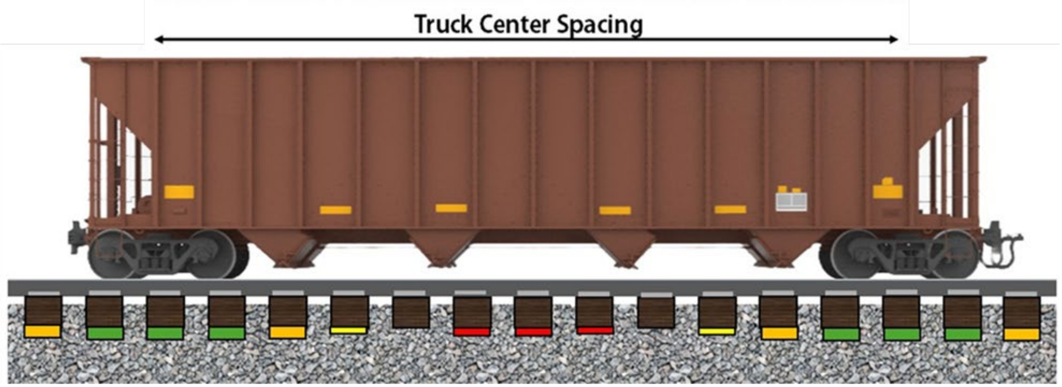
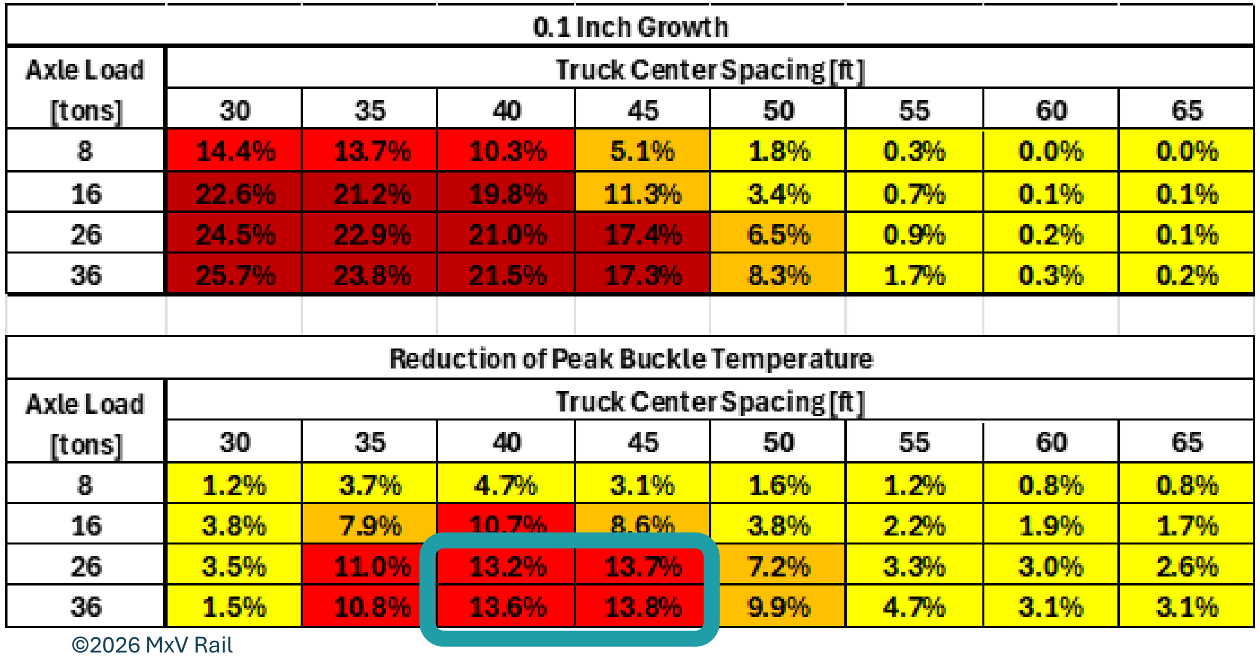
Vehicle Type





0.1 Inch Growth								
Axle Load [tons]	Truck Center Spacing [ft]							
	30	35	40	45	50	55	60	65
8	14.4%	13.7%	10.3%	5.1%	1.8%	0.3%	0.0%	0.0%
16	22.6%	21.2%	19.8%	11.3%	3.4%	0.7%	0.1%	0.1%
26	24.5%	22.9%	21.0%	17.4%	6.5%	0.9%	0.2%	0.1%
36	25.7%	23.8%	21.5%	17.3%	8.3%	1.7%	0.3%	0.2%

Reduction of Peak Buckle Temperature								
Axle Load [tons]	Truck Center Spacing [ft]							
	30	35	40	45	50	55	60	65
8	1.2%	3.7%	4.7%	3.1%	1.6%	1.2%	0.8%	0.8%
16	3.8%	7.9%	10.7%	8.6%	3.8%	2.2%	1.9%	1.7%
26	3.5%	11.0%	13.2%	13.7%	7.2%	3.3%	3.0%	2.6%
36	1.5%	10.8%	13.6%	13.8%	9.9%	4.7%	3.1%	3.1%

Key Findings

- **Loaded bulk commodity cars in softer track show greatest reduction (~15%)**
- **Shorter loaded bulk commodity cars may be more susceptible to small misalignments but not big buckles**
- **Longer vehicles (passenger, intermodal, autorack, flats) show marginal reduction but may be more susceptible to larger buckles**
- **Softer track conditions tend to produce more uplift and lower buckle temperatures. Softer track conditions are commonly associated with soft subgrade, surface profile**

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Summary and Acknowledgements

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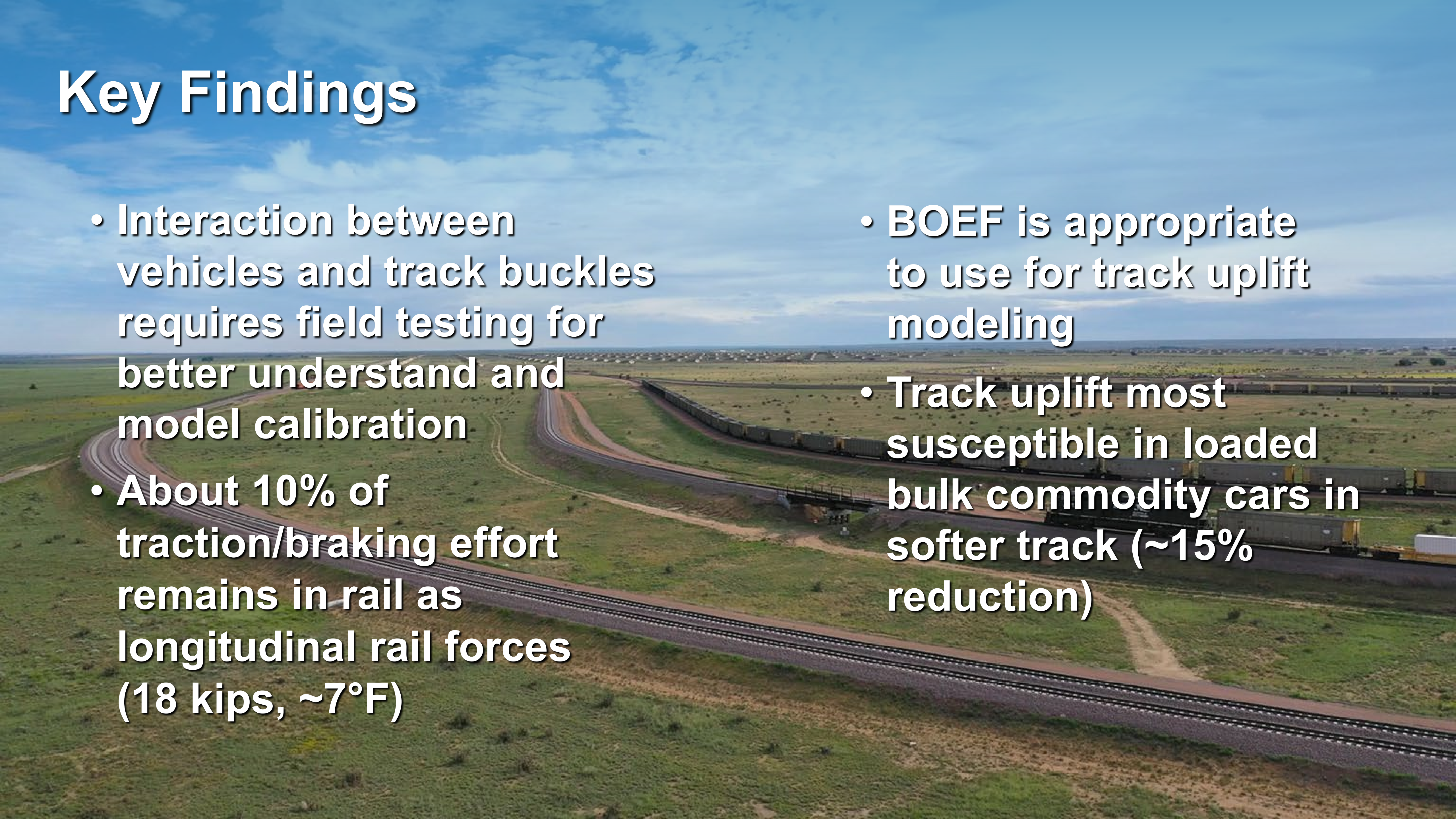
Key Findings



- Interaction between vehicles and track buckles requires field testing for better understand and model calibration
- About 10% of traction/braking effort remains in rail as longitudinal rail forces (18 kips, ~7°F)
- BOEF is appropriate to use for track uplift modeling
- Track uplift most susceptible in loaded bulk commodity cars in softer track (~15% reduction)

Acknowledgements

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- MxV Rail Instrumentation, Track, and Operations Teams
- Track Buckling Prevention and Heat Speed Restriction Technical Advisory Groups
- MxV Rail Engineering Teams (Track Infrastructure, Vehicle, and Data Science)

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Back to Plenary Agenda

Friction Product Interaction with RCF at FAST

Ulrich Spangenberg, Ph.D.

Scientist

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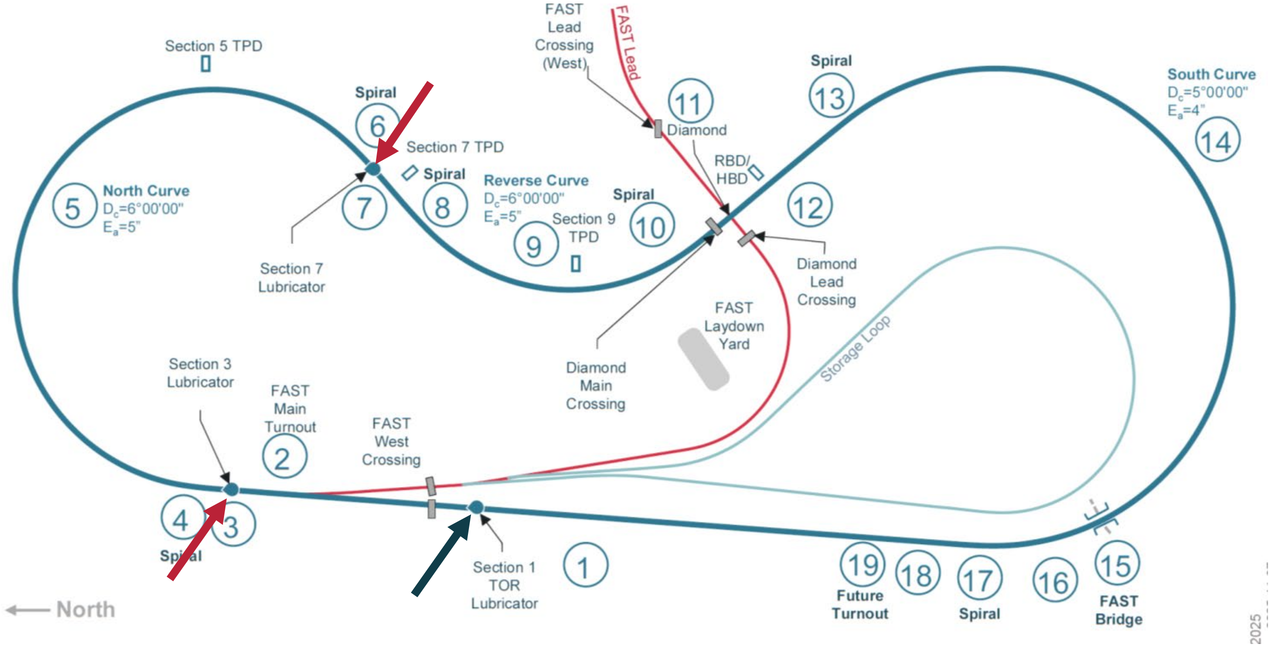
Introduction

- **Top-of-rail friction modifier (TOR-FM) applicator originally located at gage face lubricator**
- **TOR-FM applicator moved in May 2024**
- **Damage at applicator observed in 2025**

Map of FAST



Damage at TOR-FM applicator

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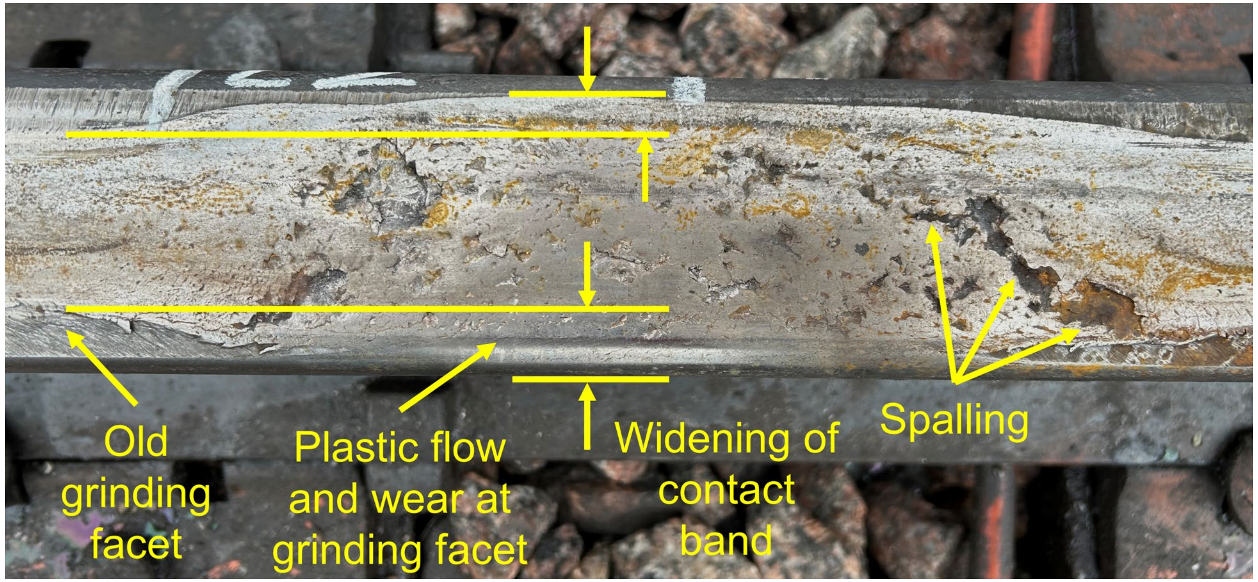
Introduction

- **Damage mainly rolling contact fatigue (RCF) and crushed head**
- **Wheel impacts at applicator**
- **Ballast and track quality degradation at applicator**

Damage observed on rail



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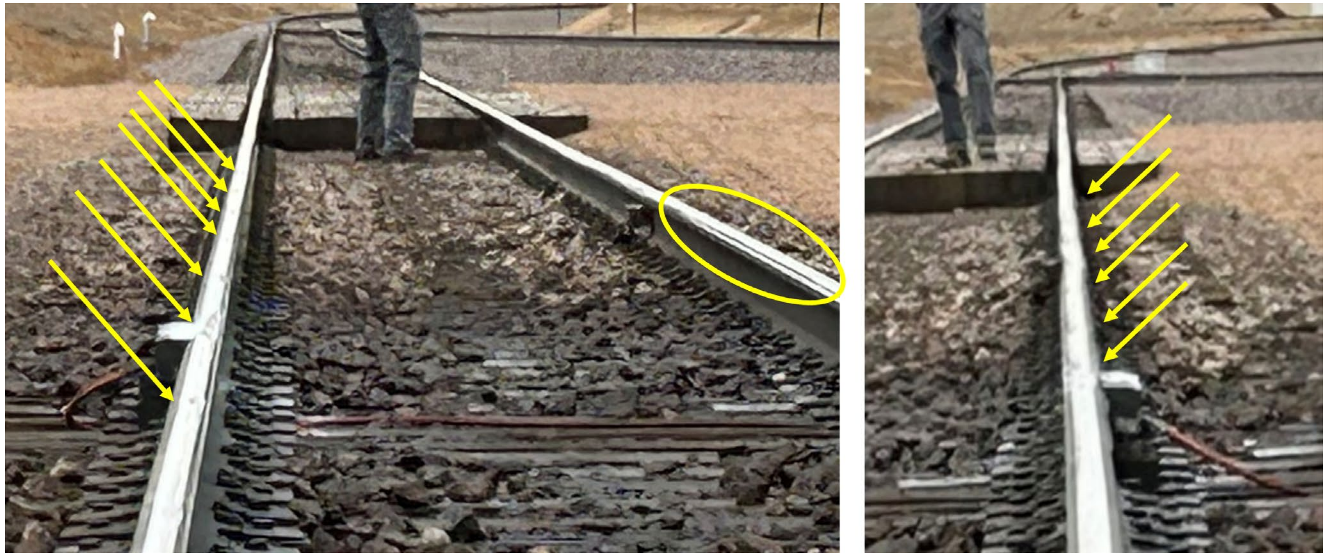
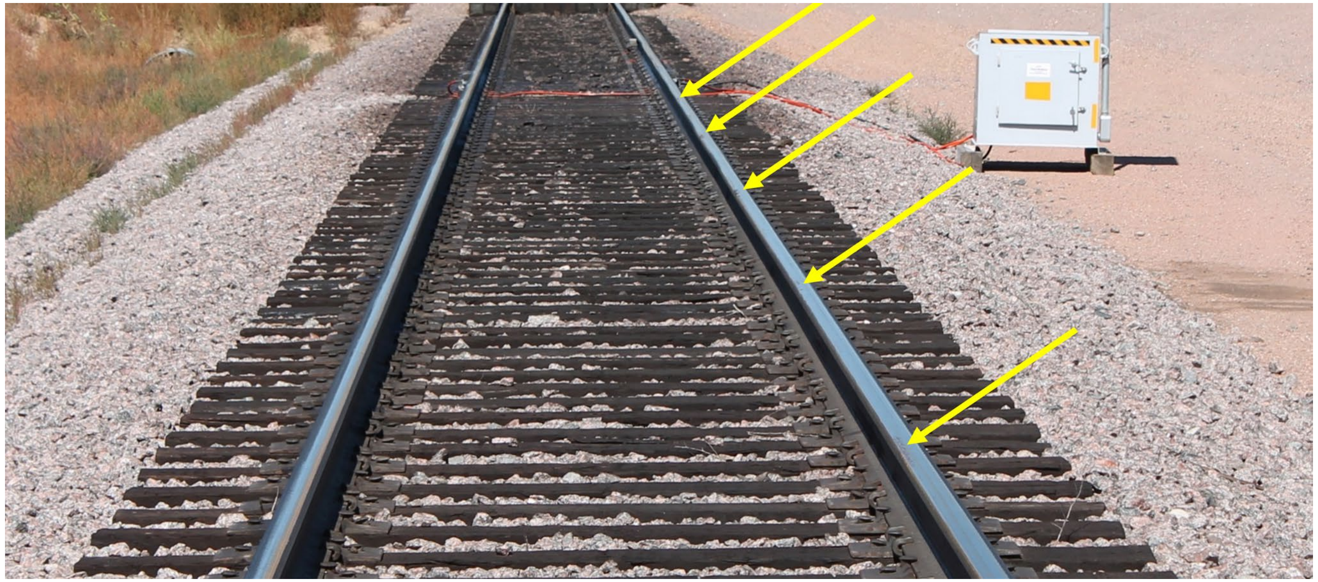
Introduction

- **Periodic RCF on left and right rails**
- **South rail ground in January 2025**
- **Damage on south rail absent in May 2025**
- **Goal**
  - Determine both the root cause of damage and actions to avoid such damage in future

Periodic dark patches on left and right rails towards the north



Periodic dark patches on right rails towards the south, September 2024



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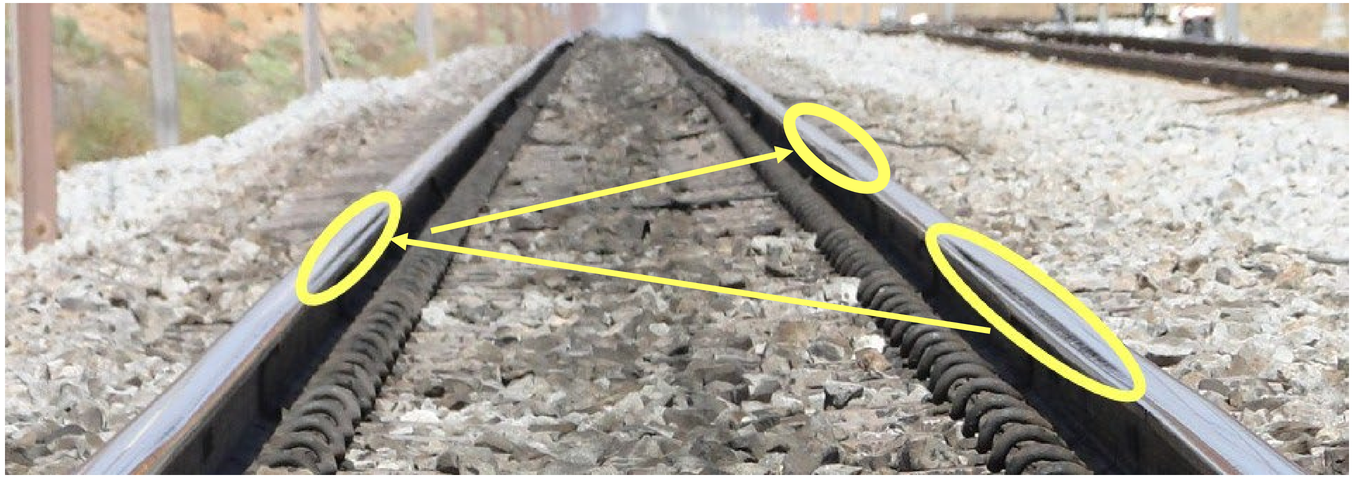
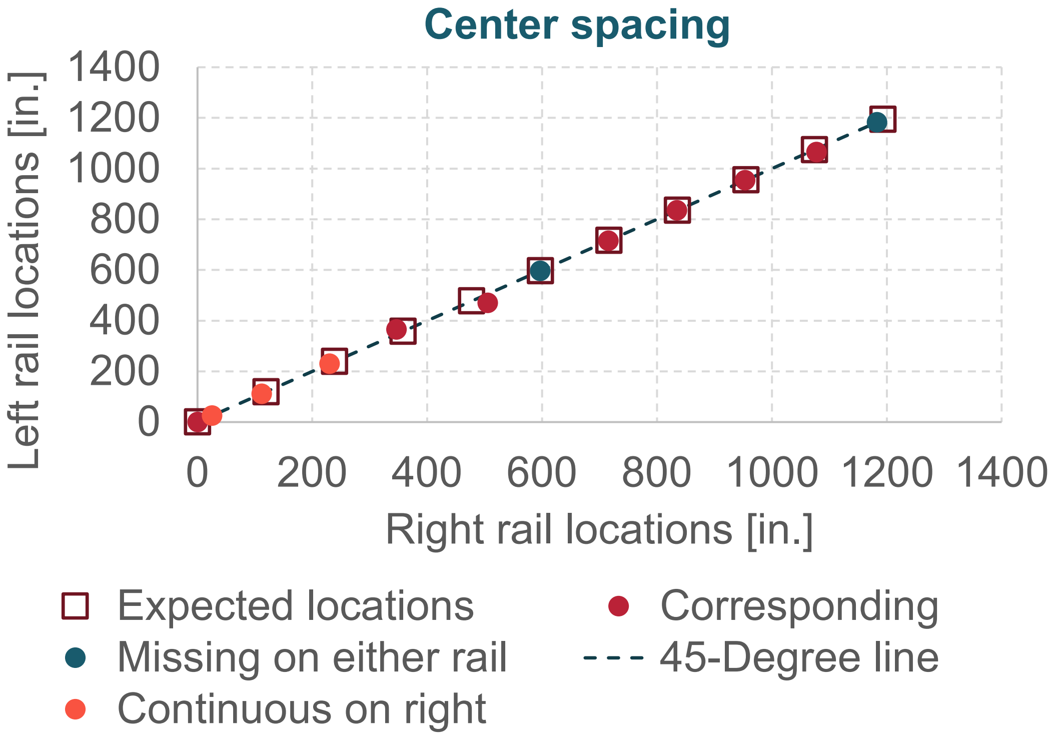
Periodic RCF – Hypothesis 1

- **Hypothesis 1**
  - Periodic RCF from vehicle instability caused by level crossing
- **Center spacing of periodic RCF**



Periodic dark patches alternating on left and right rails in South Africa[1]



[1] Spangenberg U. *Reduction of rolling contact fatigue through the control of the wheel wear shape*. University of Pretoria, 2016.

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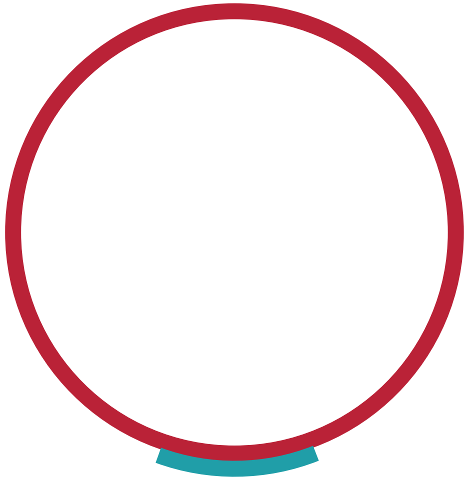
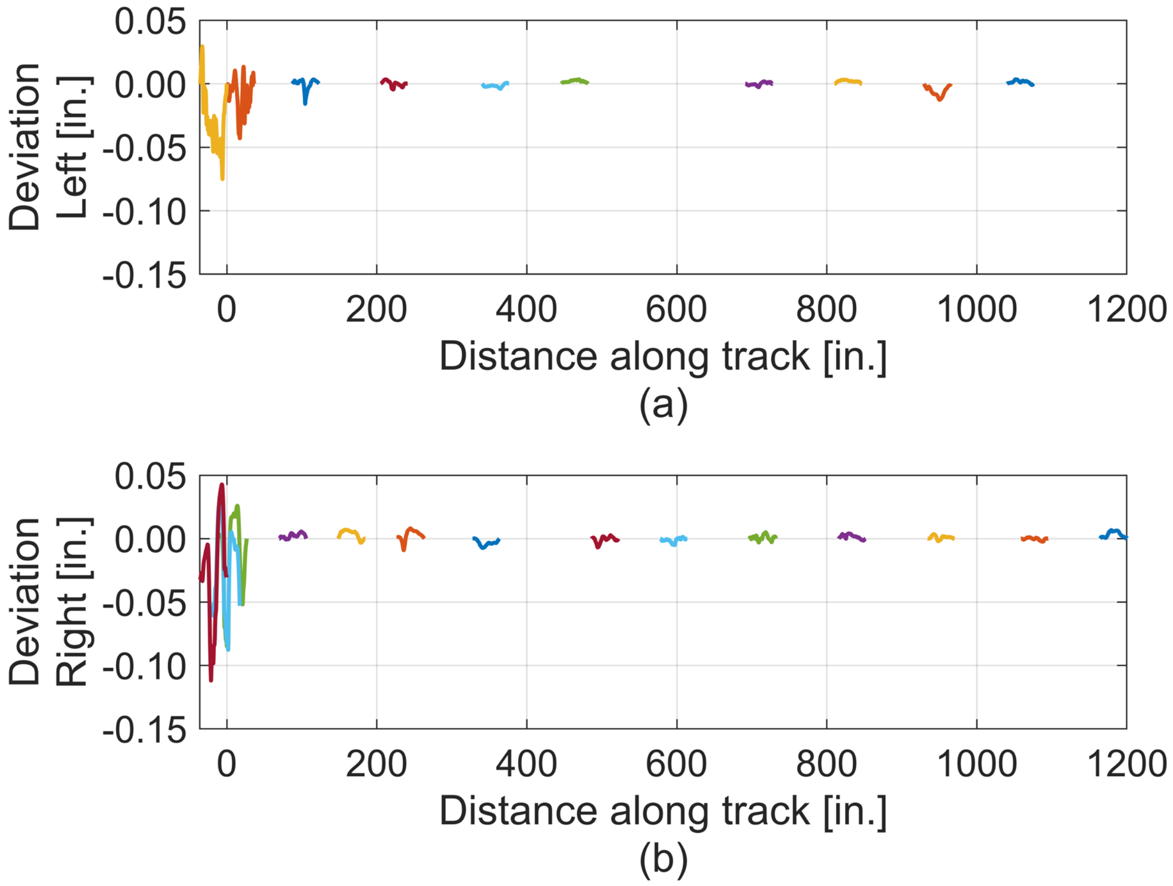
Periodic RCF – Hypothesis 2

- **Hypothesis 2**
  - Wheel TOR-FM pickup impacting track due to incompressibility
- **Rail surface depression at RCF locations**





Rail surface depression

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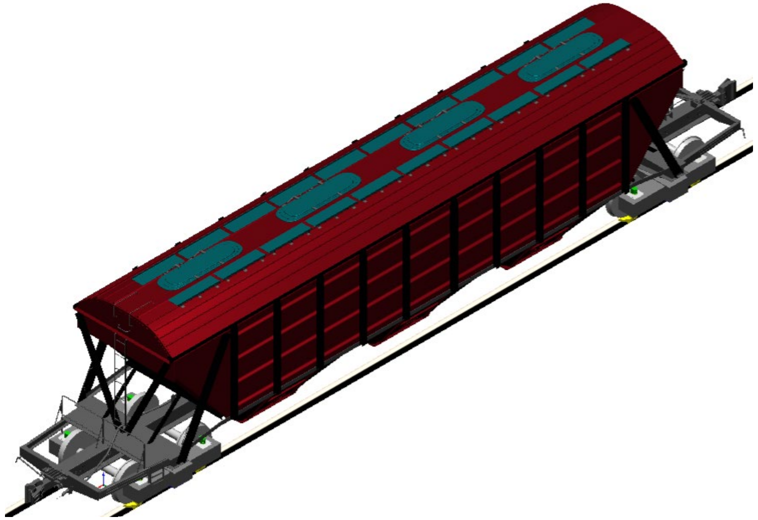
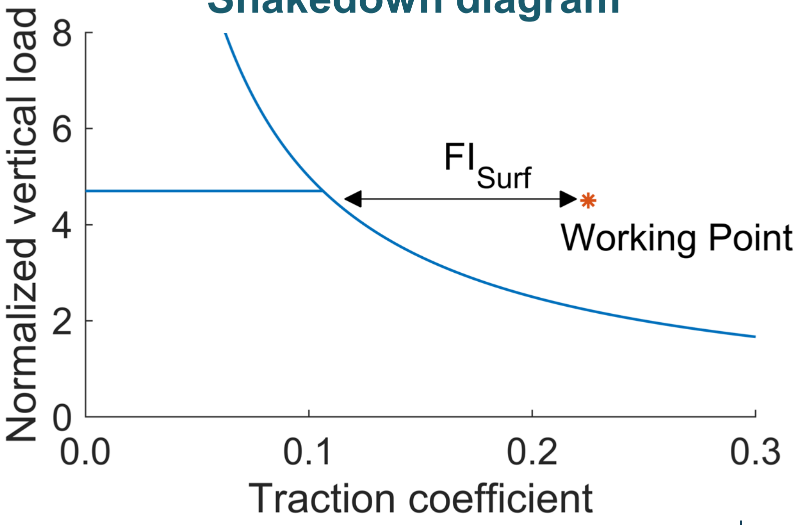
Periodic RCF – Hypothesis 3

- **Studies suggest friction products may interact with RCF**
- **Hypothesis 3**
  - RCF initiation exacerbated by TOR-FM pickup and deposit
- **NUCARS®* analyses**
  - Two main trucks with measured wheels
  - Constant speed of 40 mph
  - Wear number (Tγ) for wear
  - Surface fatigue index[2] (FI_{Surf}) for RCF

Example of a NUCARS model



Shakedown diagram



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2. Ekberg A, Kabo E, Andersson H. An engineering model for prediction of rolling contact fatigue of railway wheels. *Fatigue Fract Eng Mater Struct* 2002; 25: 899–910.

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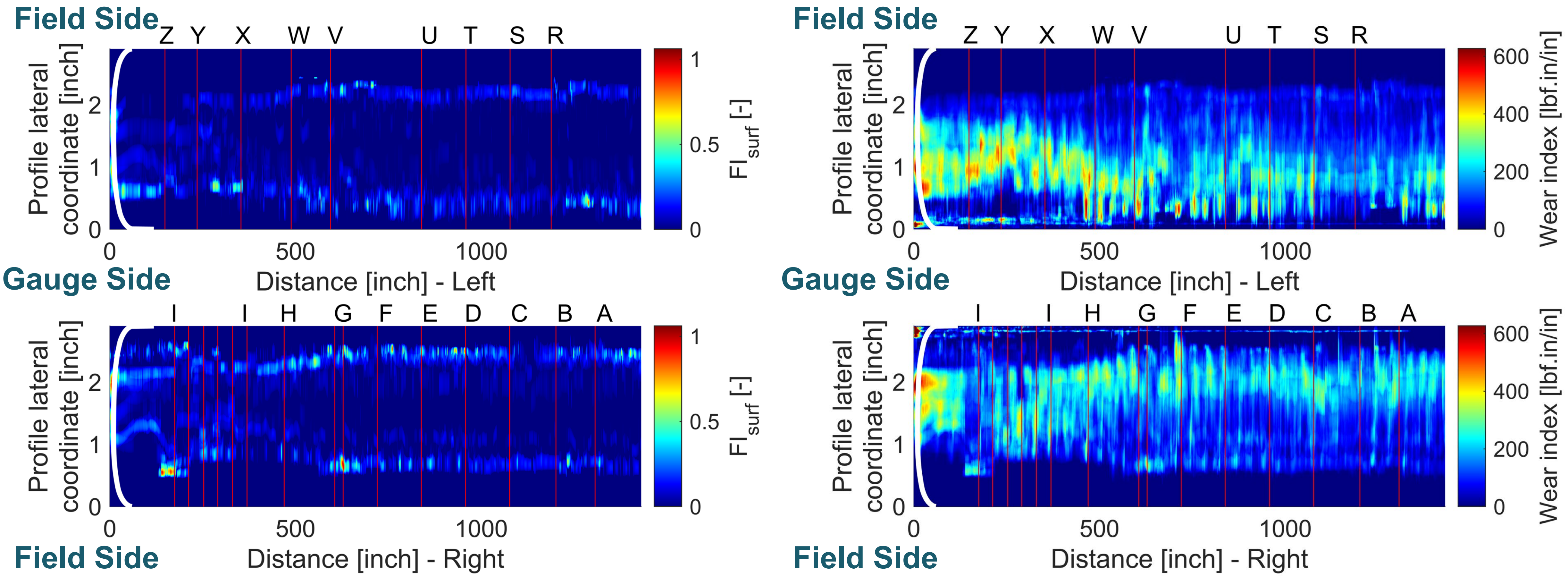
** NUCARS® is a registered trademark of MxV Rail.*

Periodic RCF – Hypothesis 3

- **Rail results for dry contact conditions**



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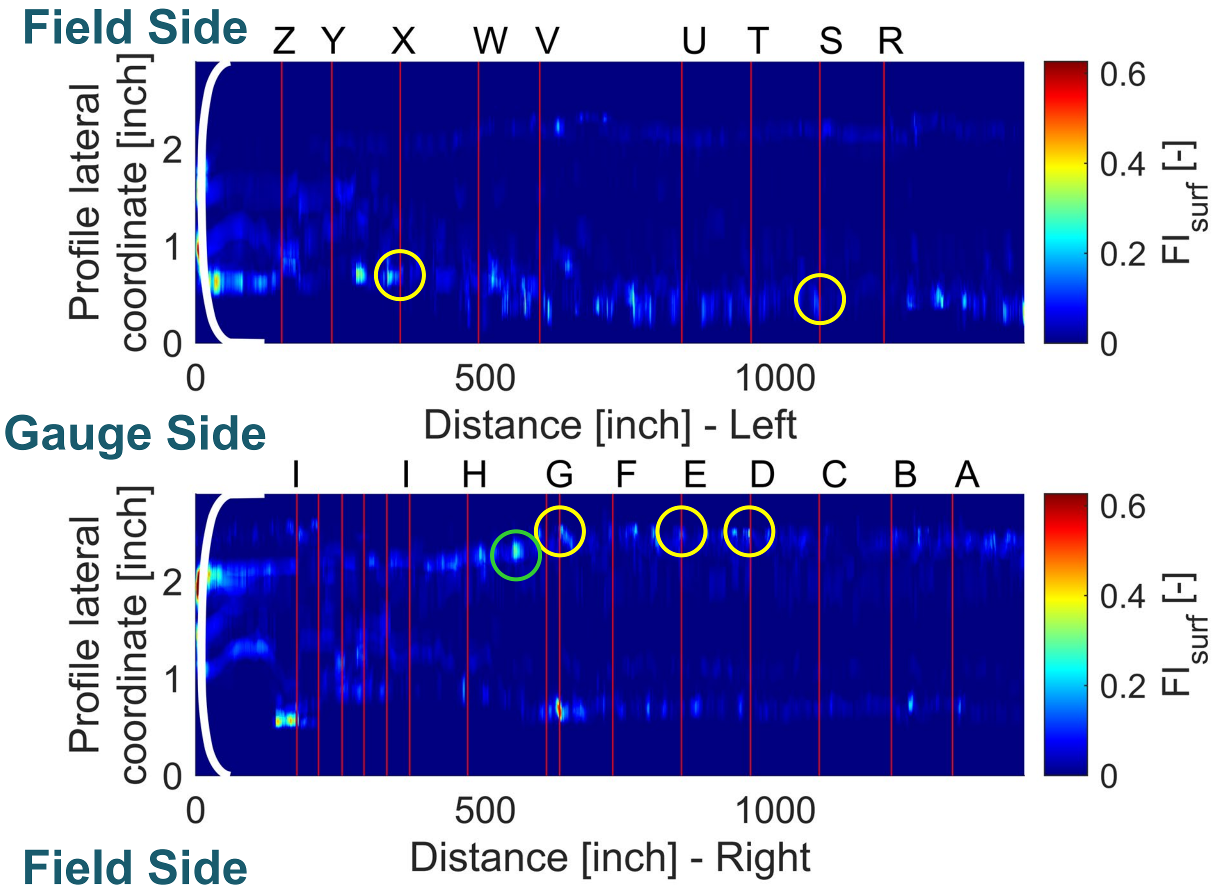
Periodic RCF – Hypothesis 3

- **Wear mask overlaid on FI_{Surf}**
- **RCF initiated first, exacerbated by TOR-FM product**



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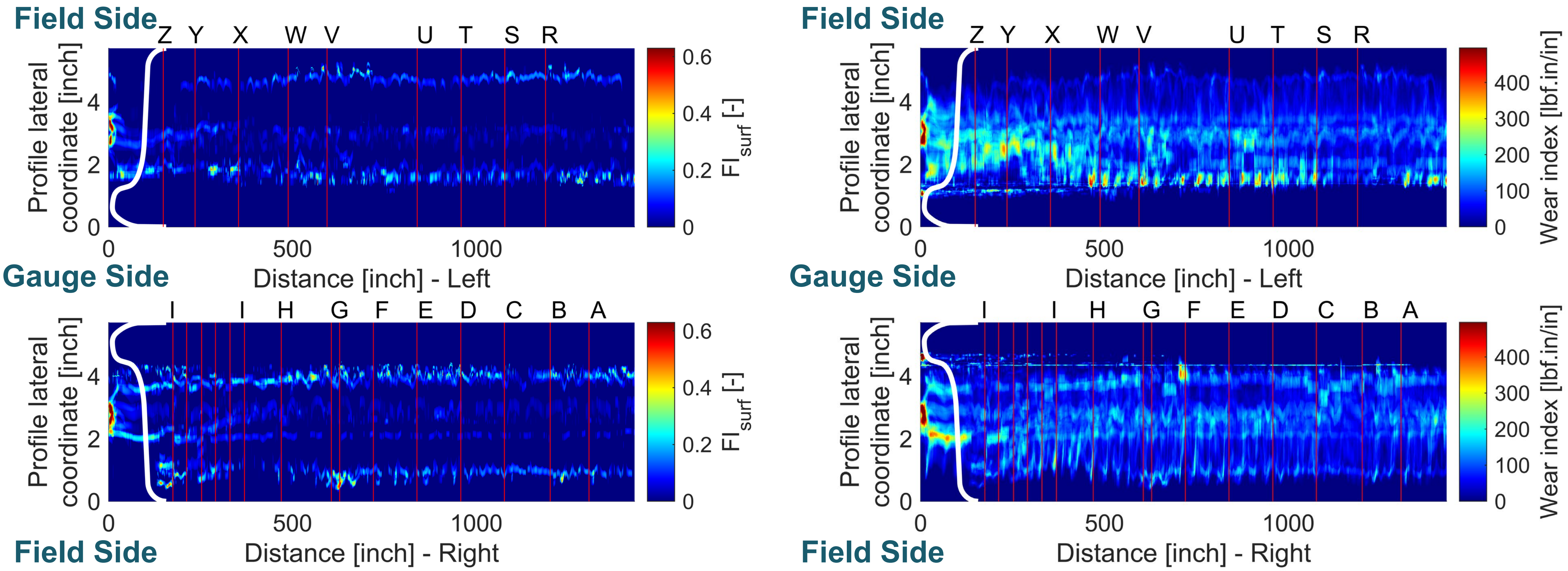
Periodic RCF – Hypothesis 3

- **Wheel results for dry contact conditions**



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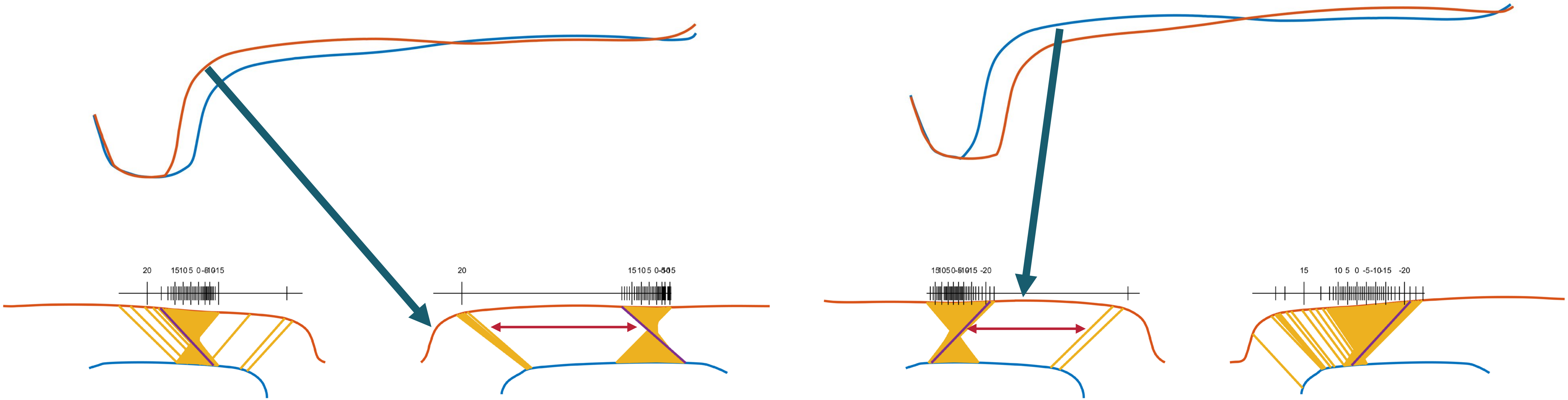
Periodic RCF – Hypothesis 3

- **Worn wheel contact locations**



Car A

Car B

Contact point jump

Contact point jump

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Conclusion

- **Rail deterioration at TOR-FM applicator**
  - Frequency of deterioration = once per 38-inch wheel revolution
  - RCF initiated first likely under dry conditions
  - TOR-FM exacerbated RCF
  - FAST worn wheel profiles caused RCF initiation on tangent track
- **Mitigation options**
  - Trial a different TOR-FM product
  - Grinding to reduce worst RCF
  - Remove worn wheels suspected of initiating RCF

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- **Charlie Jaquez, MxV Rail Instrumentation Engineer**
- **MxV Rail track crew**

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Turnout Derailment Prevention

Corey Pasta

Scientist

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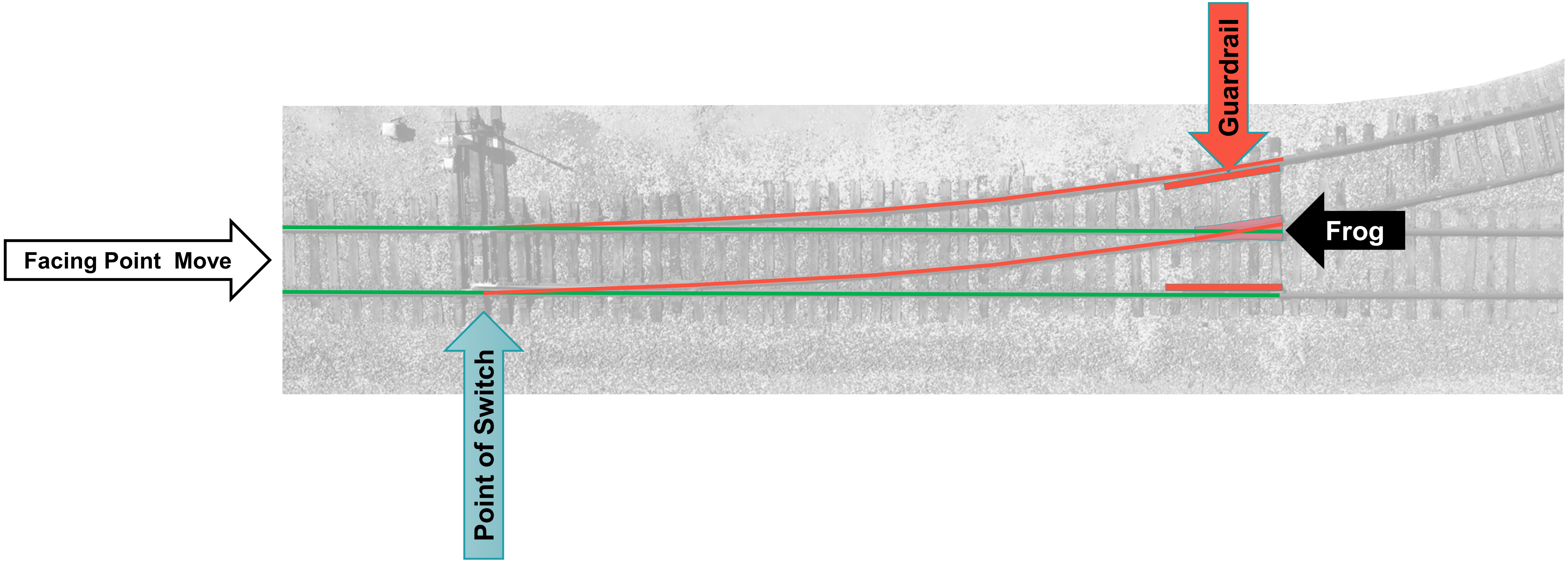
Objective

Identify wheel and rail profile conditions with elevated risk of derailment in a turnout



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Overview

- **Background**
  - Technical Advisory Group (TAG) formation
  - Derailment data survey
  - Current state of turnout prevention/inspection
- **First Area of Focus – Derailments at Switch Points**
  - Wheel profile measurement & classification
  - Turnout measurement
  - 3D modeling of wheel/rail interaction
- **Next Steps**

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TAG Formation

- **Formed at Request of Research Committee**
    - Participation of all Class I freight railroads
    - Common challenges
    - Support development of best practices

BNSF RAILWAY

CPKC

NORFOLK SOUTHERN

CN

CSX

UNION PACIFIC

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Derailment Report Data Analysis

- **Derailments in Yard Turnouts**
  - Low speed
  - Often multiple factor incidents
    - Class I track, worn mechanical components, and dynamic in-train forces
- **Leverage Derailment Report Data to Understand Scope, Reflect on Commonalities and Prioritize Research Areas**
  - Federal Railroad Administration (FRA) reportable incidents (2025 threshold: $12,400)
  - Non-reportable incidents
    - Data sampled from four railroads
    - Three-year span: 2022, 2023, 2024

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Non-Reportable Incidents at Switches*

Rank	Cause Code	Description
➡ 1	T314	Switch point worn or broken
➡ 2	T311	Switch damaged or out of adjustment
➡ 3	T319	Switch point gapped (between switch point and stock rail)
➡ 4	E64C/L	Worn flange (Car / Locomotive)
5	T403	Engineering design or construction
6	T207	Broken Rail - Detail fracture from shelling or head check
7	T110	Wide gage (due to defective or missing crossties)
8	T315	Switch rod worn, bent, broken, or disconnected
9	T307	Spring/power switch mechanism malfunction
10	T221	Broken Rail - Vertical split head

* Narrative mentioning: “Switch,” “Turnout,” “T.O.,” “Crossover,” “X-over”
Source: Non-reportable incident data provided by multiple Class I railroads.
Only Track & Equipment codes included. No human factor, signal, or miscellaneous codes.

➡ Cause potentially related to wheel or rail profile.

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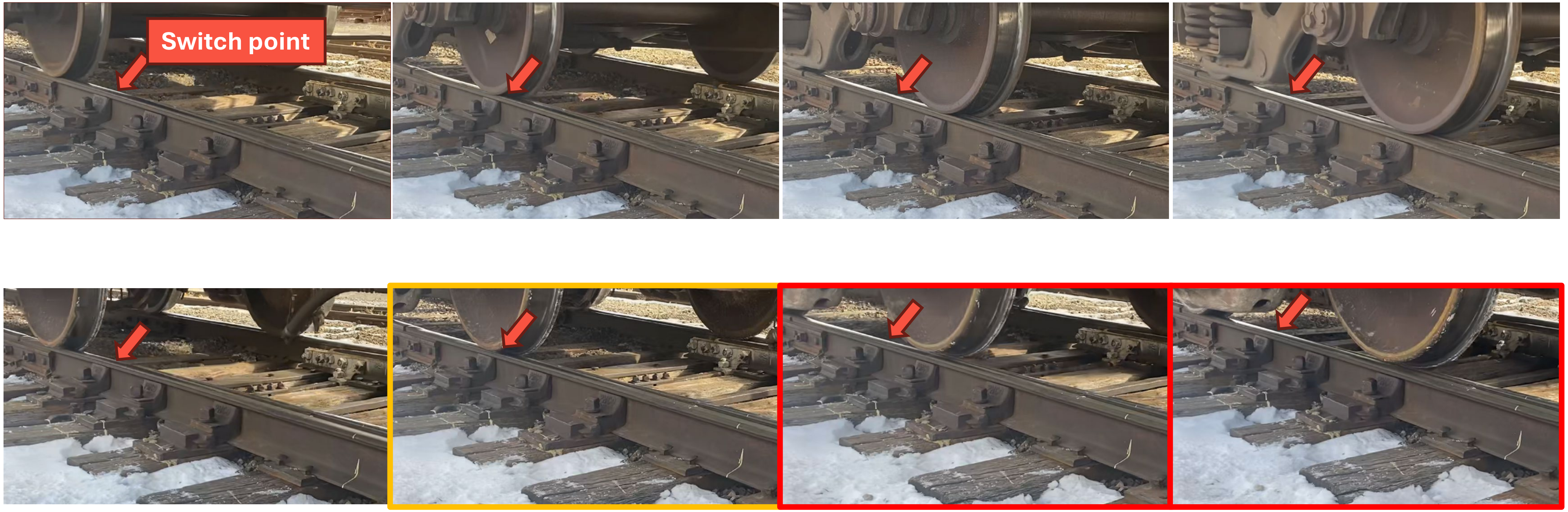
Switch Point Climb Reenactment

Lead Axle Prior Truck

Lead Axle Derailed Truck



Wheel Climb

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Switch Point Climb Reenactment

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Derailment at or Near Switch Point

Wheel Climb at Switch Point

- Worn or chipped switch point
- Gapped point
- Derailed wheel with shallow flange contact angle
- Gage face wear on switch point creating a ramp-like shape
- Stock rail wear causing poor fit with switch point
- Derailed wheel with vertical flange or sharp flange tip

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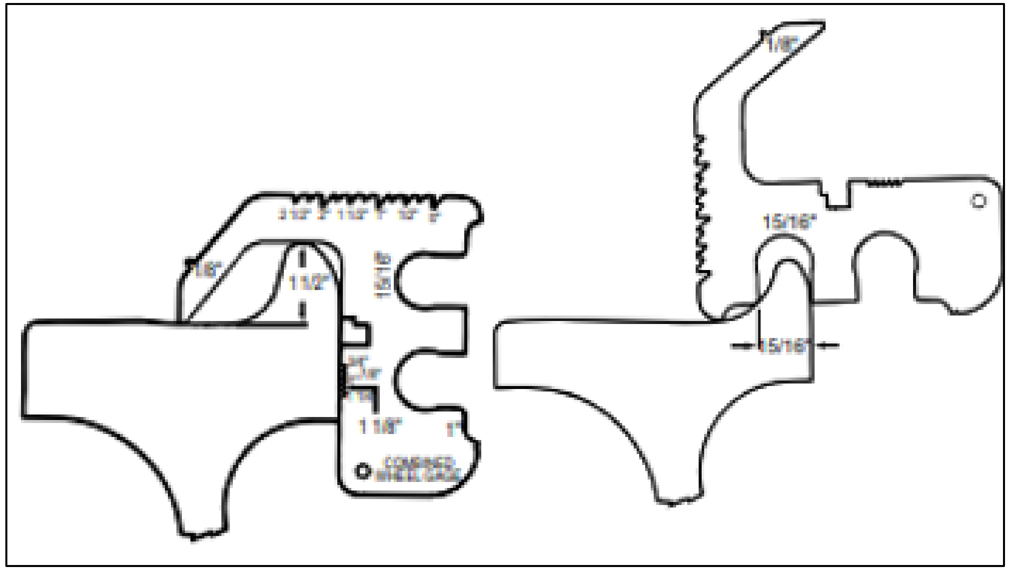
Wheel/Rail Classification Today: Go / No-Go Gauges

- **Wheel Assessment**
  - Association of American Railroads (AAR) Wheel Gauges

AAR High Flange & Thin Flange Gauges



- **Switch Point**
  - IDEAS Project gauges

Two of Five Sample IDEAS Gauges

Source: Zarembski, A. M. (2017). *Switch Point Inspection Gauges to Prevent Wheel Climb Derailments*. University of Delaware, RIVIT Conference.

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Challenges & Proposed Method

- **Challenges**
  - Identify specific profile conditions leading to elevated risk
  - Consider current conditions when establishing proposed gauges or inspection procedures
- **Proposed method**
  - Use 3D contact modeling: NUCARS®* / CONTACT software
    - High accuracy wheel profiles & switch point profiles
    - Account for vehicle conditions such as speed, weight, truck type, etc.
    - Explore relative influence of wheel and rail profile conditions on wheel/rail forces and risk of climb or picked point

* NUCARS® is a registered trademark of MxV Rail.

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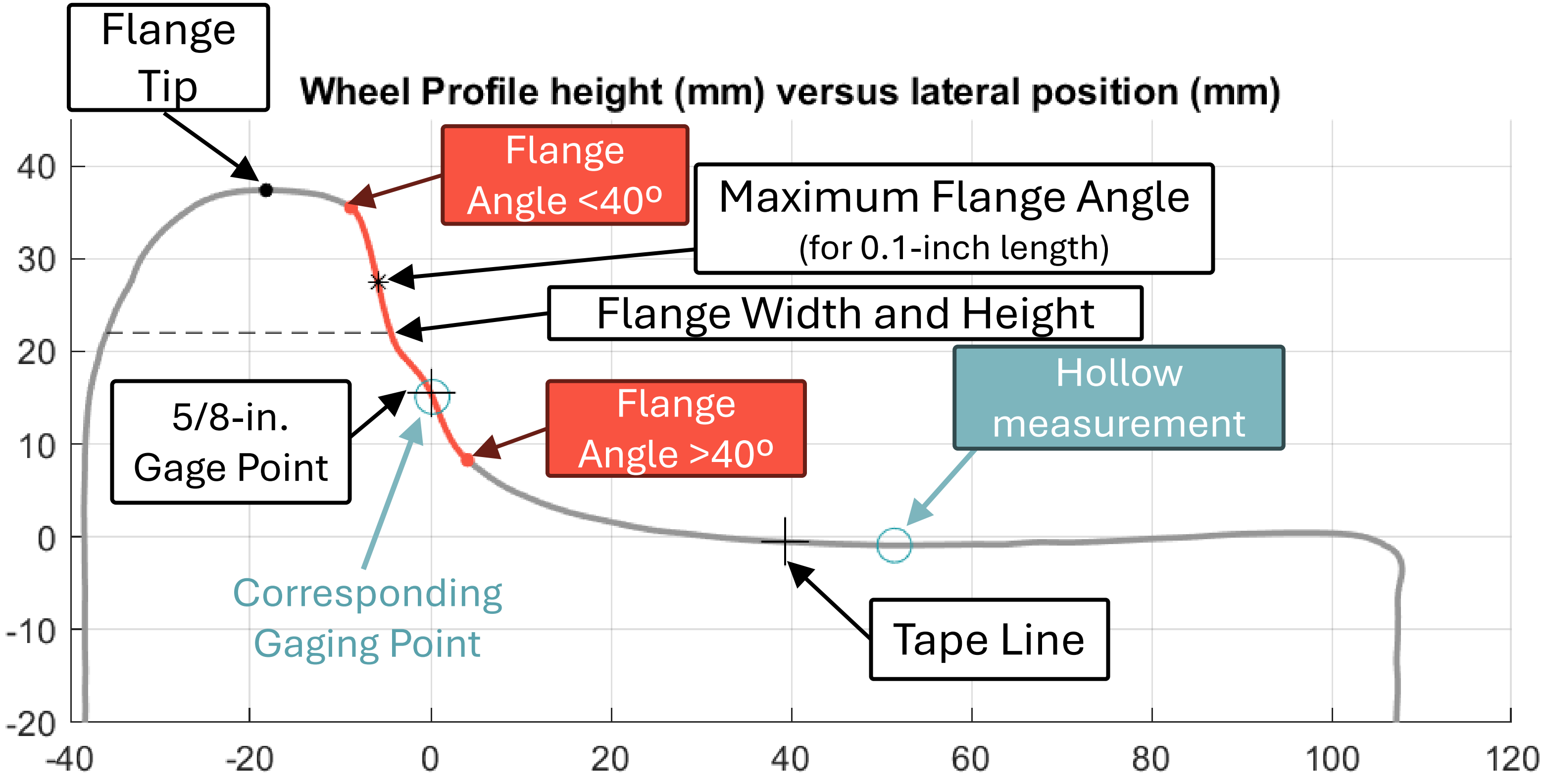
Wheel Profile Categorization

- **Sample of over 300,000 wheel profiles processed**
  - Categorized by condemning limits <u>and</u> various profile attributes



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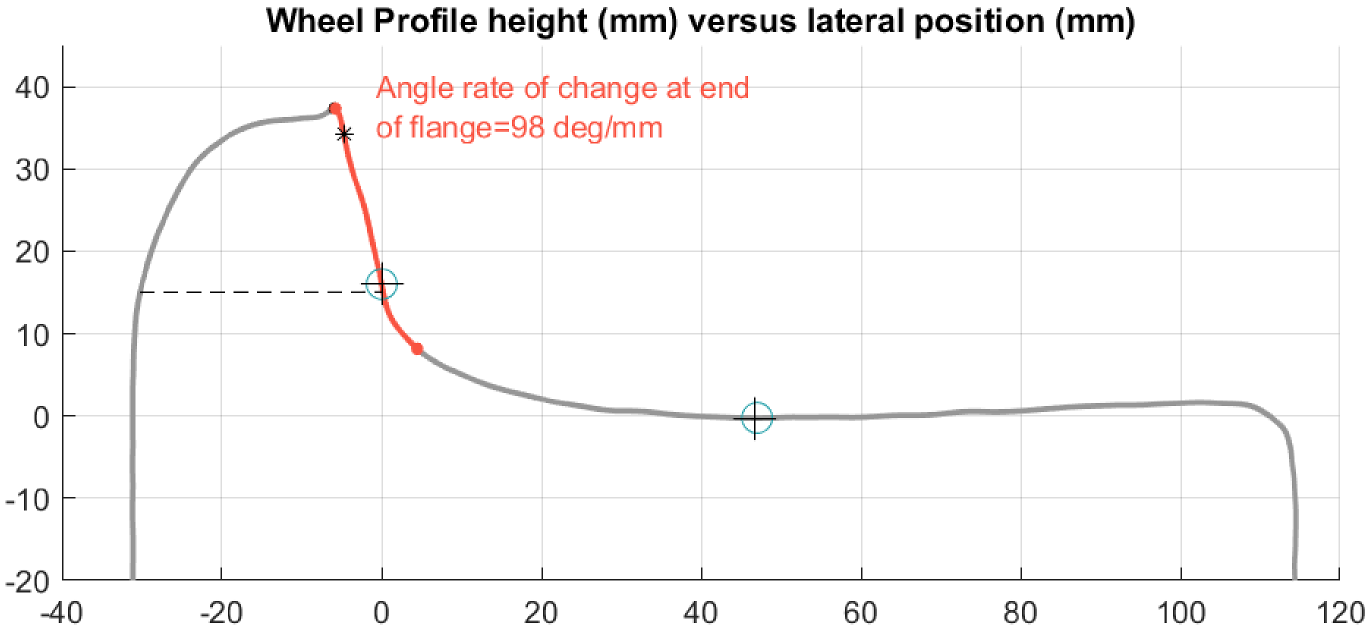
Wheel Profile Categorization

- “Pick” Flanges
- Low Flange Angle
- Short Flange
- “Stepped Flange”
- Reduced Flange Angle
- Steep Flange
- Climb

- “Pick” logic to identify profiles with an acute angle change at the flange tip.
- 100% of “Pick” profiles failed for thin flange



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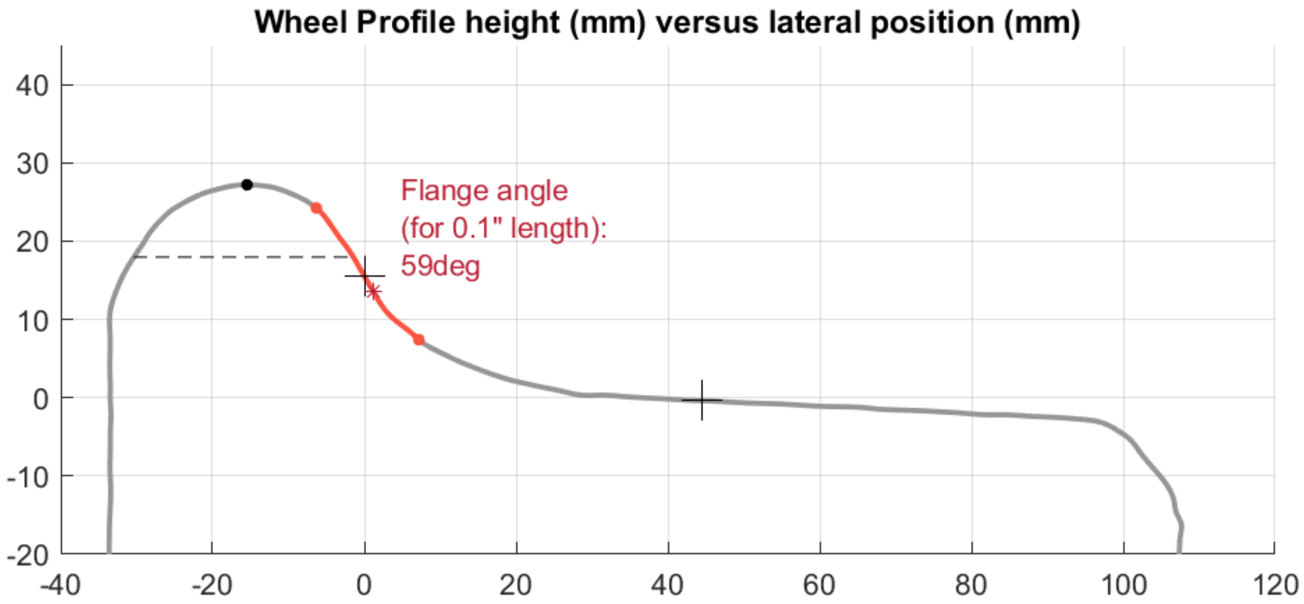
Wheel Profile Categorization

- “Pick” Flanges
- Low Flange Angle
- Short Flange
- “Stepped Flange”
- Reduced Flange Angle
- Steep Flange
- Climb

- The “Top-20” low flange angle wheels are exclusively six-axle cars
- The lowest three-axle truck measured ~59deg
- The lowest two-axle truck measured ~65.5deg



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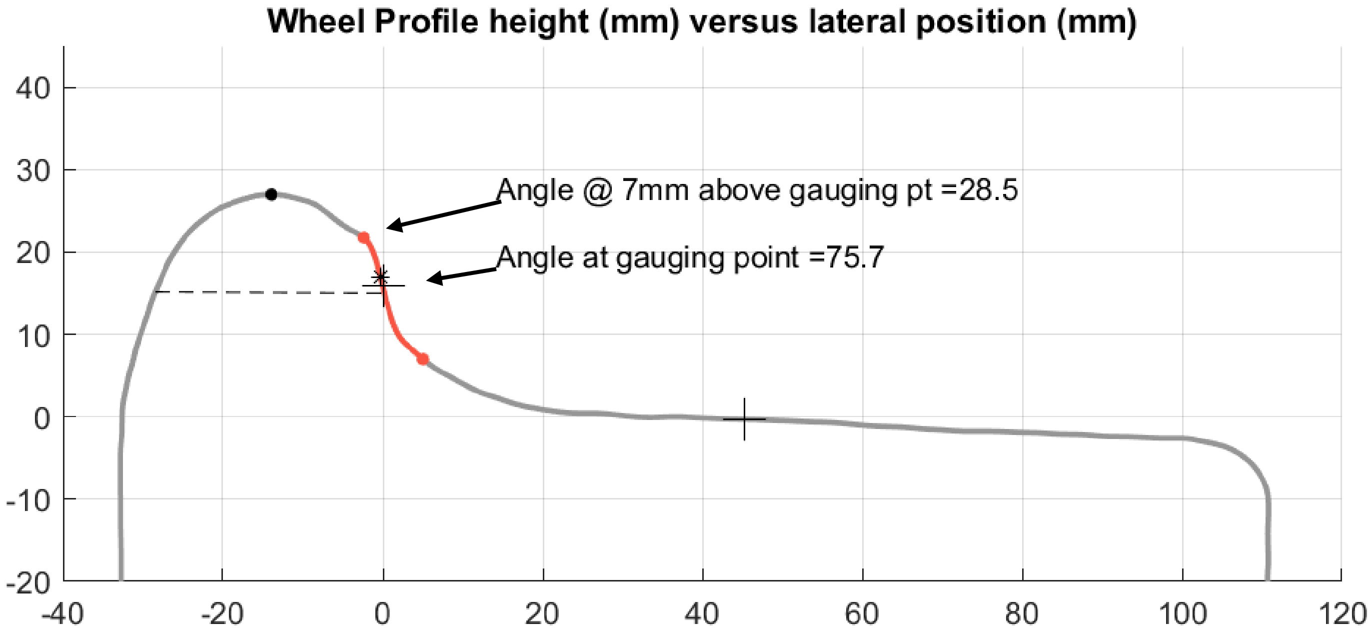
Wheel Profile Categorization

- “Pick” Flanges
- Low Flange Angle
- Short Flange
- “Stepped Flange”
- Reduced Flange Angle
- Steep Flange
- Climb

- “Reduced Flange Angle” considers low flange angles towards the flange tip.
- Sometimes the “stepped” and “reduced” profiles look similar



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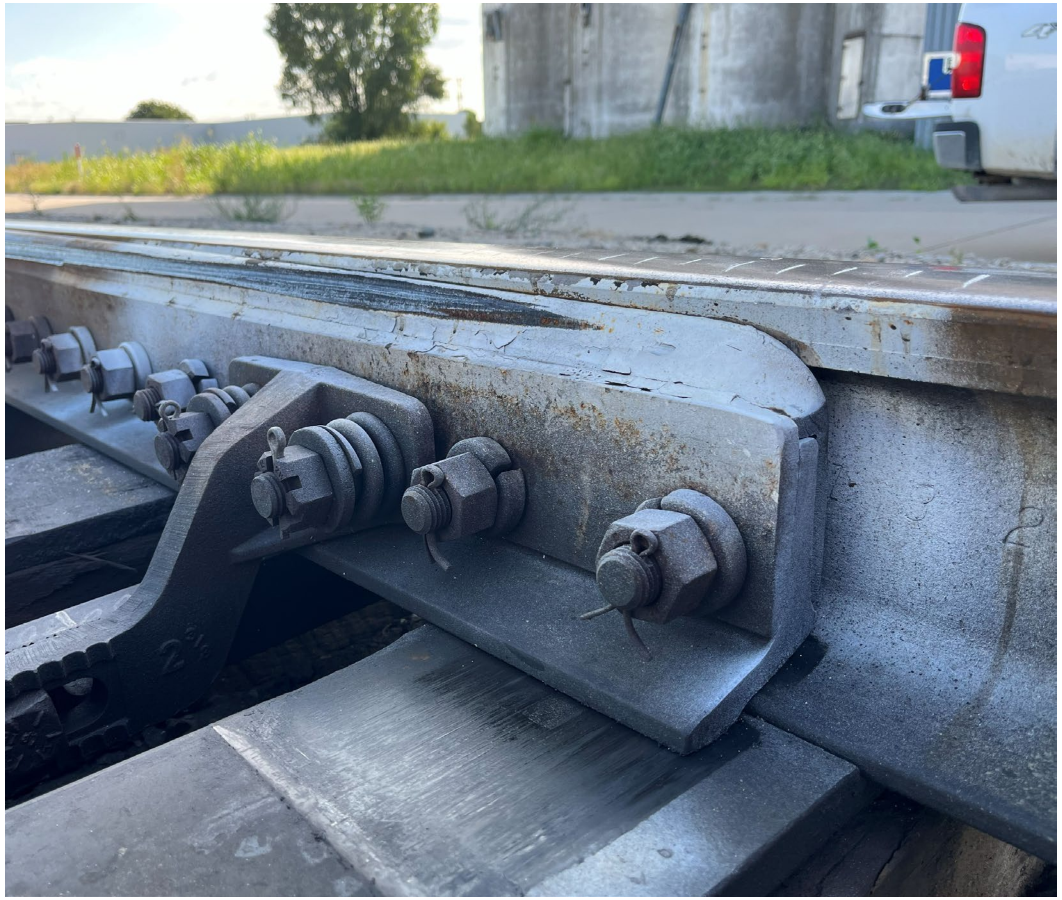
Turnout Measurement Example

Number 10 turnout

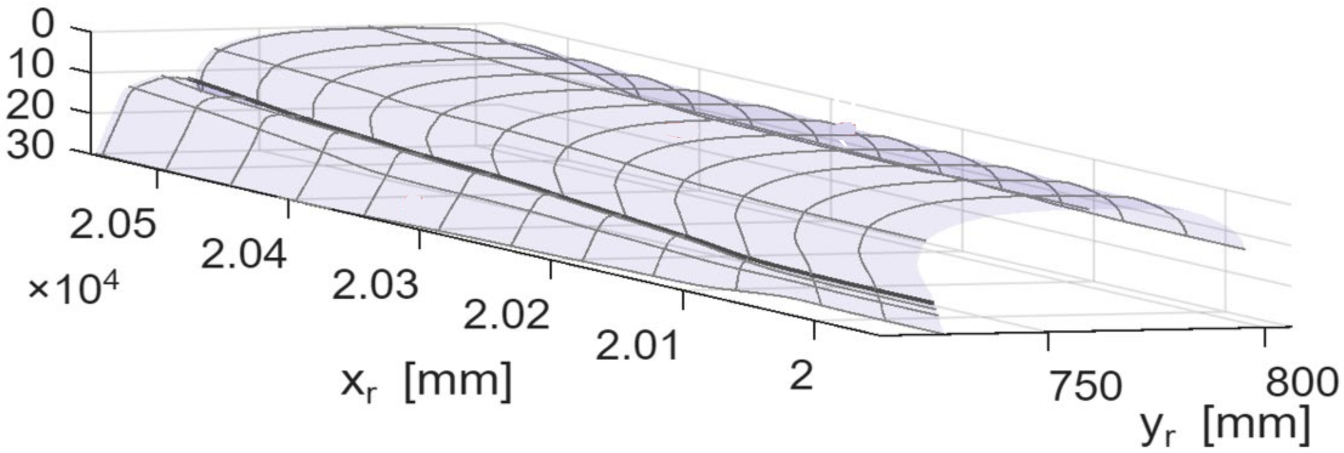
Undercut point design

Lined for diverging route



Turnout Measurement

- **80 cross-sectional profiles**
  - 1-inch spacing for first 56 inches, 2-6 inches further in
  - Manual process
    - Some railroads are testing automated inspection technologies



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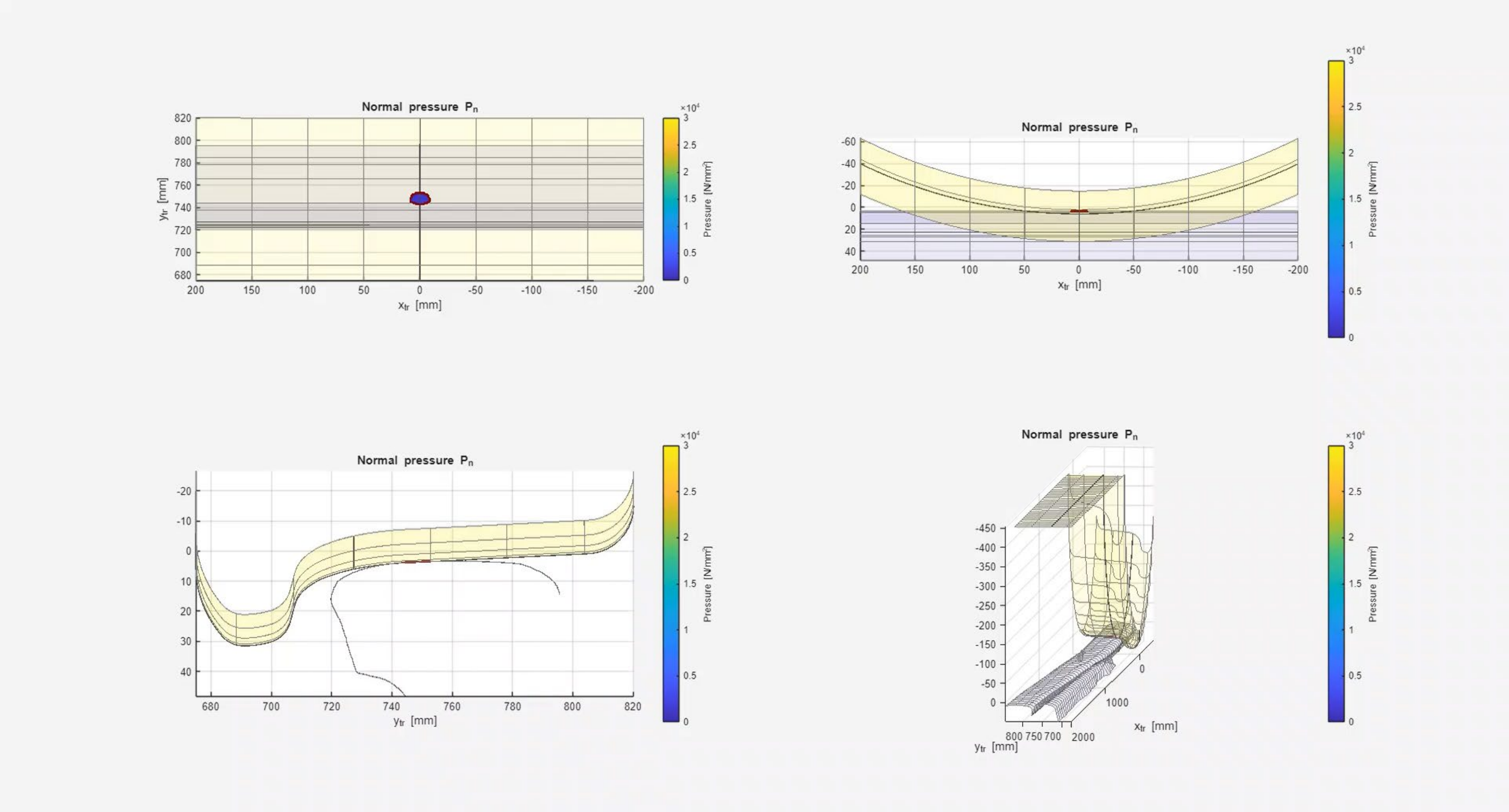
3D Turnout Modeling Sample: New Wheel



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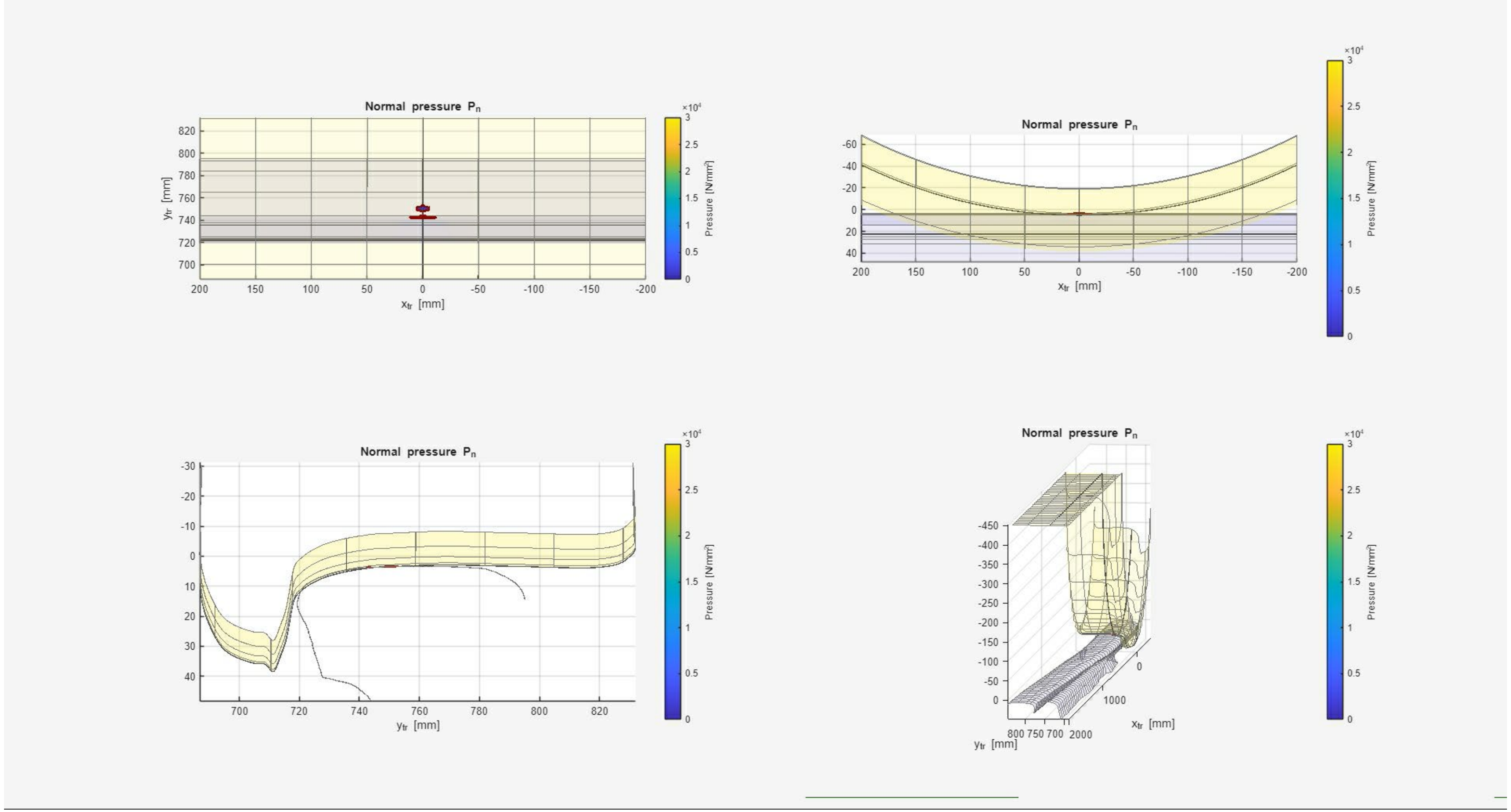
3D Turnout Modeling Sample: Worn Wheel



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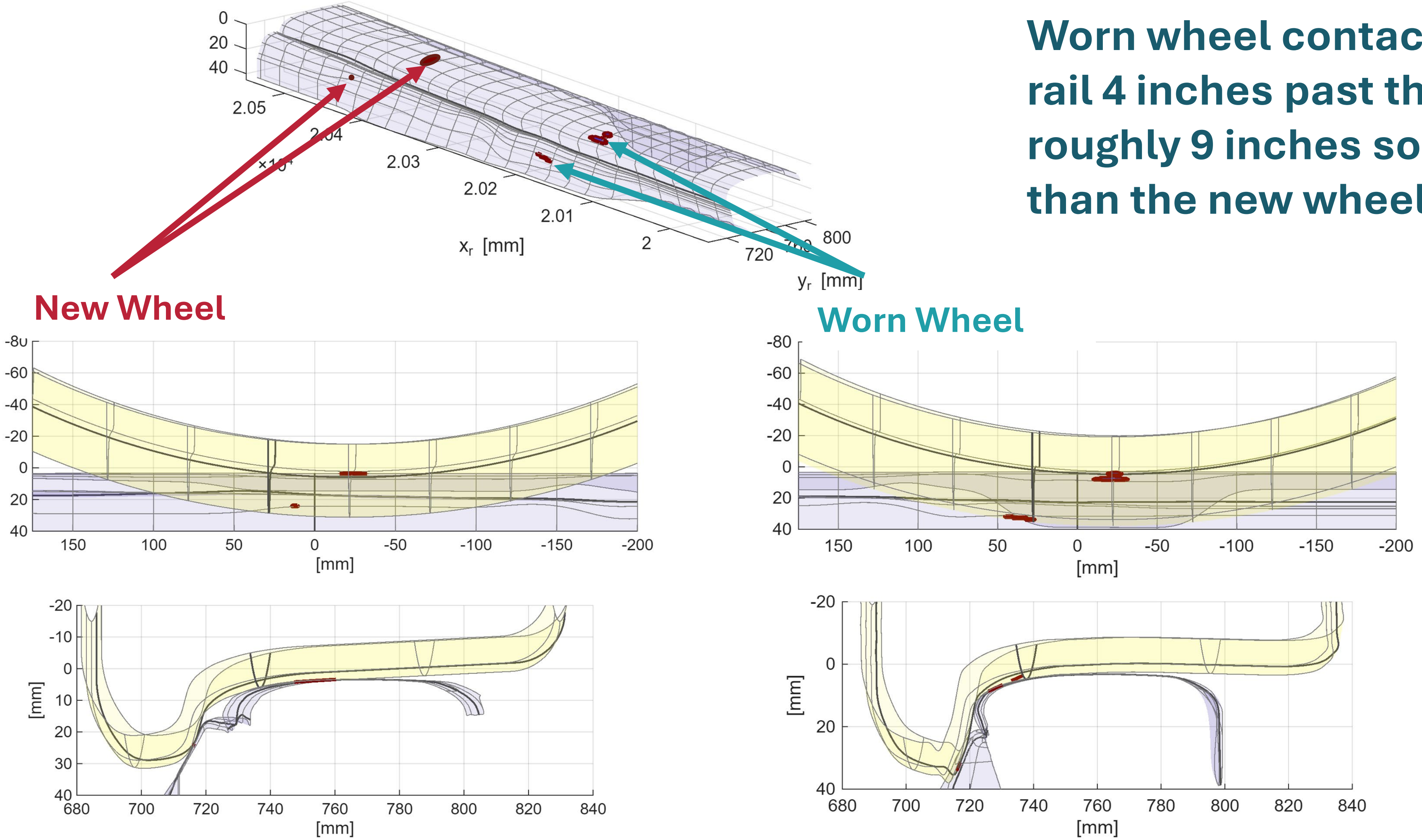
Comparison of Initial Switch Rail Contact



Worn wheel contacts switch rail 4 inches past the point, roughly 9 inches sooner than the new wheel profile.

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Continuing Research

- **Modeling of various point/wheel profile conditions**
  - Gapped points, chipped points, railroad-provided suspect profiles
  - Select wheel-wear categories, railroad-provided suspect wheels
- **Switch point derailment mitigation strategies**
  - Inspection techniques (profilometers, gauges, etc.)
  - Maintenance
- **Shoving movements and guard rail climbs (future)**

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- Turnout Derailment Prevention TAG
- BNSF Railway TR&D Team
- Ulrich Spangenberg (MxV Rail) and Edwin Vollebregt (Vtech CMCC)

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Restricted Speed Enforcement

Thomas Nast
Scientist, C&TC

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Train Control/Automation Technology Roadmap

- **The Roadmap is set of incremental train control and automation technology enhancements**
  - Independently deployable
  - Tangible benefit
    - Safety
    - Consistency of operation
    - Efficiency
  - Increments build upon one another for realization of greater benefit
- **AAR Train Control, Communications, and Operations (TCCO) Committee provides guidance and oversight**
- **Program Scope**
  - Define and refine interoperable increment concepts and requirements for independent implementation
  - Investigate potential to leverage technology from non-rail sectors
  - Find approaches to accelerate deployment of beneficial technology

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Foundational Increment: Restricted Speed Enforcement

Positive Train Control (PTC) Overview

- **Rail Safety Improvement Act of 2008 (RSIA ‘08)**
  - Federal mandate for PTC system to be deployed on:
    - Rail lines used to transport poisonous or toxic-by-inhalation hazardous materials
    - Rail lines with regularly scheduled intercity or commuter rail passenger service
- **PTC Systems Prevent:**
  - Train-to-train collisions
  - Over-speed derailments
  - Incursions into established work zone limits
  - Movement of a train through a switch left in the wrong position

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Restricted Speed Operation

- **A Restricted Speed Operation is a method of operation defined by railroad operating rules**
- **The following are used when hazards may exist:**
  - Movement through bulletin-protected work zones
  - Movement after “Stop and Proceed” or “permission to pass Stop” received
  - After red flags or fusees
  - Other situations
- **Train movement is made at a speed that:**
  - Allows stopping within half the range of vision
  - Does not exceed rules defined maximum
- **Currently, PTC only enforces maximum allowable speed**

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PTC-Restricted Speed Enforcement (RSE)

- **PTC-RSE to prevent collisions while train operating at restricted speed**
  - Enforcement of maximum train speed
    - Allows train stop within half of clear distance
    - Not to exceed the maximum allowable speed defined by the rules
  - Enforcement of stop targets short of:
    - Locomotives and vehicles
    - Rolling stock and on-track equipment
    - People
  - Enforcement of stop targets short of other hazards that are currently out of scope
- **Onboard sensing of environment ahead of train enables RSE**
  - Must verify train may safely proceed along intended route
  - Must provide distance ahead of train verified to be safe to traverse
  - Must function over a broad range of operating conditions

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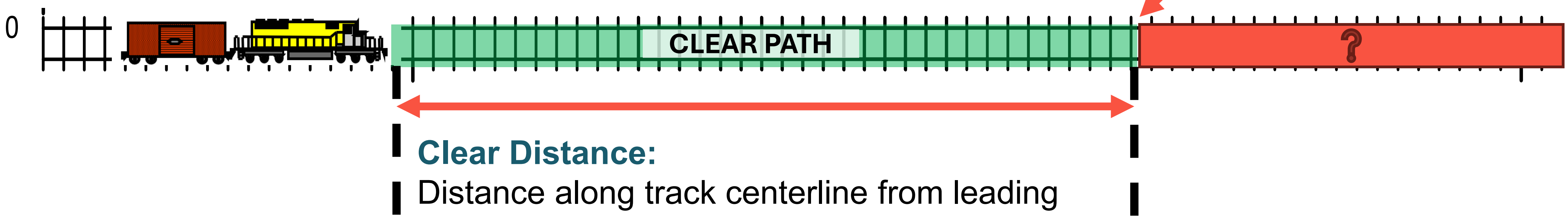
Key RSE Concepts

- **Clear Path and Clear Distance**



Clear Path:
Region ahead of the train, along the train's intended route, for which the foul volume is verified safe for the train to traverse.

End of clear path:
Nearest location where path cannot be verified safe for the train to traverse.

Clear Distance:
Distance along track centerline from leading edge of train to the end of clear path.

Safety provided by detection of clear path not detection of obstructions

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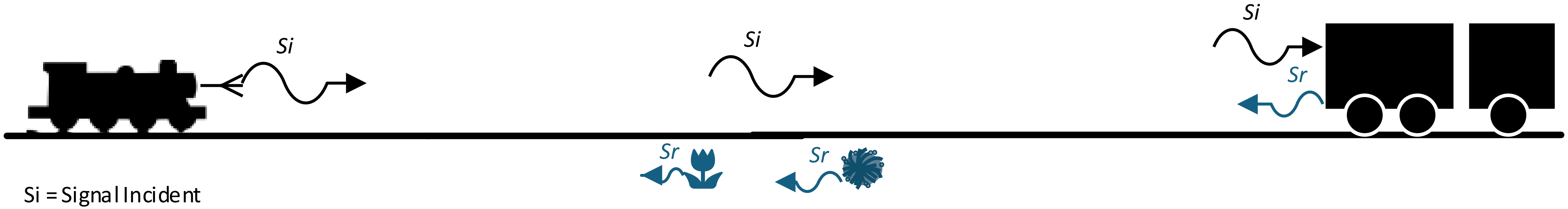
Leveraging Technology

Automotive Radar Proof of Concept

- **Assess viability of applying automotive radar as RSE solution**
- **Demonstrate sensor functional requirements for RSE achievable**
  - Clear path detection
  - Clear distance measure
- **Demonstrate sensor performance requirements of RSE achievable**
  - Sensor range
  - Sensitivity
  - Response time
- **Leverage prior work and market benefits**
  - Compliance with functional safety standards
  - Compliance with FCC emissions requirements
  - Economy of scale
- **Identify technical challenges to meeting requirements**
- **Test conducted at MxV Rail**

Clear Path Detection w/ Automotive Radar



① Radar pulse propagates down range

② Radar pulse passes through volume ahead of train

④ When radar pulse is incident of large obstruction, large amount is reflected

③ Clutter within FV produce small reflection

- Si = Signal Incident
- Sr = Signal Reflected

- **Radar signal propagates through entirety of Monitored Foul Volume (MFV), providing active inspection within range of the radar**
- **Clear path detectable via analysis of observed Sr**
- **Sr associated with clear path << Sr associated with obstructions**

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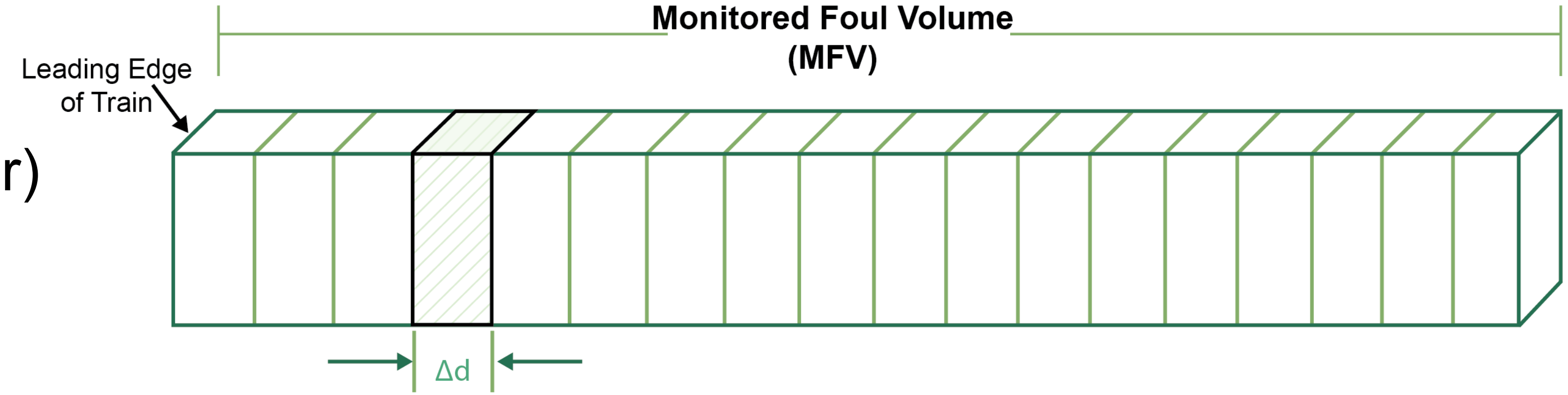
Clear Path Detection Data Analysis – Approach



- **Radar captures:**
  - Power of reflected signal (Sr)
  - Distance to Sr origin
  - Direction to Sr origin
- **Data segmented in space:**
  - Analysis limited to data associated with MFV
  - Data parsed into MFV cross sections of Δd thickness
- **Cumulative Sr (ΣSr) is calculated for each MFV Δd cross section**
- **Statistical characterization of ΣSr developed for:**
  - Clear Path
  - RSE Objects

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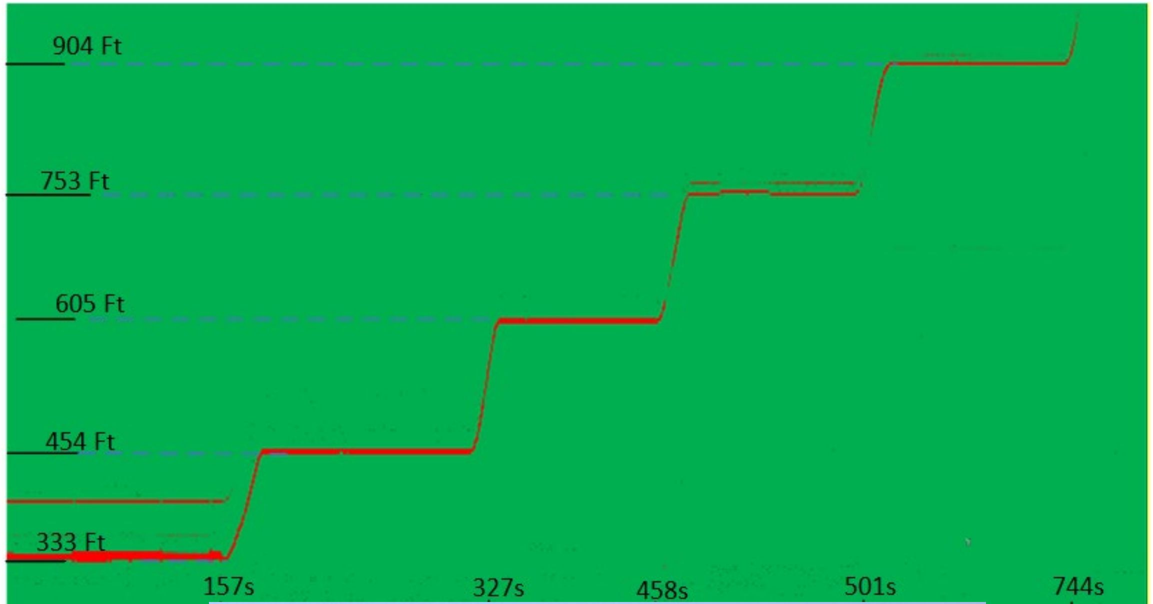
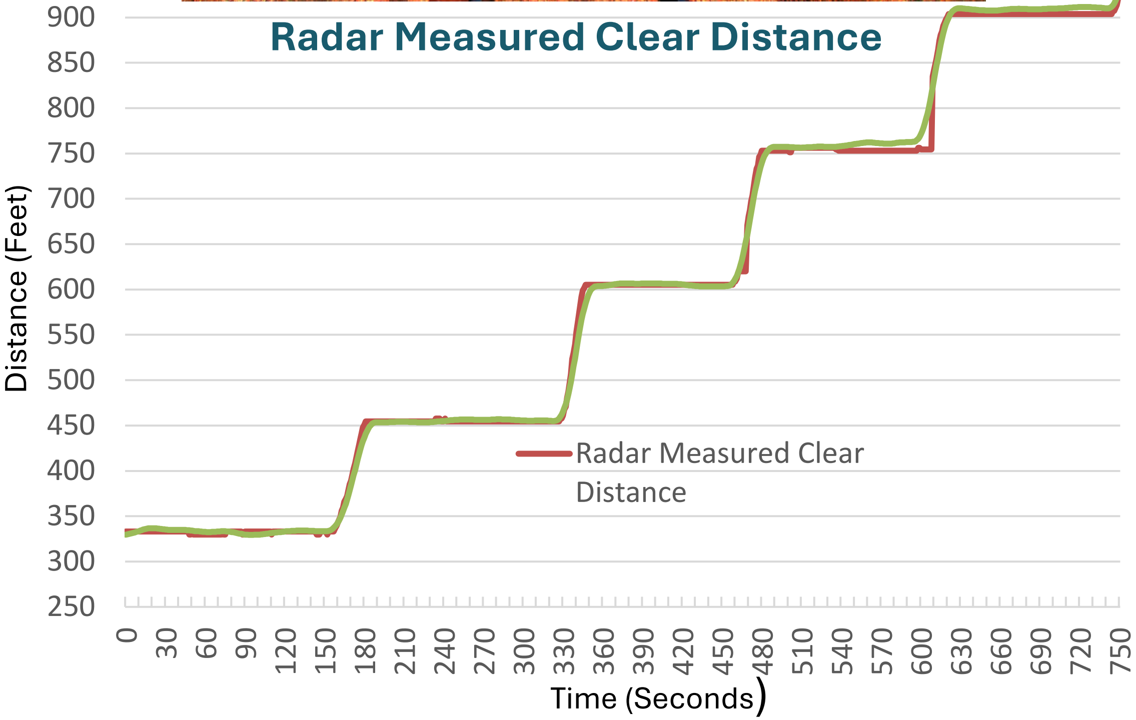
Automotive Radar Example - Flatcar

Monitored Foul Volume Radar Heat Map





Radar Measured Clear Distance

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Preliminary Observations

1. Statistical difference between clear path and rolling stock is significant.
2. A deterministic approach to clear path detection is feasible.
3. A low computational complexity approach to clear path detection is feasible.

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Accelerate Deployment

Locomotive Sensor Pre-integration Test

- **Equipment performance verification conducted in service environment**
- **Pre-production equipment tested without interaction with PTC**
- **Test provides data from equipment operating in a broad range of uncontrolled conditions**
- **Benefits of Pre-Integration Testing**
  - Consistent analytics of onboard sensor equipment performance
  - Guidance to suppliers on presenting test results to industry consistently
  - Promotes industry understanding of technology readiness
  - Data usable to suppliers to further refine products

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Anticipated 2026 Activities

- **Refinement of RSE requirements underway with assistance from railroad and supplier representatives**
- **Research and testing of additional modes of sensors and multiple radar variants to continue**
- **Opportunities to conduct tests on sensor equipment in railroad service environment expected**

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Acknowledgements

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- **AAR TCCO Committee**
- **Participants in program technical working groups**

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Plenary Sessions
Technical Sessions - Mechanical

Click titles to access presentation

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Agenda | Technical Sessions

Wednesday, April 29, 2026

Infrastructure (AM) | Fortino Ballroom A/B

Rail Base Inspection	Anish Poudel
Track Inspection Technologies	Yin Gao
In-Service Rail Testing	Ananyo Banerjee
Q&A	

Infrastructure (PM) | Fortino Ballroom A/B

Special Trackwork	Duane Otter
Tie and Fastener Systems	Yin Gao
Rail Neutral Temperature	Steve Wilk
Q&A	

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Rail Base Inspection Using Laser Air-Coupled Ultrasound

Anish Poudel, Ph.D.
Scientist

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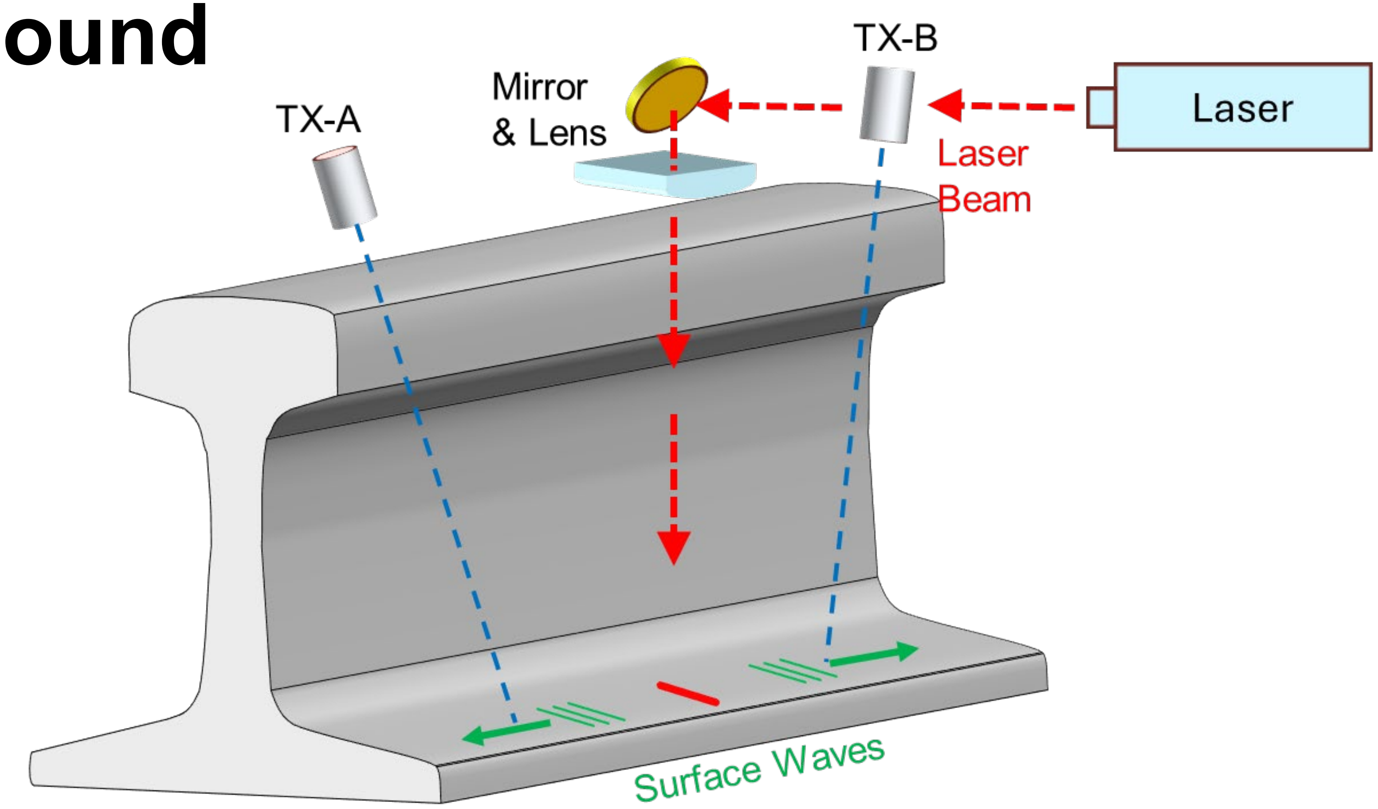
Overview

- Project Motivation
- Laser Air-Coupled Ultrasound Testing (LACUT)
- Prior Work
- LACUT Laboratory Test Setup
- LACUT Test Results
- Summary & Next Steps
- Acknowledgements



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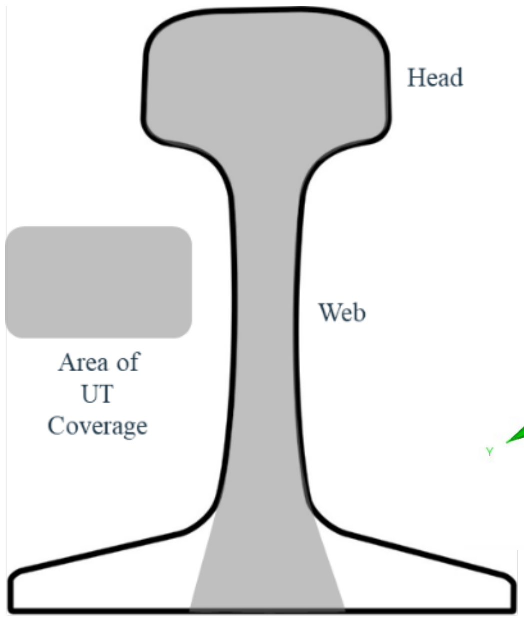
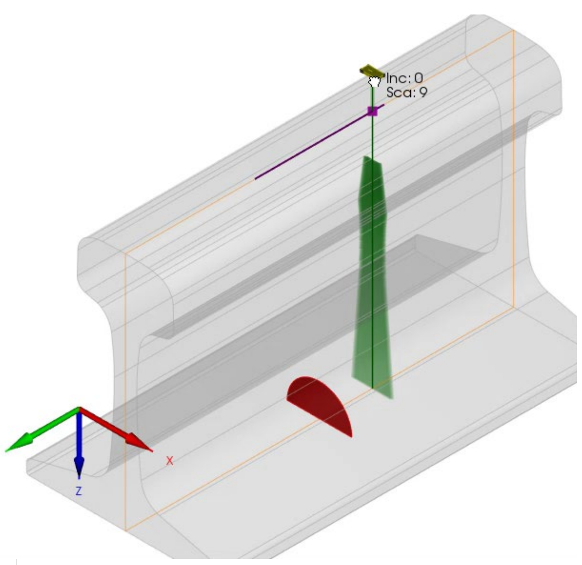
Project Motivation

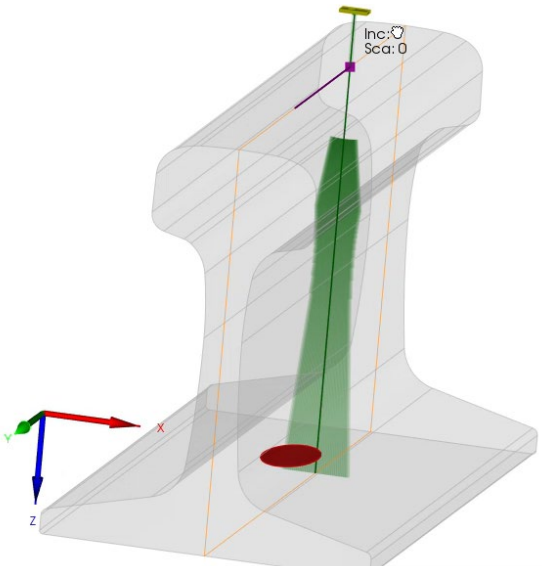
- **Existing rail ultrasonic testing (UT) method does not provide coverages in the rail base**



Rail UT Coverage

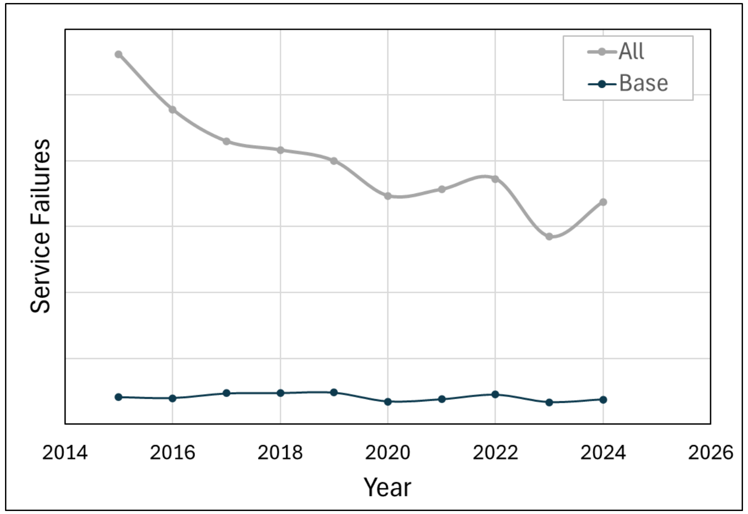


Not detectable



Detectable

Rail Base Breaks



Rail Base Service Failures (US Class I RRs)

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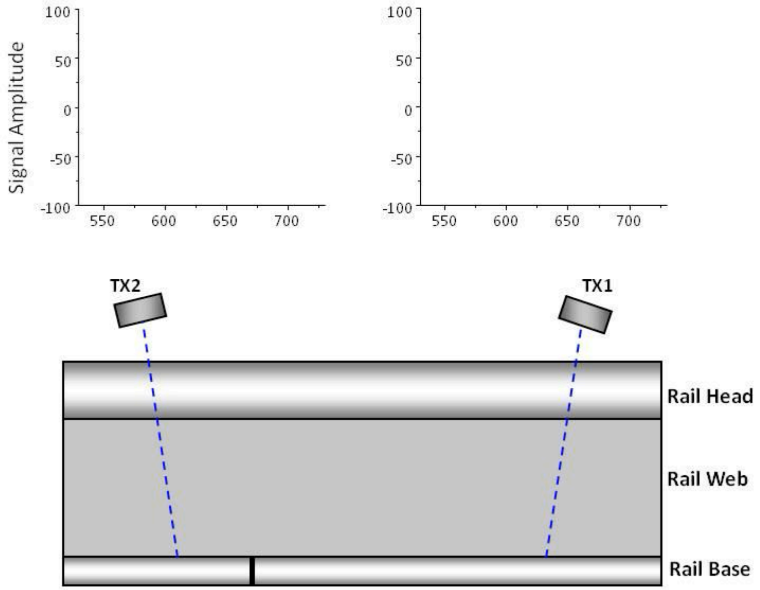
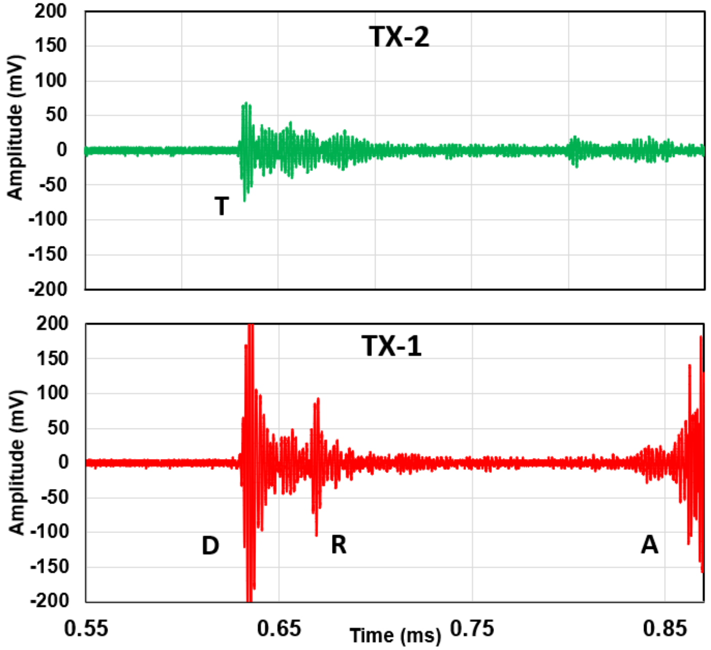
Laser Air-Coupled Ultrasound Testing (LACUT)

- **A non-contact ultrasonic method that uses a high-power laser to generate ultrasound waves (surface acoustic waves) and air-coupled transducers to detect them**

LACUT Working Principle





D: Direct wave
T: Transmitted wave
R: Reflected Wave
A: Air wave
(compressional)

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Prior Work

- **U-Rail System Development (2002–2013)**
  - Partnership with Technogamma and Johns Hopkins University
  - Efforts focused on full rail inspection
  - Suffered/ failed from reliable technical demonstration
    - High false calls
- **Challenges**
  - Laser and optics
  - Data capture & analysis
  - Signal processing
  - Software
  - Vehicle

2002 – 2013

Second Generation URail Truck

2002

Push-Cart System

2006

First Generation URail Truck

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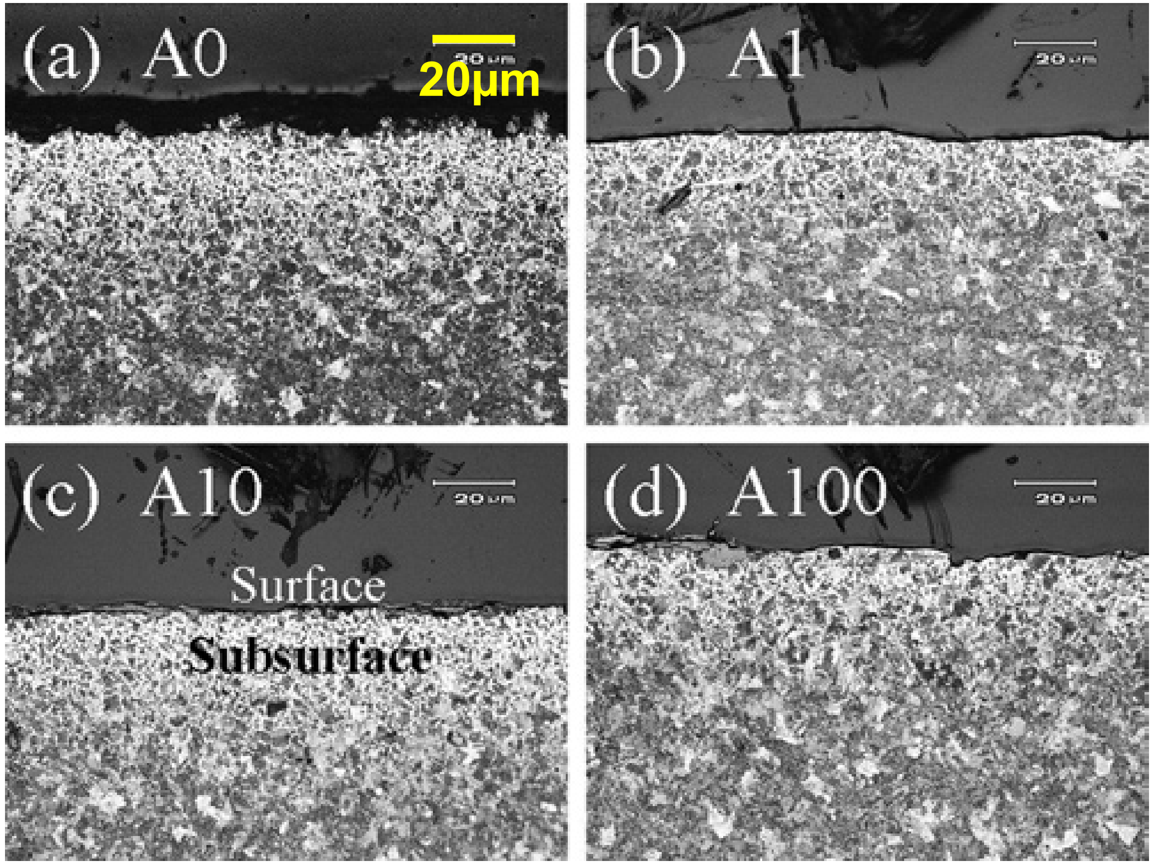
Laser Energy

- **Neodymium-doped Yttrium Aluminum Garnet (Nd:YAG) pulsed solid-state laser**
  - 4-7ns pulse width, max. energy 800 mJ per pulse at 10Hz
- **The intensity of the laser beam is above the threshold for ablation**
  - Does not damage or compromise the microstructure or strength of the rail base surface

Optical micrograph images of a rail specimen at various ablative laser pulses showing lack of damage from ablation



Kenderian, S., B.B. Djordjevic, B.B., D. Cerniglia, G. Garcia. 2006. Dynamic Railroad Inspection using the Laser-air Hybrid Ultrasonic Technique. Insight 48(6): 336-340.

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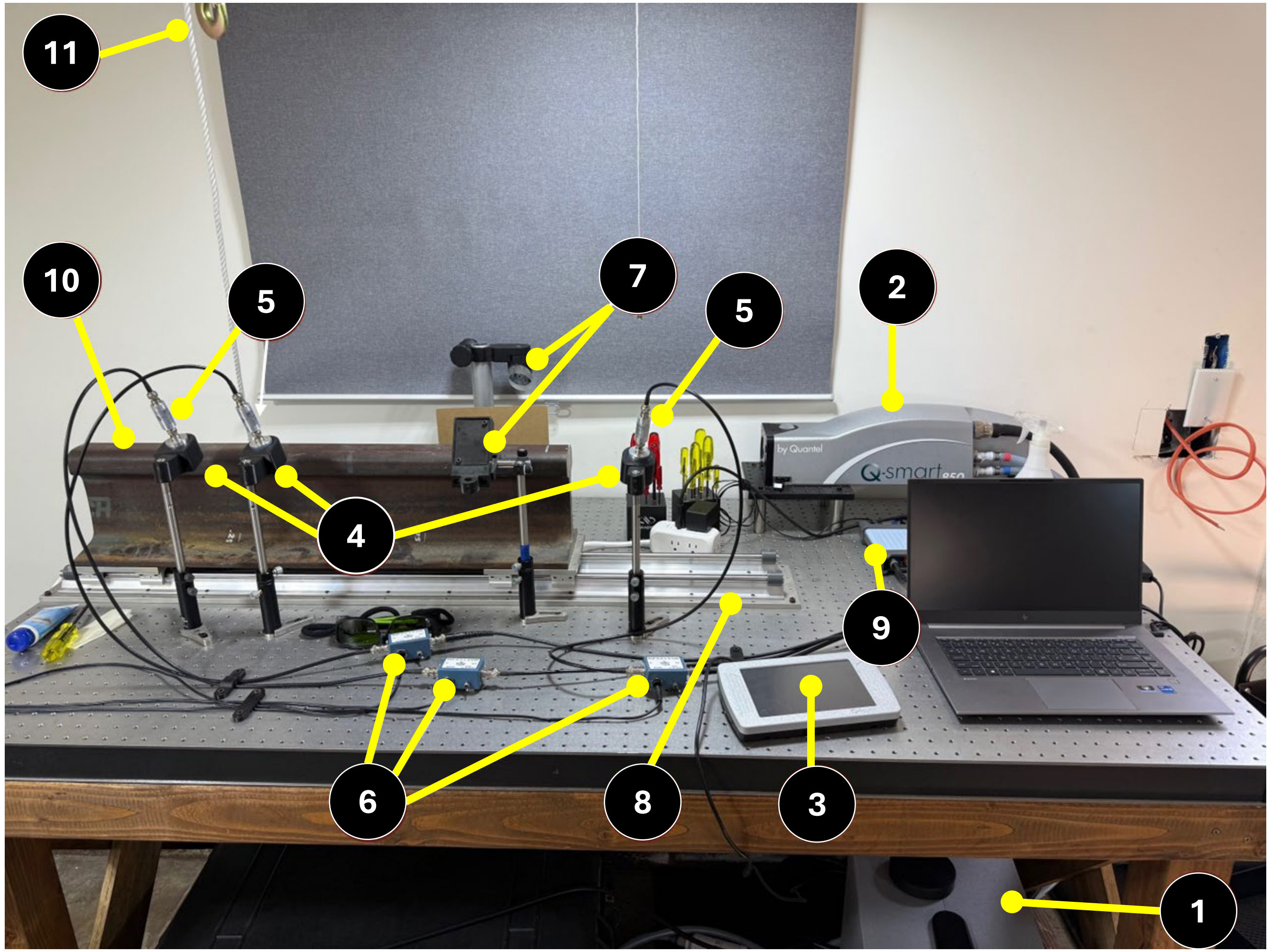
LACUT Laboratory Test Setup



1. **Laser Machine**
2. **Laser Head**
3. **Laser Control Unit**
4. **Air-coupled Transducers**
5. **Pre-amplifiers**
6. **Preamp Gain**
7. **Mirrors and Lenses**
8. **Sliding Stage Track**
9. **Data Acquisition System**
10. **Rail**
11. **Pulley System**

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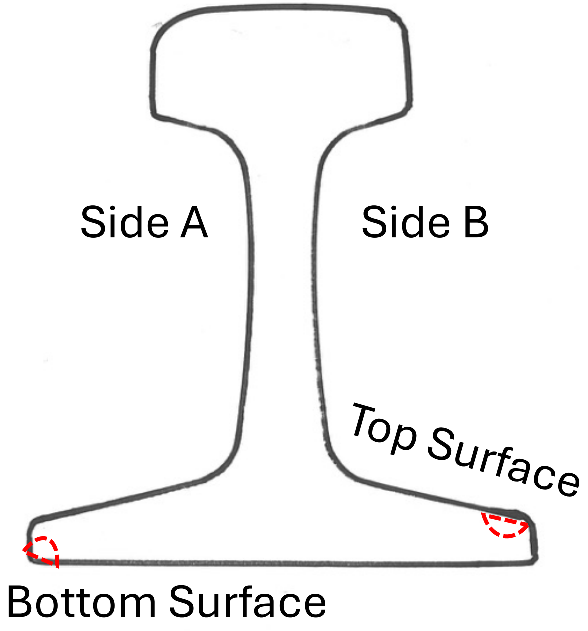
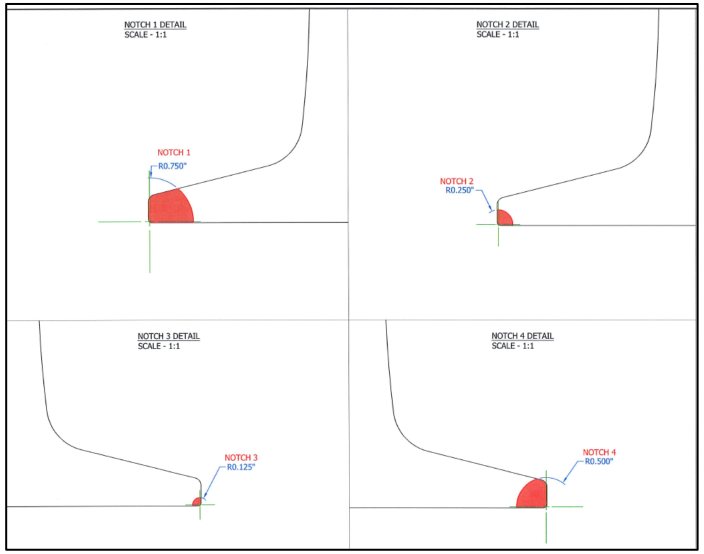
Rail Specimens

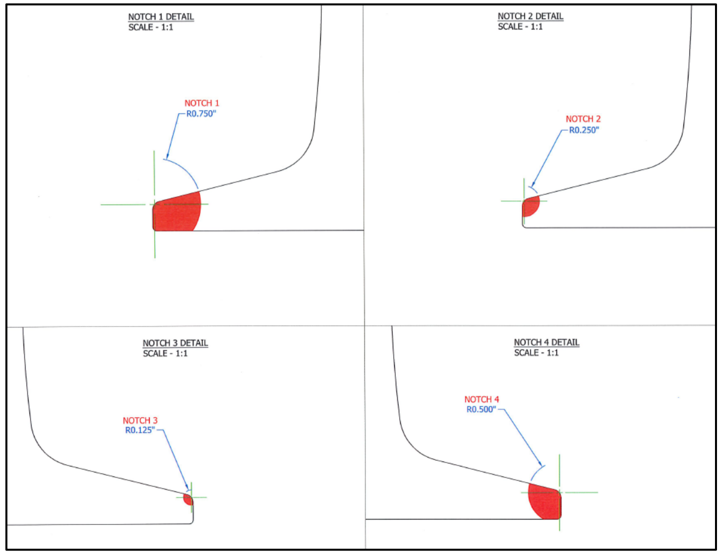
Rail	Side	EDM* Notch	Size	Surface
Rail 1	Side A	N 1	3/4"	Bottom
		N2	1/4"	
	Side B	N 1	1/2"	
		N2	1/8"	
Rail 2	Side A	N 1	3/4"	Top
		N2	1/4"	
	Side B	N 1	1/2"	
		N2	1/8"	

*EDM - Electrical Discharge Machining



Rail showing notch in the base





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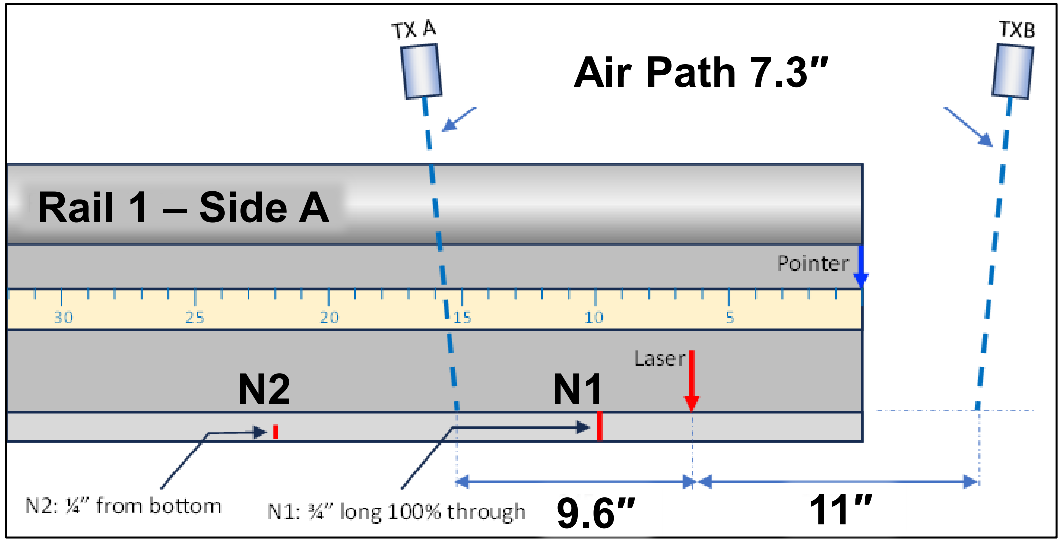
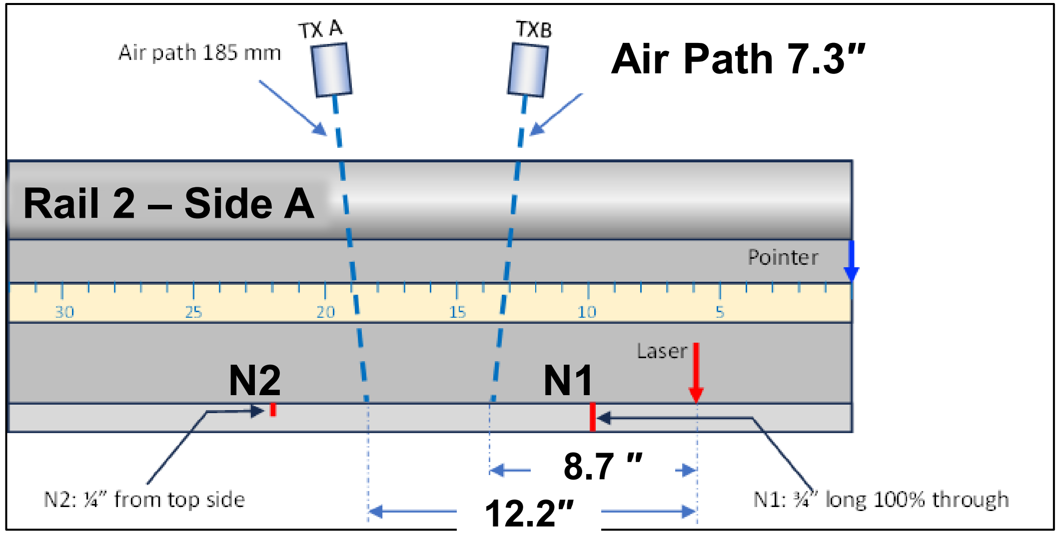
LACUT Test Configuration

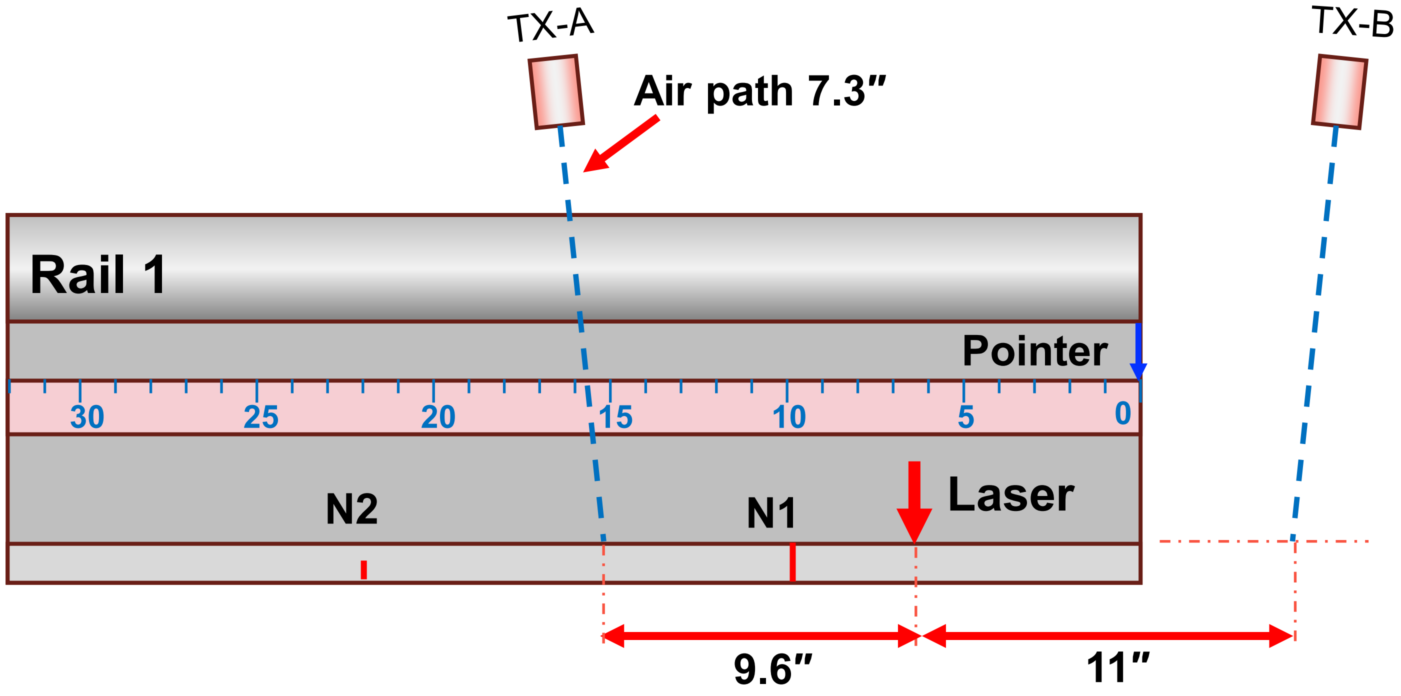
- **Two test setups used**
  - **Rail 1**: TX-A left of laser, TX-B right of laser
  - **Rail 2**: Both transducers placed left of the laser
- **Two 750-kHz air-coupled transducers angled at 6.5-degrees to capture leaky surface waves**
- **All equipment positioned above the top of the rail**
- **Laser focused into a line to generate surface waves that travels in both directions**





LACUT Scanning Procedure

- **The first measurement was taken with the pointer at position 0**
- **The rail was moved in 0.5-inch increments and a new measurement collected until TX-A/B reached the end of the rail**



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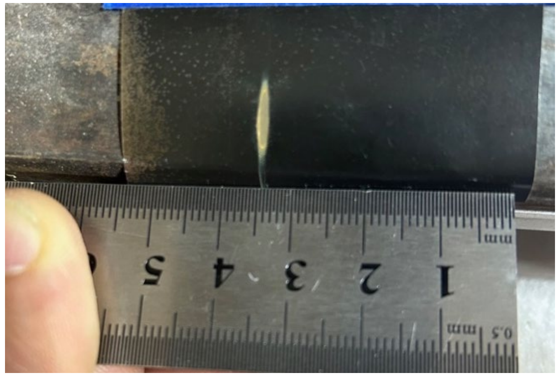
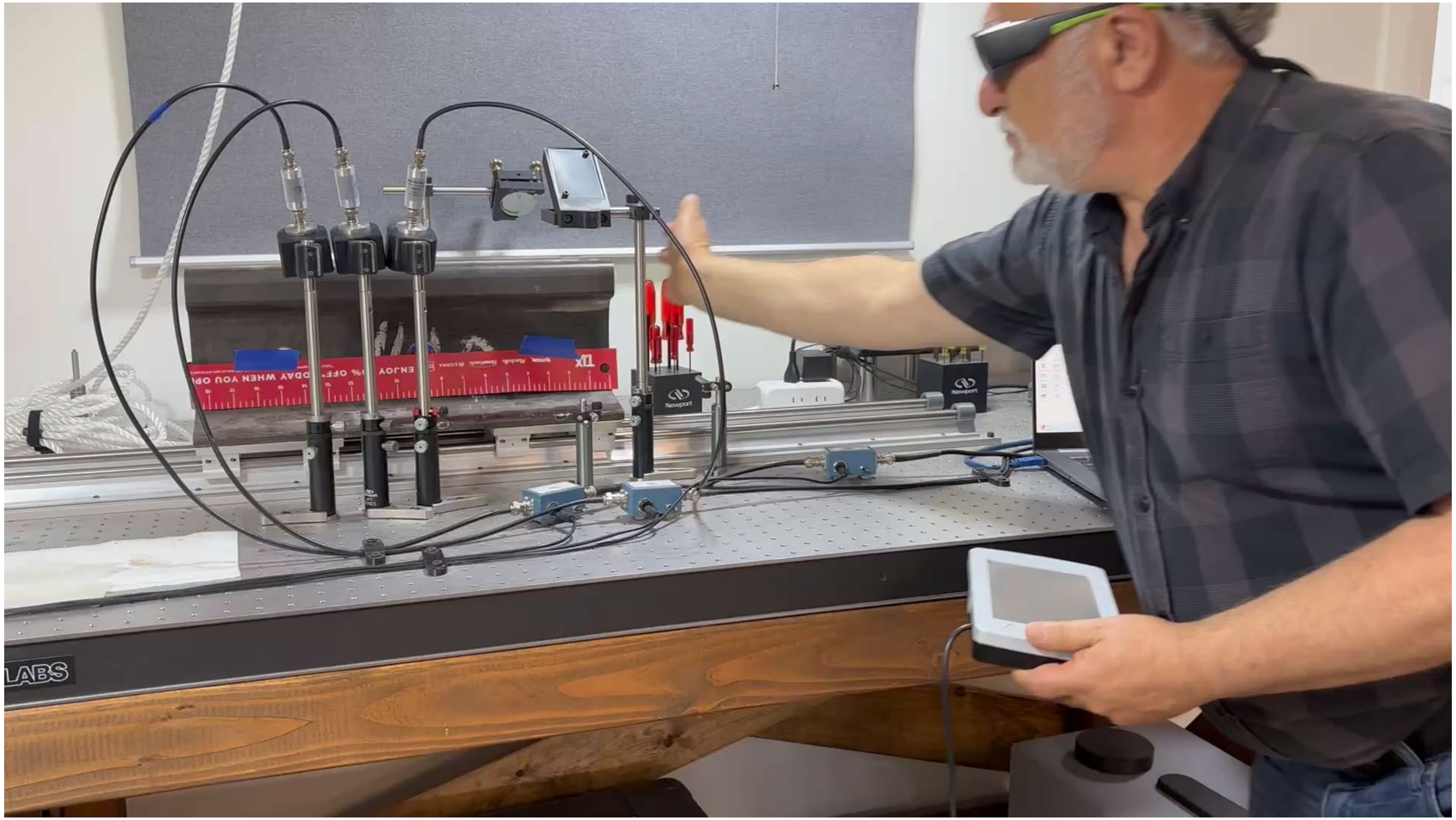
LACUT Laboratory Demonstration



Laser illumination pattern on laser burn paper



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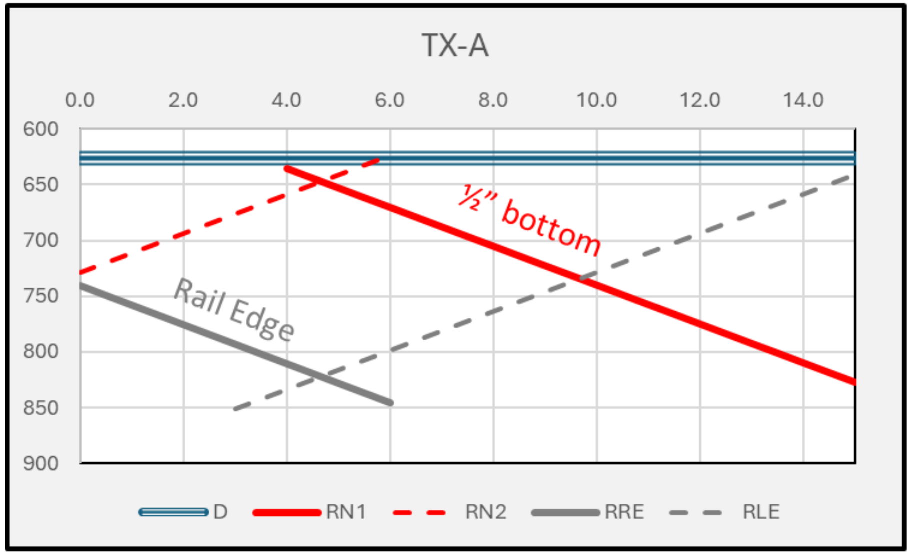
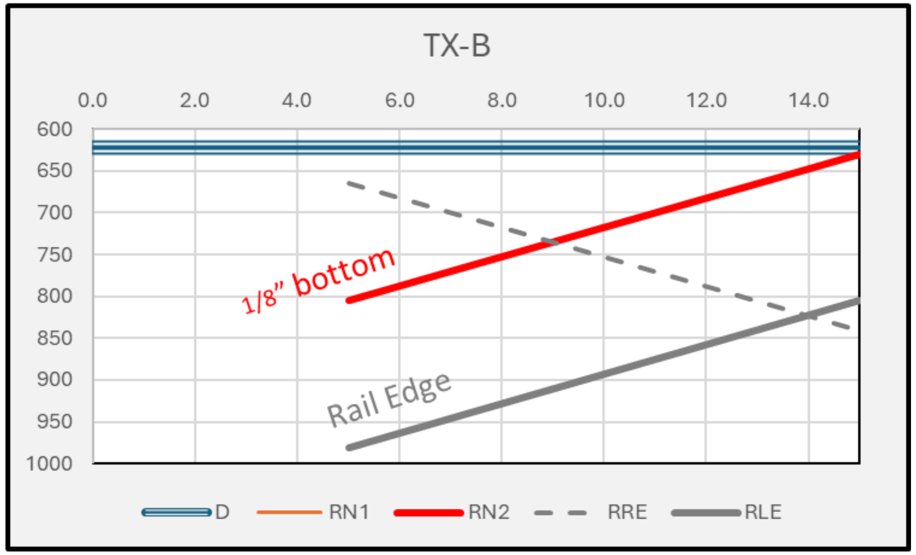
B-Scan Results – Rail 1 Side -B

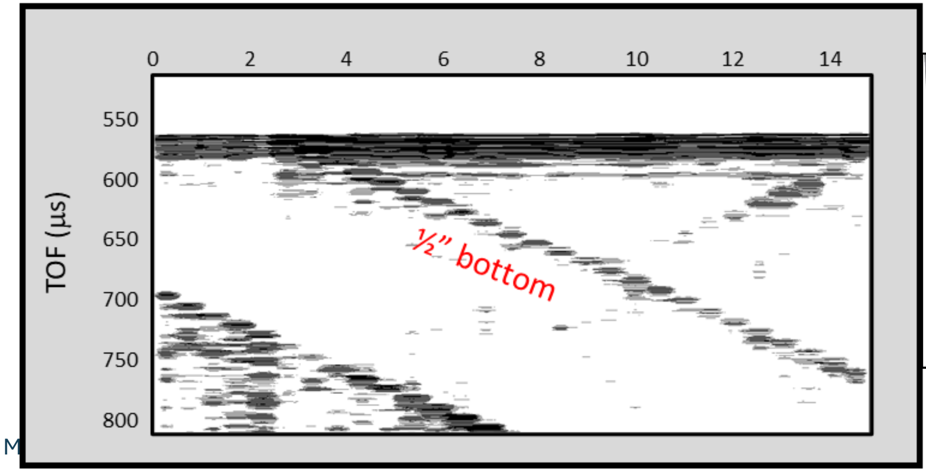
1/2" EDM Notch (Bottom)

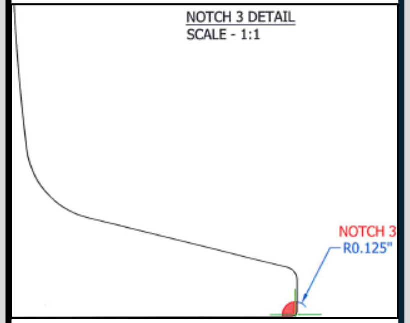


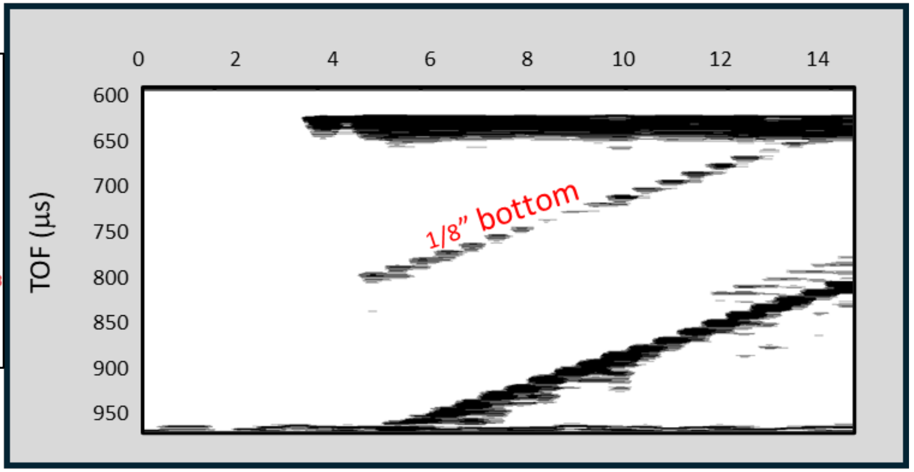
1/8" EDM Notch (Bottom)



Predicted B-Scan







Actual B-Scan

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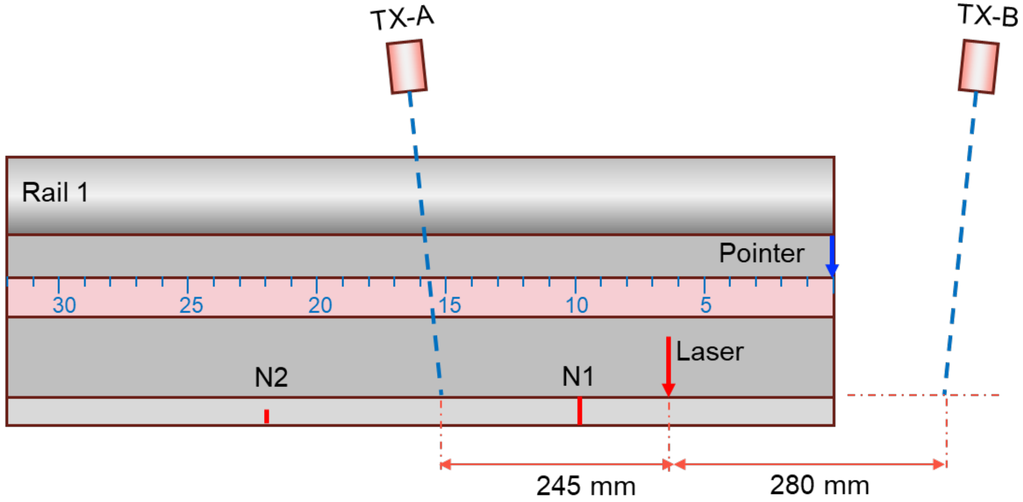
Detectability Range of R-Wave

- **By taking a measurement every 4 inches, at least two points can be recorded, indicating the presence of reflected wave (R-wave)**
  - The actual length on a continuous rail should be more than 4 inches



Length of rail longitudinal movement where an R-wave can be detected

EDM Notch		Length of Travel
Size	Placement	
3/4"	Through	>10"
3/4"	Through	>10"
1/2"	Top	>10"
1/2"	Bottom	>12"
1/4"	Top	>4"
1/4"	Bottom	>9"
1/8"	Top	>4"
1/8"	Bottom	>10"

Note: The distances in laboratory trials were limited by the short length of the rail specimen and detector positions

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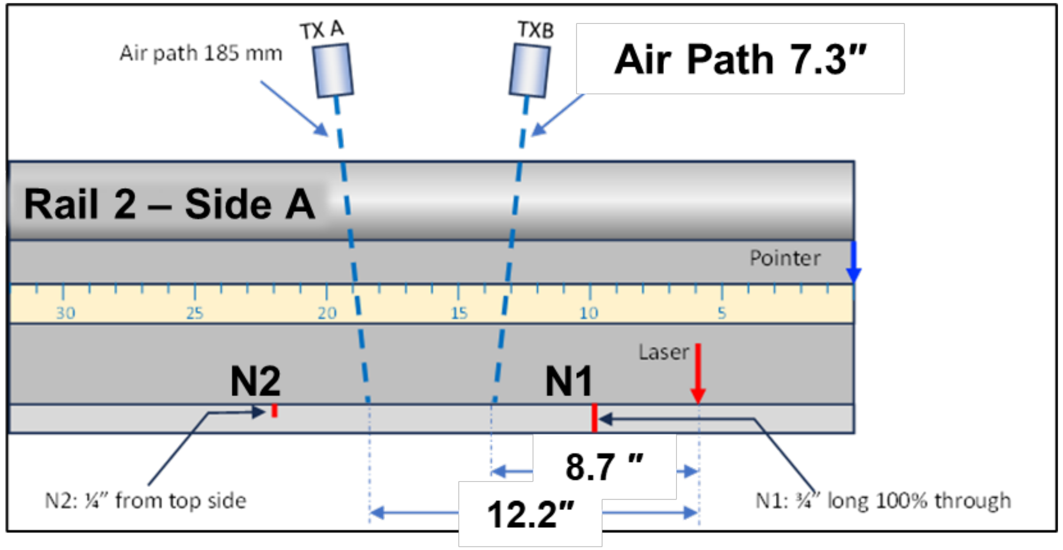
Detectability Range of T-Wave

- **Only 3/4- and 1/2-inch notches were detected**
  - When the T-wave was expected, the transducer was outside the rail
- **By taking a measurement every 2 inches, at least one point of significantly attenuated T-wave can be captured**
- **Combined with the R-wave, this means a 6-inch space between measurements is enough to detect rail base cracks**

Parameters	3/4-in. Notch	1/2-in. Notch
Max. drop in D-Wave	2.4 dB	2.3 dB
Min. attenuation in T-Wave	6.9 dB	9.8 dB
Shortest detectability distance	2.5 in.	2 in.

- Max Drop in D-wave = Min/Average
- Shortest detectability distance = the shortest distance from the laser source where T-wave attenuation is > 6 dB



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Key Takeaways

✅ **Reliable Detection**	• All notches detected using a two-transducer configuration
📊 **Results Validation**	• Experimental B-scans closely matched theoretically predicted scan patterns
🔎 **Clear Defect Signature**	• Notches detected via reflected (R) and attenuated transmitted (T) waves • R-wave forms a distinct linear trace with slope = 2/Vs (surface wave velocity)
🎯 **Optimized Configuration**	• Favorable transducer tilt ensured consistent ultrasound echo detection
🚄 **High-Speed Feasibility**	• 120 Hz laser + 6-inch spacing enables inspection speeds up to 41 mph
📈 **Scalability Potential**	• Performance expected to improve on a continuous rail

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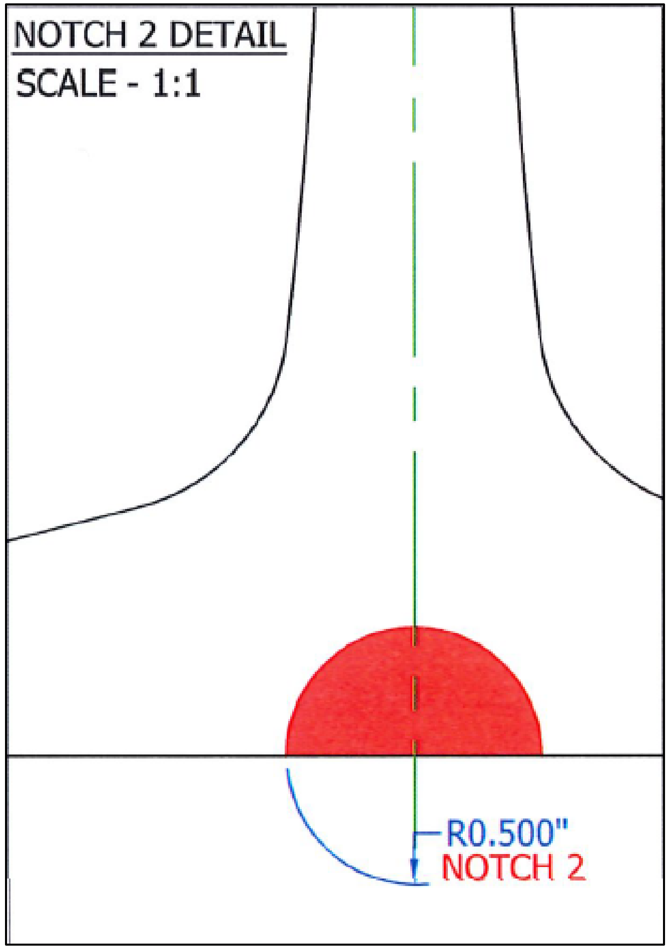
What's Next:

- **Refine LACUT approach and optimize test parameters for field demonstration**
  - Effect of obstacles and surface condition on Type 1 and 2 EDM notches
    - Ballast, tie plates, and fasteners
    - Grease, thin layer of ice
  - Develop approach for detecting challenging flaws, such as Type 3 EDM notches
- **Explore mounting the system on a moving platform to verify high-speed capability**
- **Explore machine-learning approaches for automated defect detection**



Type 3 EDM Notches

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Acknowledgements

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- **Dr. Shant Kenderian, Modality LLC**
- **MxV Rail Team**
- **Rail Inspection TAG**
- **AAR Research Committee**

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Back to Infrastructure Agenda

Track Inspection Technology

Yin Gao, PhD

Principal Investigator I

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Overview

- **Introduction**
- **Tests and measurements update**
  - Unattended Track Geometry Measurement System (TGMS)
  - Inertial Measurement Unit (IMU)-Based TGMS
  - Automated Turnout Inspection
- **Summary**
- **Future work**

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Introduction

- **Track health assessment is a priority for safe operations**
  - Evaluate non-traditional track monitoring technologies
  - Improve track monitoring and maintenance efforts
  - Optimize use of resources for maintenance efforts

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Unattended TGMS

- **Locomotive-mounted TGMS**
  - Onboard system collects and analyzes track measurement data during locomotive operation
  - Facility for Accelerated Service Testing (FAST®) evaluation/testing setup completed (data transfer and formatting)

FAST® is a registered trademark of MxV Rail

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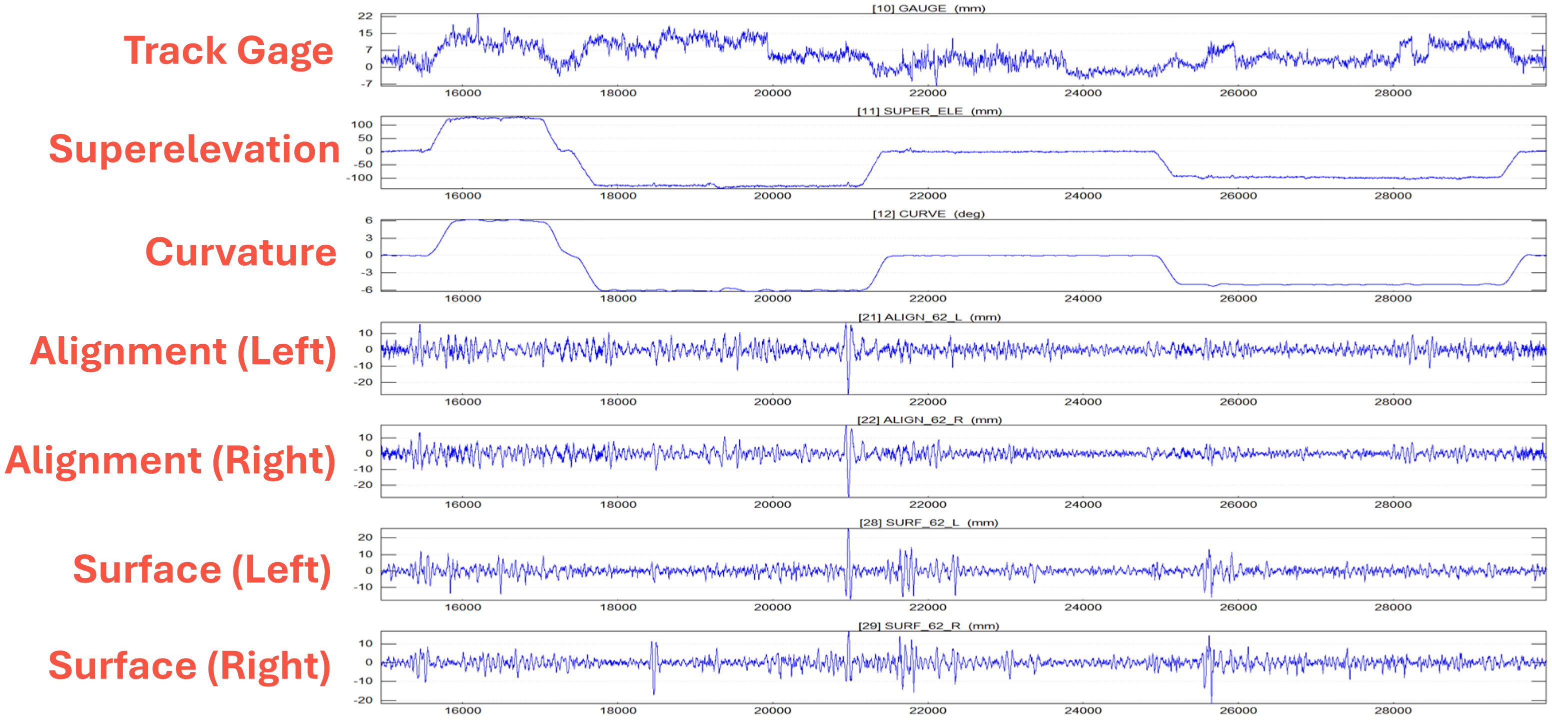
Unattended TGMS (cont'd)

- **Improved performance at FAST through evaluation and system push update**
  - The data quality of the track geometry (TG) is acceptable and usable
  - Continue to evaluate TG measurements under different conditions at FAST



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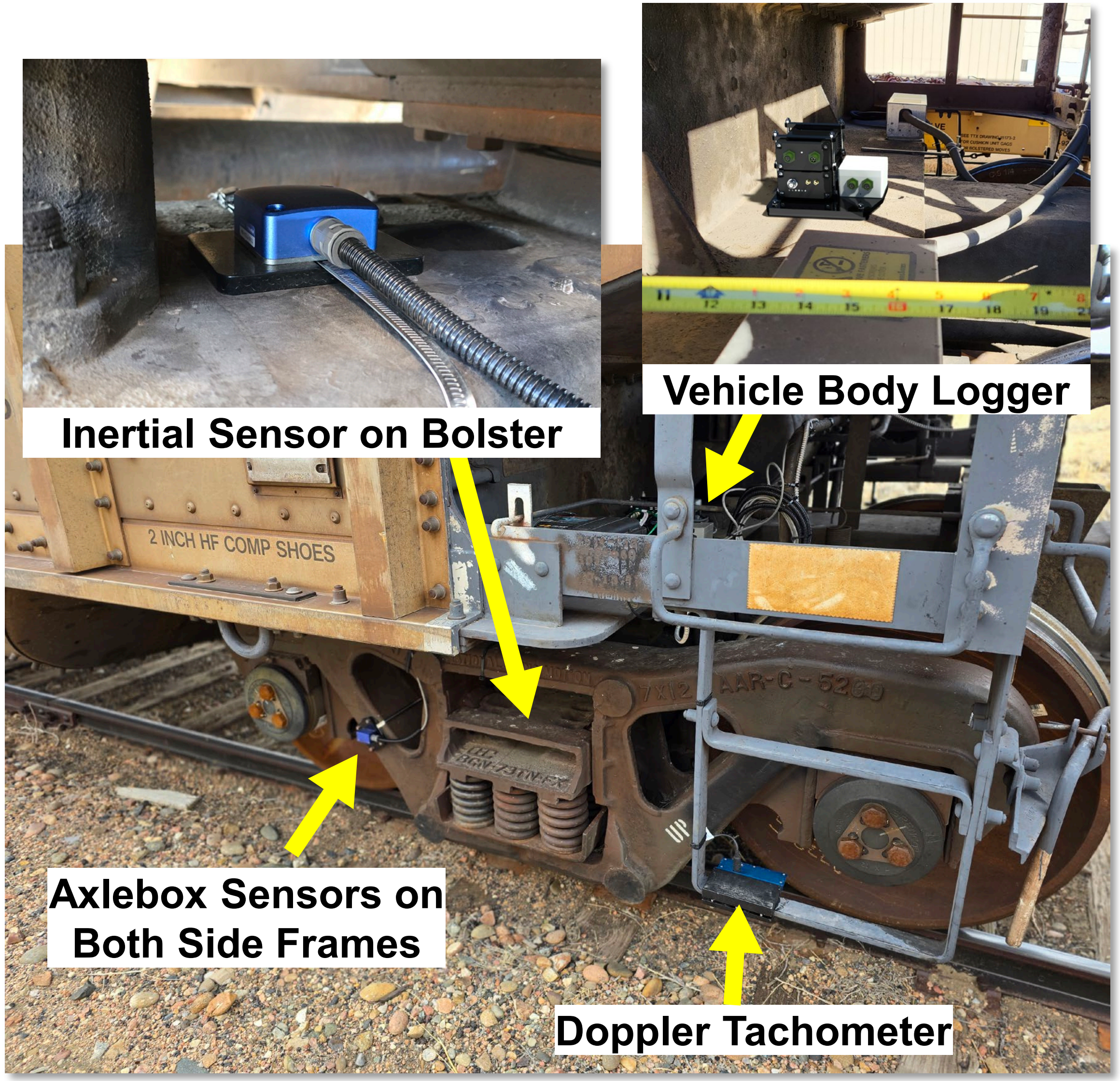
Inertial Measurement Unit (IMU)-Based TGMS

- **IMU-based TGMS successfully deployed on a FAST car**
  - Acceleration-based TG measurements
  - Solar-powered supply system
  - Fully automated operation after initial setup



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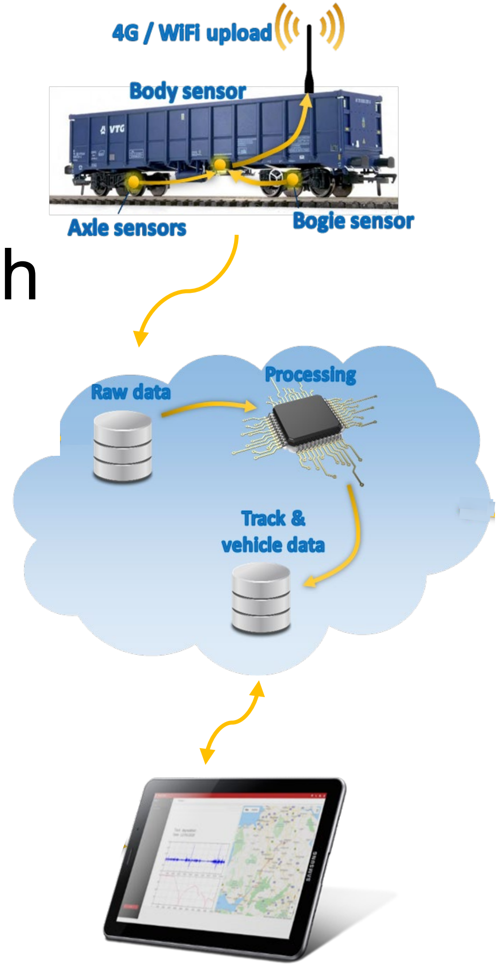
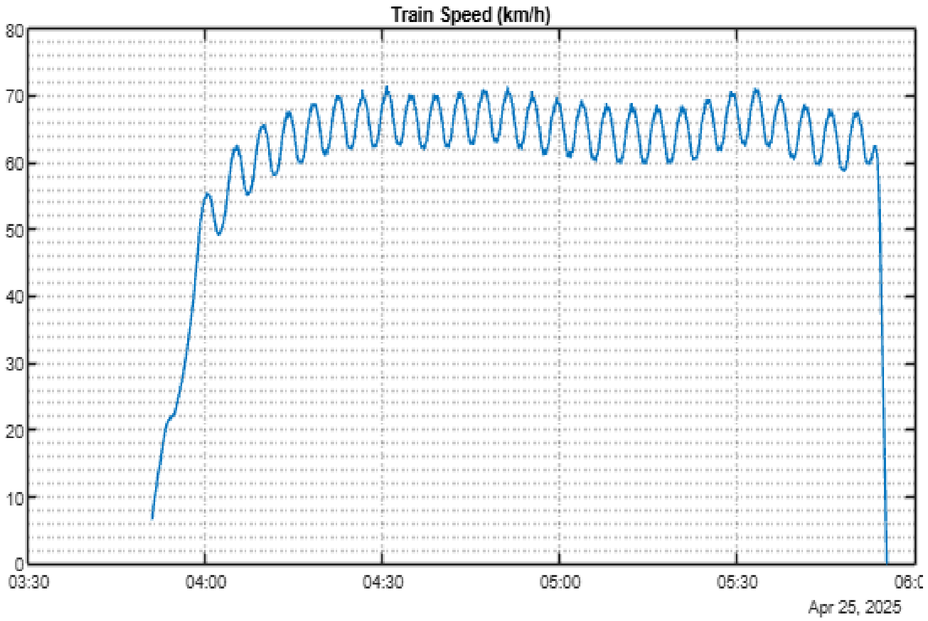
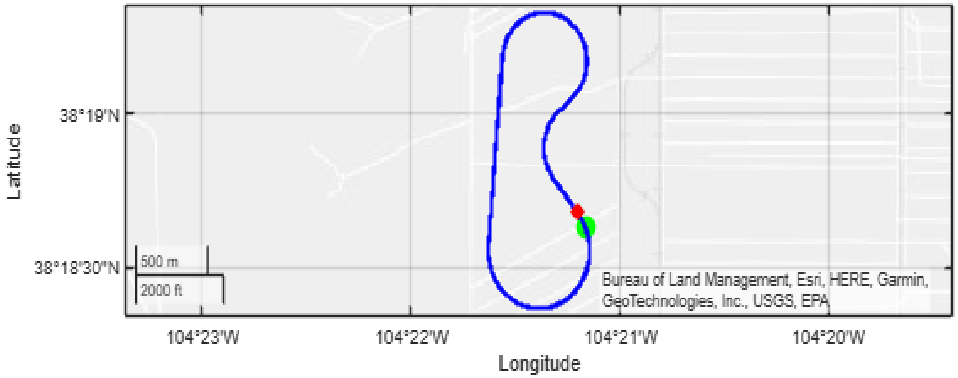
IMU-Based TGMS (cont'd)

- **IMU-based TGMS**
  - Automated cloud-based data transfer
  - Rapid post processing with user-friendly visualization
  - Customized to support FAST operational environment
  - Benefits and limitations







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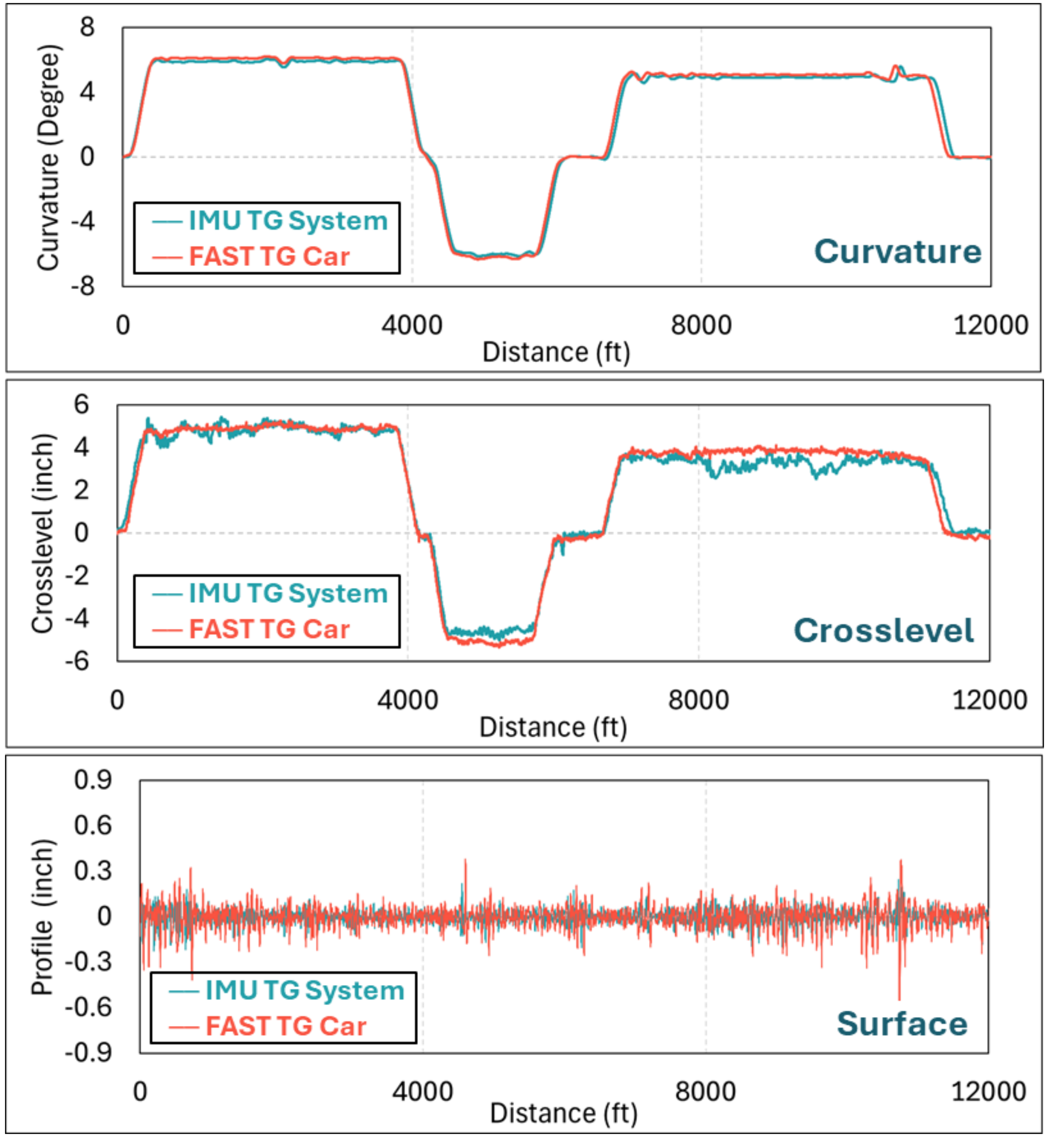
IMU-Based TGMS (cont’d)

- **Compared results with TG Car at FAST**
  - Curvature and bogie top (profile) showed acceptable overall agreement
  - Cross level showed discrepancies
- **Combination of system limitations and vehicle-track interaction effects**



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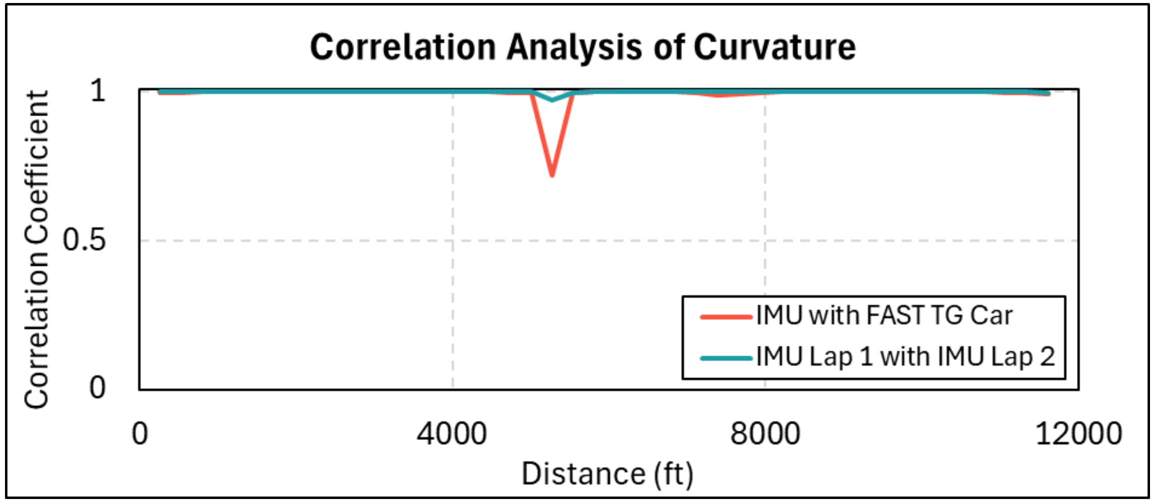
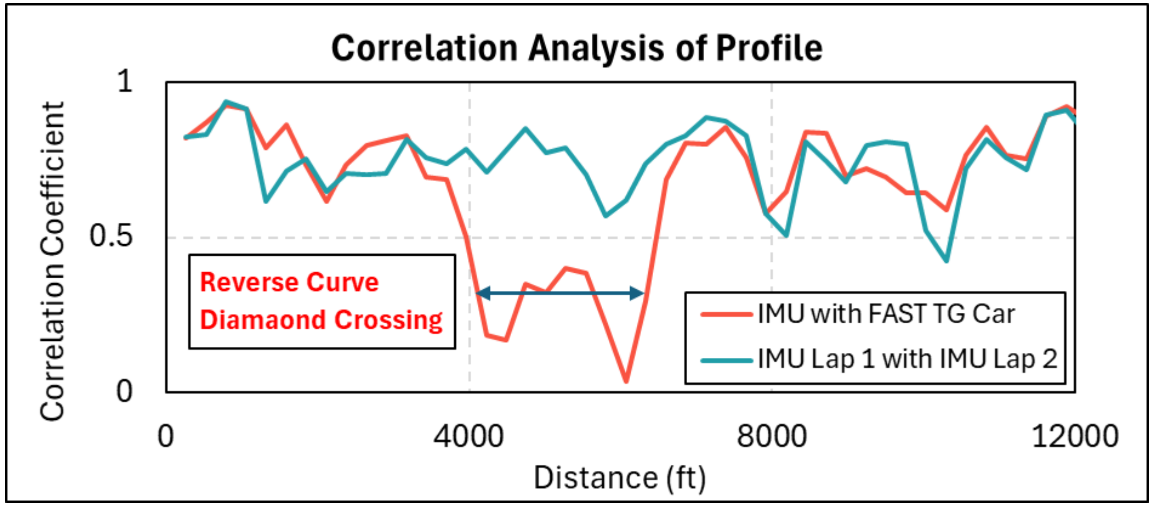
IMU-Based TGMS (cont’d)

- **Based on FAST evaluation, the IMU-based system data is repeatable but does not match TG car data in high-vibration areas**
  - Curvature data: A strong positive correlation between the system and the FAST TG car
  - Profile data: A moderate positive relationship between runs, with low correlations at reverse curves and diamond crossings





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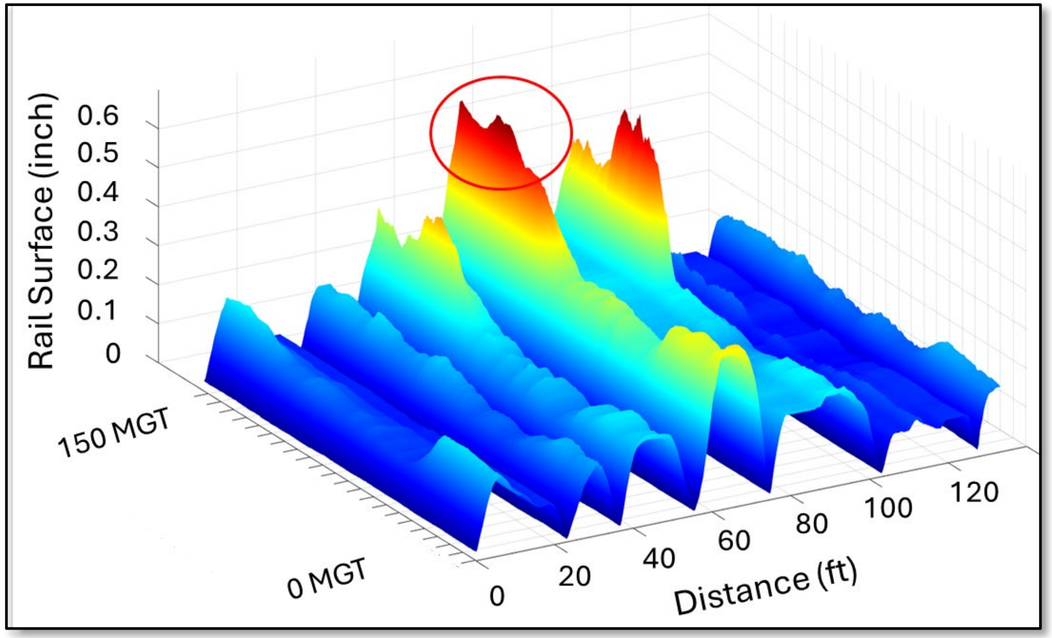
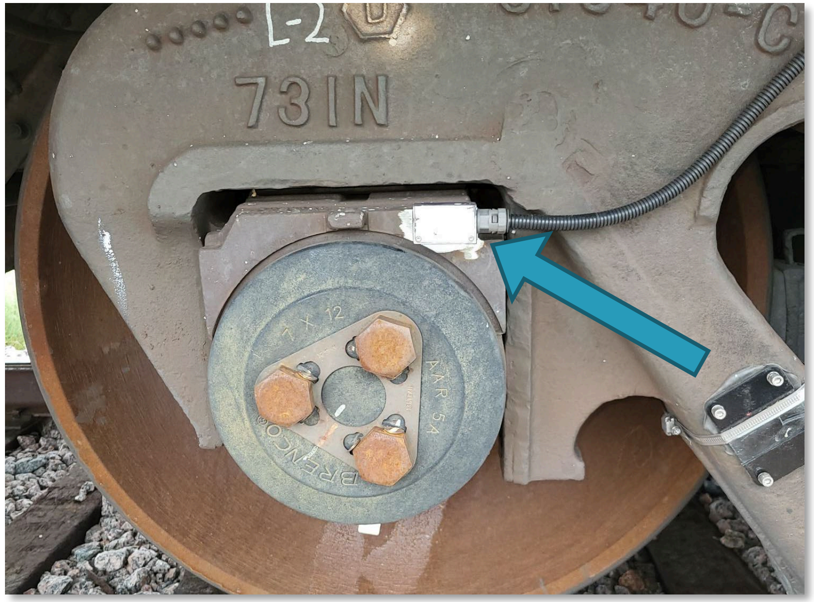
IMU-Based TGMS (cont'd)

- **Effectively provided progressive track change over a long period**
- **Ongoing work and improvement**
  - Sensors on bearing adapters in sync with vertical rail trajectory





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Automated Turnout Inspection (ATOI)

- **Summarized FRA regulations and current railroad best practices**
- **Evaluated capabilities of current ATOI technologies**
  - ATOIs are designed for frequent and rapid screenings, providing objective and repeatable data for early defect detection, condition monitoring, and long-term asset management

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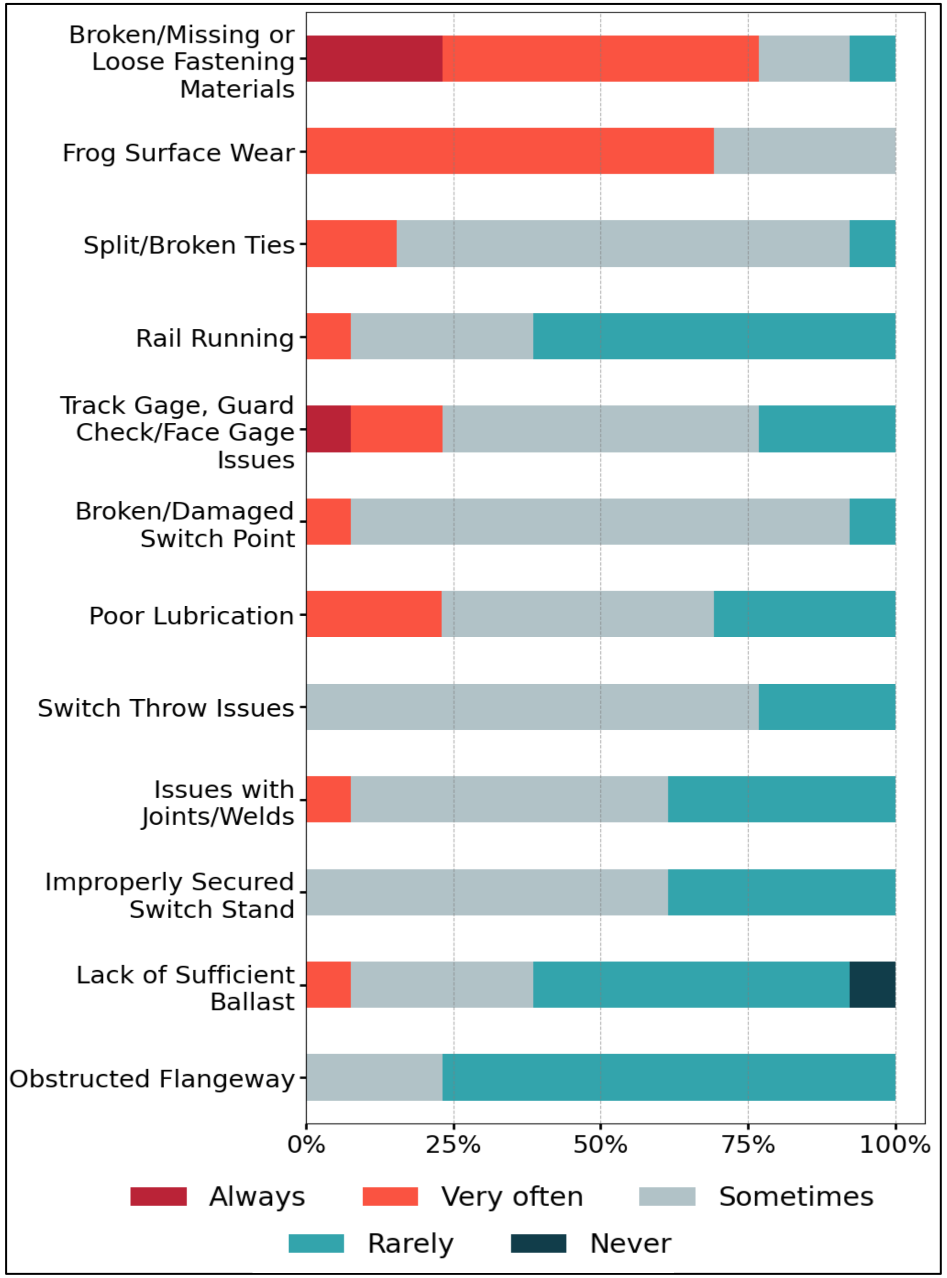

Survey Results

ATOI

- **Conducted an industry survey on current manual inspection practices and efforts in automated technologies**
  - All Class I railroads participated and showed strong interest in ATOI
  - Several railroads are currently using or testing emerging automated turnout inspection tools and techniques
  - Common concerns included the accuracy and repeatability of ATOI measurements, high rates of false positives

Summary

- **Completed the setup of locomotive-mounted TGMS for FAST operation**
- **Completed the setup of IMU-based TGMS on a FAST car**
  - At FAST, the IMU-based system’s data quality falls short compared to a comprehensive TG system
  - A year-long analysis indicated that the IMU-based TG system effectively monitors long-term track condition changes and can detect sudden shifts
- **Survey of automated turnout inspection reflected strong industry interest in adopting tools**
  - All Class I railroads showed interest

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Future Work

- **Continue to evaluate existing systems used at FAST**
- **Evaluation of TG thresholds**
  - Identify appropriate TG tolerances under frequent TG measurement
- **Automated inspection of track and turnouts**
  - Support AAR and Class I railroads to aggregate automated track inspection data in open track
  - Research to better understand the benefits of automated track inspections in turnouts

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Acknowledgements

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- Class I Railroads
- Alex Keylin, Silvia Galvan Nuñez, Ekrem Koc, Ryan Alishio
- MxV Rail Teams (Track, Operations, Instrumentation, and Data Science)

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Rail Testing in Revenue Service

Ananyo Banerjee, PhD, PE
Principal Investigator II, Manager NDE-Metallurgy

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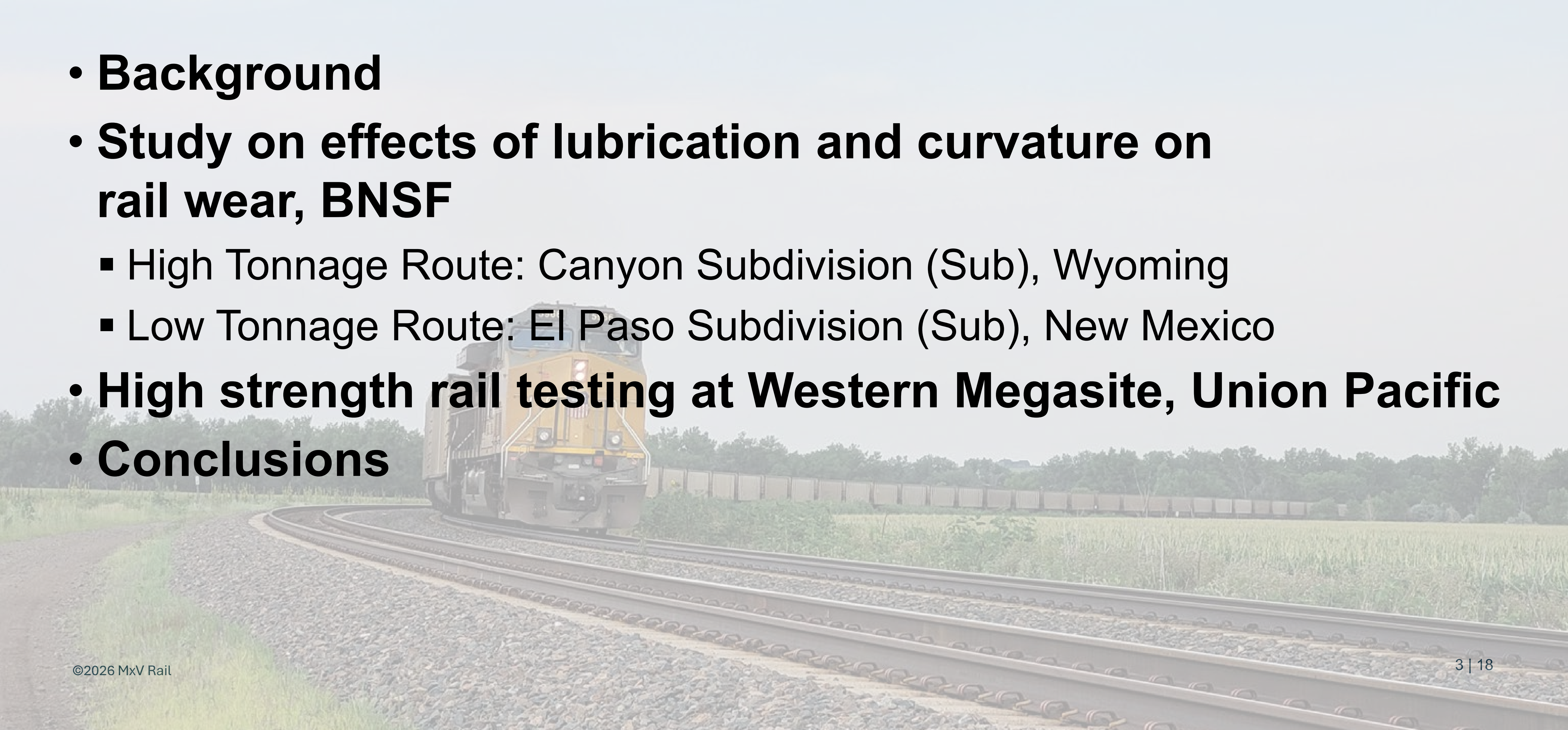
Overview



- **Background**
- **Study on effects of lubrication and curvature on rail wear, BNSF**
    - High Tonnage Route: Canyon Subdivision (Sub), Wyoming
    - Low Tonnage Route: El Paso Subdivision (Sub), New Mexico
- **High strength rail testing at Western Megasite, Union Pacific**
- **Conclusions**

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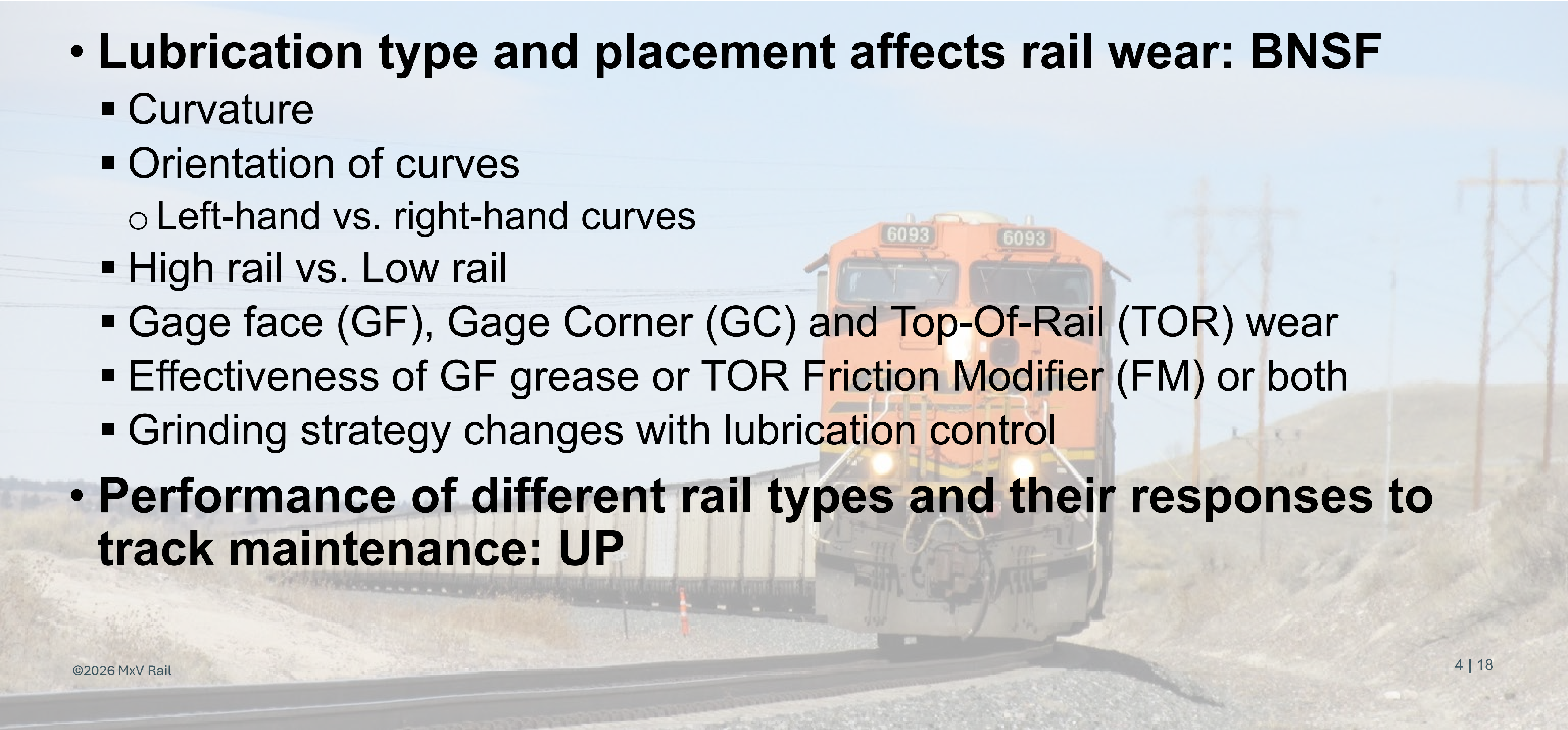
Background



- **Lubrication type and placement affects rail wear: BNSF**
  - Curvature
  - Orientation of curves
    - Left-hand vs. right-hand curves
  - High rail vs. Low rail
  - Gage face (GF), Gage Corner (GC) and Top-Of-Rail (TOR) wear
  - Effectiveness of GF grease or TOR Friction Modifier (FM) or both
  - Grinding strategy changes with lubrication control
- **Performance of different rail types and their responses to track maintenance: UP**

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Comparison Among Test Sites

	Canyon Sub BNSF	El Paso Sub BNSF	South Morrill Sub UNION PACIFIC
Annual Tonnage	>90 MGT	>20 MGT	>100 MGT
Tie/Sleeper Type	Concrete	Wood	Concrete
Fastener Types	Elastic	Cut Spikes	Elastic
Rail Size	141RE	136RE	136RE
Traffic Type	Primarily Coal	Grains, Misc. (Local)	Coal and Intermodal
Curvature (Rail Testing)	1°-5°	1°-6°	2° (Two curves)
Test Duration	2021-2024	2021-2024	2014-Ongoing

Setup of Tests at BNSF Sites

- **Grinding marked beginning and end of testing phases**
  - Phase I: No TOR-FM or GF lubrication
  - Phase II: Only GF lubrication
  - Phase III: Both GF and TOR-FM (Canyon sub only)
    - Grinding schedules and tonnage differences in high and low tonnage sites necessitated test duration changes

El Paso Sub

	Inspection Dates		No. of days between inspections
Phase I	5/19/2021	4/21/2022	337
	5/18/2022	10/24/2023	524
Phase II	Grinding		No inspection
	11/28/2023	5/22/2024	176

Canyon Sub

	Inspection Dates		No. of days between inspections
Phase I	4/8/2021	8/11/2021	125
	1/28/2022	6/20/2022	143
	Grinding		No inspection
Phase II	7/12/2022	3/28/2023	*(Grind occurred during this phase, data not considered)
	Grinding		No inspection
	6/12/2023	8/14/2023	63
Phase III	8/14/2023	3/20/2024	219

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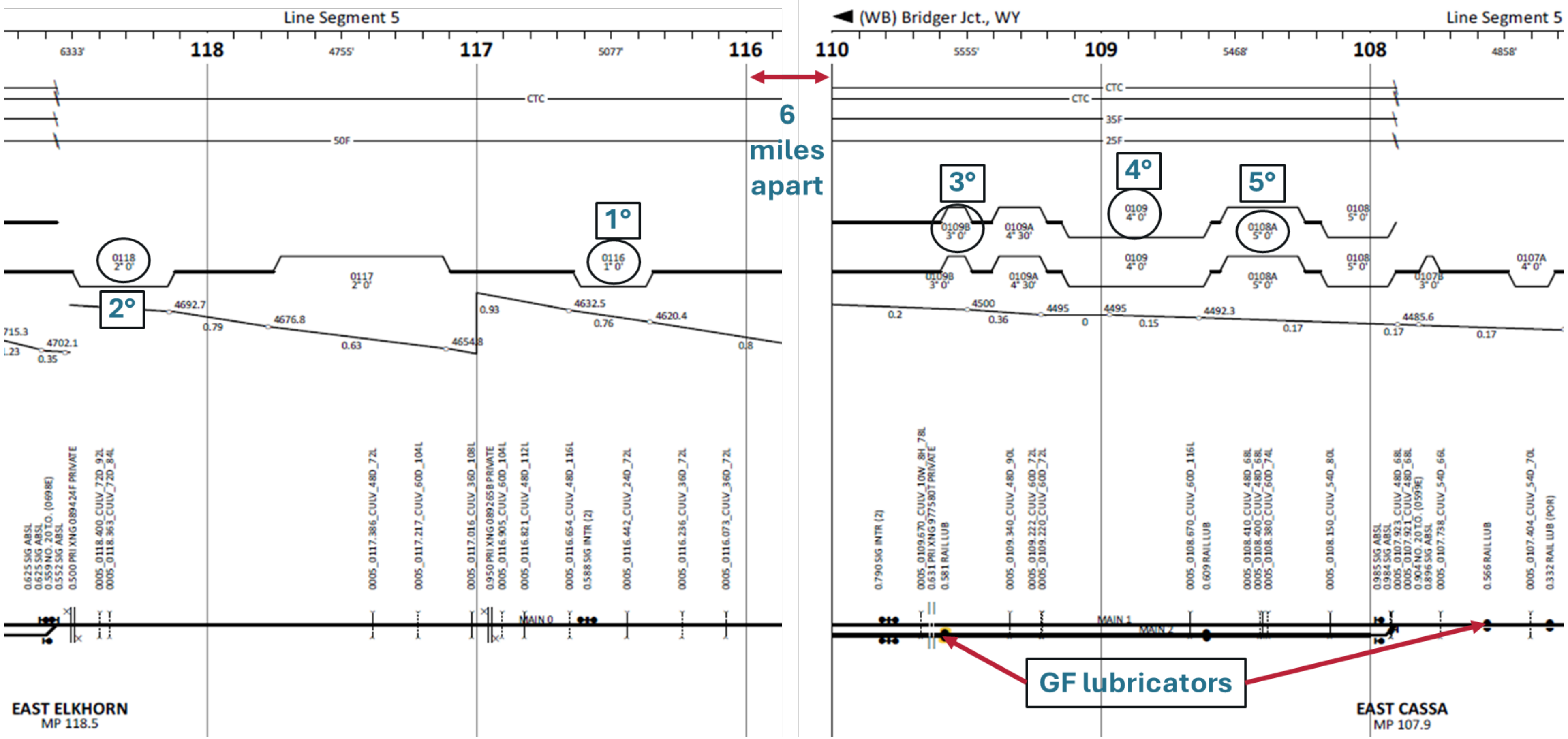
Canyon Sub: Test Setup

- **Track chart shows locations of curves and distances in between curves**



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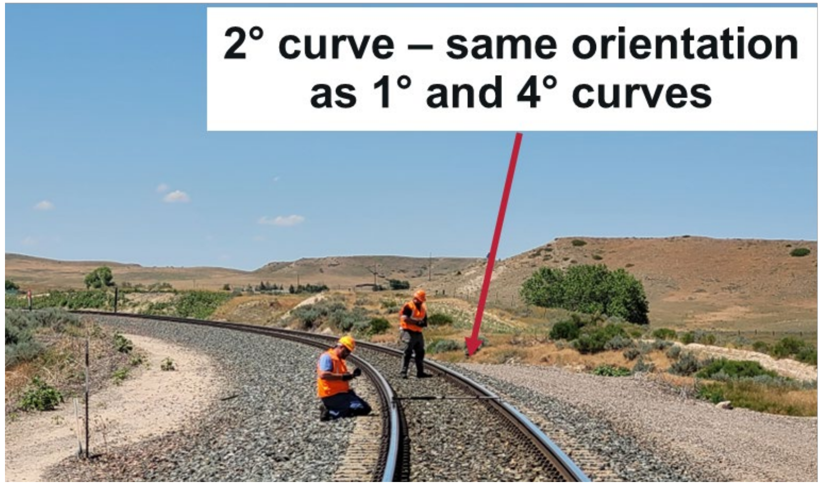
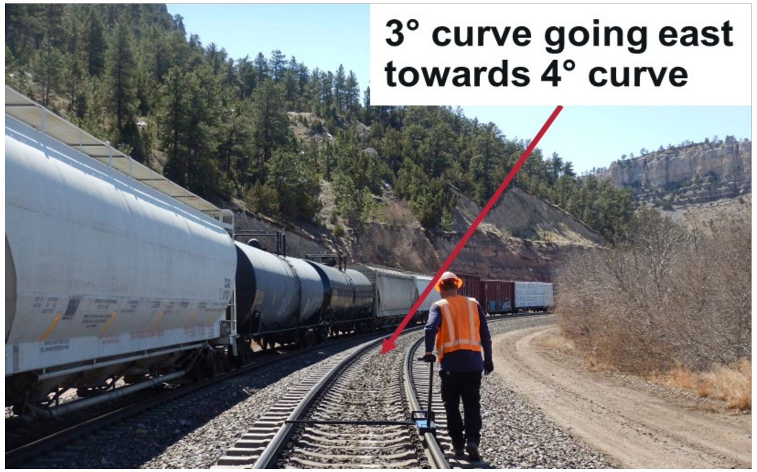
Canyon Sub: Curve Orientation


4° curve going west towards 3° curve


2° curve – same orientation as 1° and 4° curves


3° curve going east towards 4° curve


5° curve going west towards 4° curve

05/07/2024

- **4-degree curve is oriented opposite to 3- and 5-degree curves**
- **1-, 2-, and 4-degree curves are oriented in the same manner**

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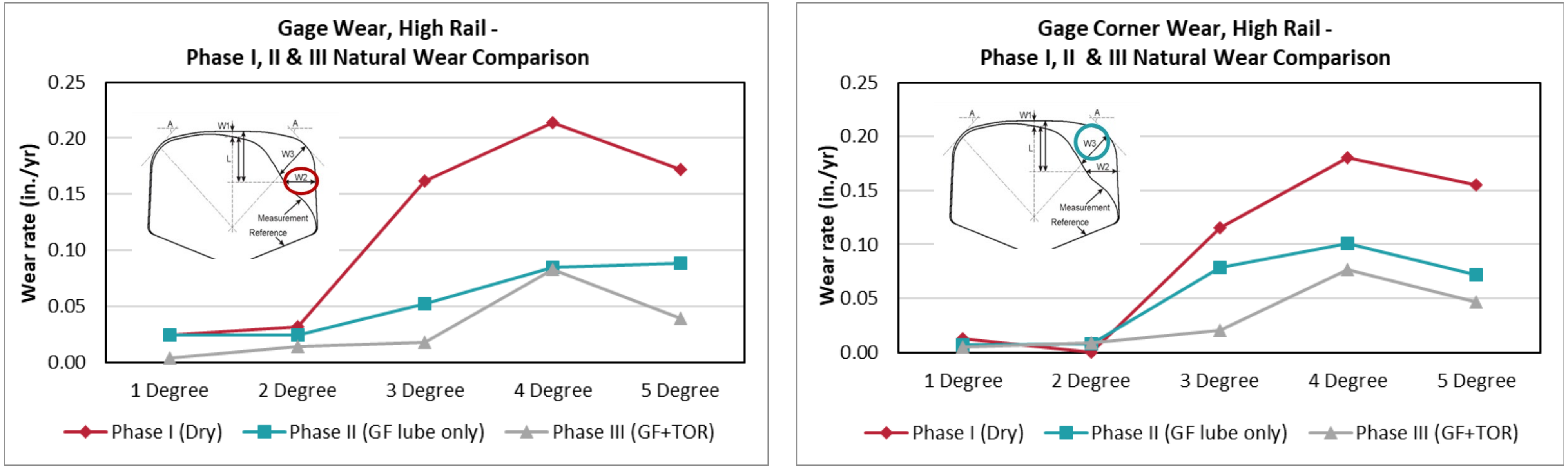
Canyon Sub: Rail Wear Results

- **Wear rates normalized over number of days in between grinds**
- **Phase II and Phase III affected curves higher than 2 degrees**
  - Lesser effect on 4-degree curve because of opposite orientation
    - Distance of lubricator from curve affects wear rates
  - Lube carryover and orientation affected wear rates

GF (left) and GC (right) high rail wear rate comparison between five curves



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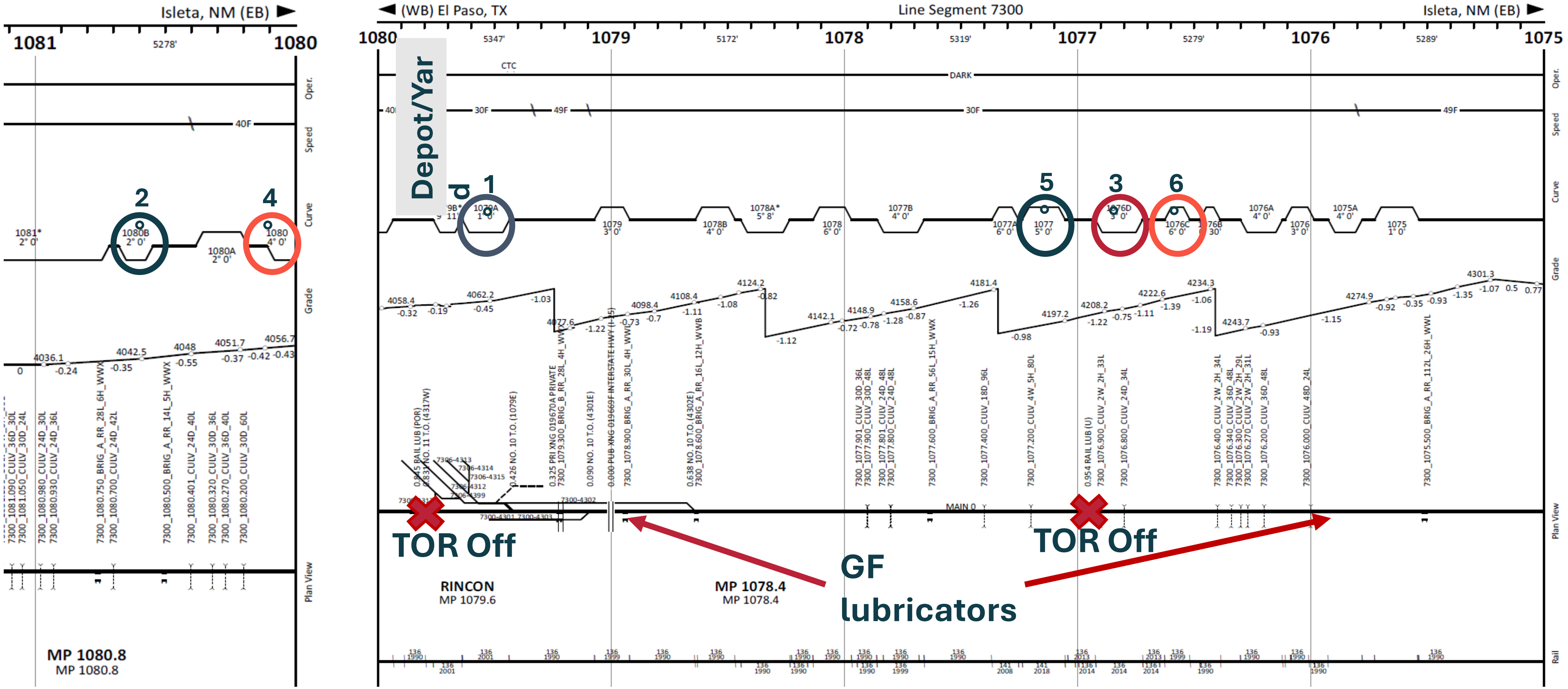
El Paso Sub: Test Setup

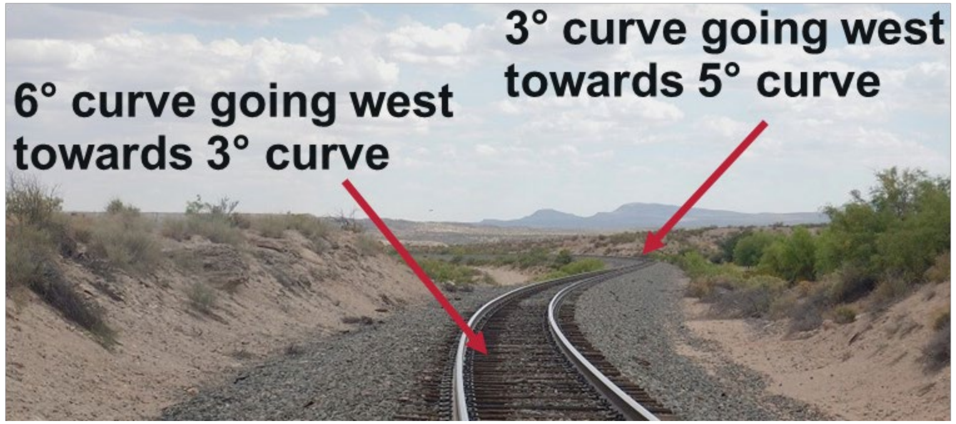
- **Track chart shows locations: TOR-FMs are always off**



El Paso Sub: Curve Orientation

- 3-degree curve is oriented opposite to 5- and 6-degree curves
- Curves 1-, 2-, and 4-degree are near depot; train speeds are slow

1° curve next to depot



6° curve going west towards 3° curve

3° curve going west towards 5° curve

4° curve going towards depot, trains slowing going east, accelerating going west

3° curve going east towards 6° curve

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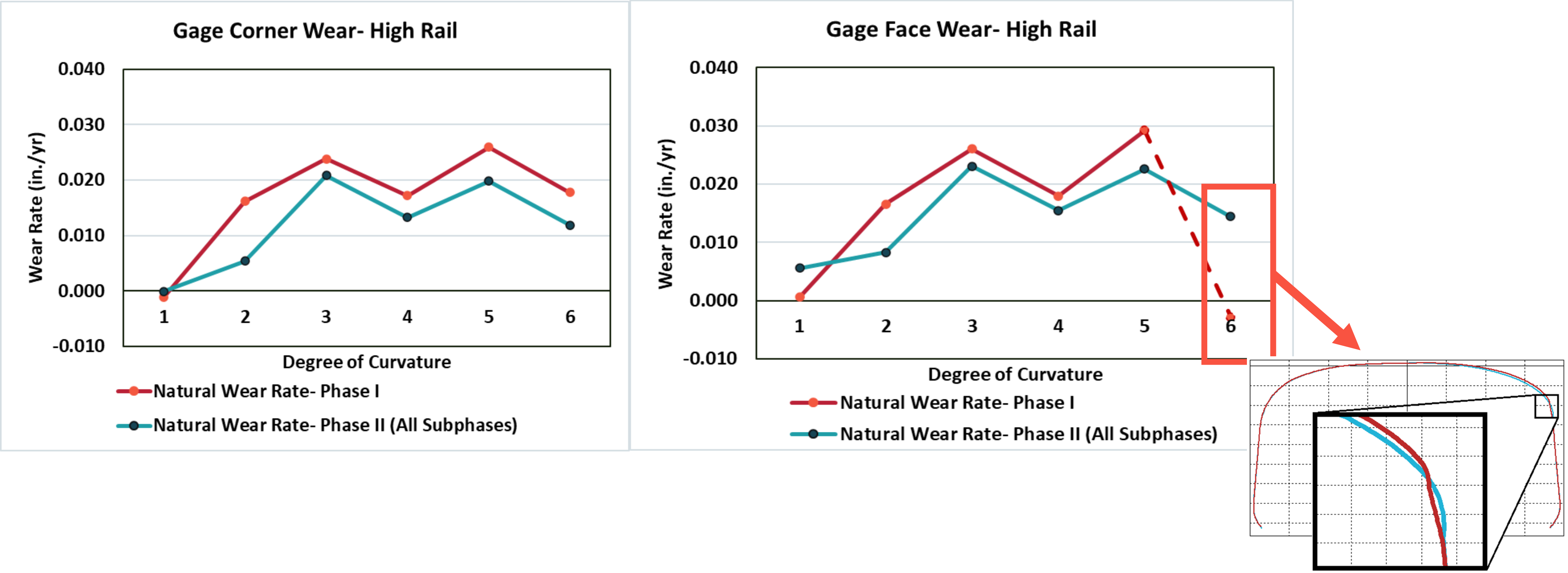
El Paso Sub: Rail Wear Results

- **GF lubrication lowered rail wear for 1- to 5-degree curves**
  - Biggest effect observed on high rail of 2-degree curve
  - 6-degree curve had metal flow causing GF wear rate to appear negative

GC wear rates and GF wear rates for high rail in all six test curves



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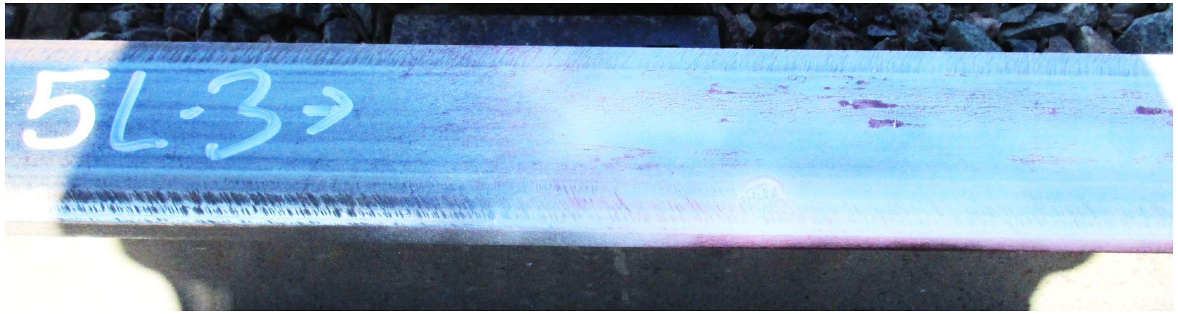
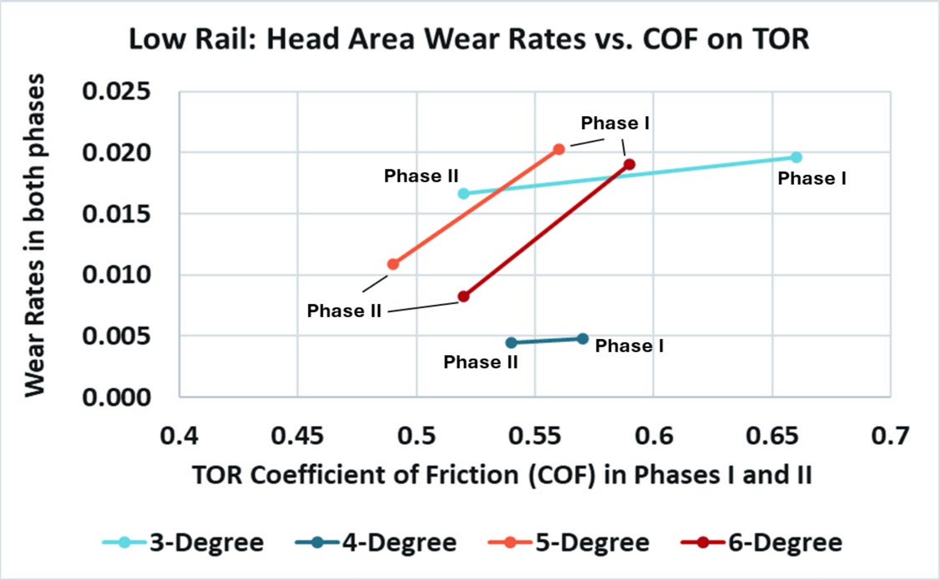
Friction and Wear Correlation

- **Friction values showed affects of lube carryover, curve orientation and distance from lubricators**
- **Rail surface conditions monitored for each phase**
  - Low rail developed more surface RCF in Phase I than Phase II



Low rail in 5-degree curve at start (above) and end (below) of Phase I

Low rail head area wear rates as a function of COF in 3-, 4-, 5-, and 6-degree test curves

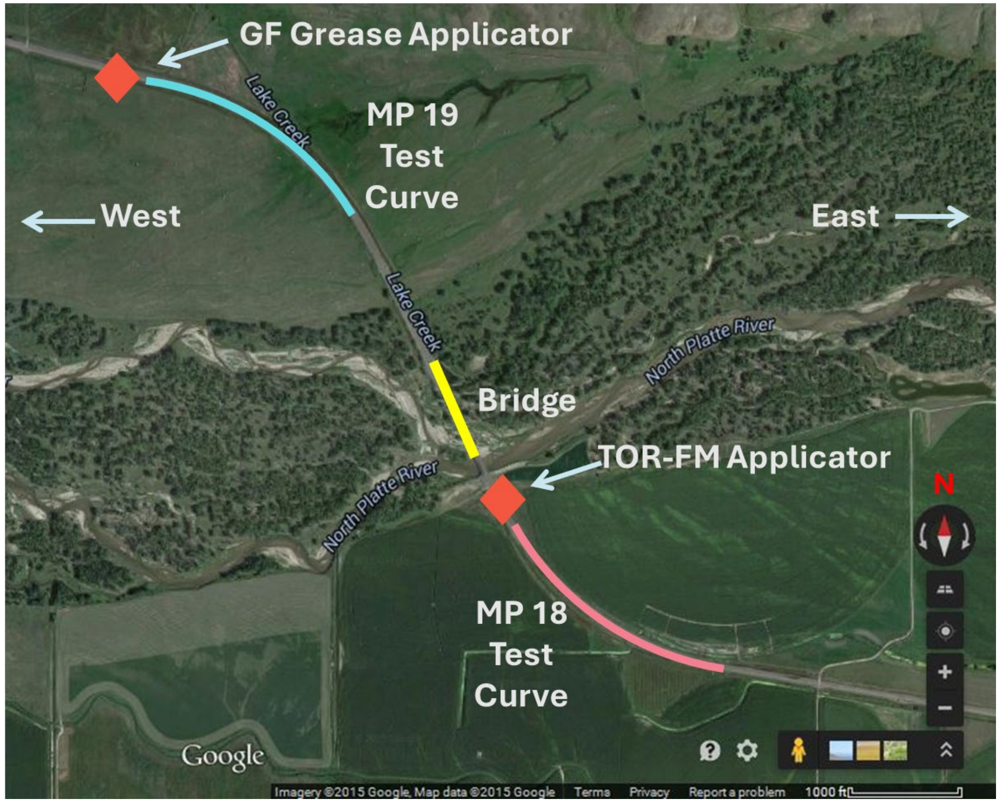


Western Megasite Rail Test

- **Performance of four rail types**
  - Accumulated +1,400 MGT since 2014 install
  - Two 2-degree curves of opposite orientations
  - Curves having both GF lube and TOR-FM
  - Preventative grinding schedule 2020–2026
    - 2014–2020
      - Corrective grinding in MP18 curve
      - Preventative grinding in MP19 curve

Manufacturer	Rail Type
Rocky Mountain Steel Mills (USA)	OCP
JFE (Japan)	SP3
Cleveland Cliffs (USA)	AHH
Nippon Steel (Japan)	HE-X

Rail test curves in MP18 and MP19 in the South Morrill Sub of western megasite



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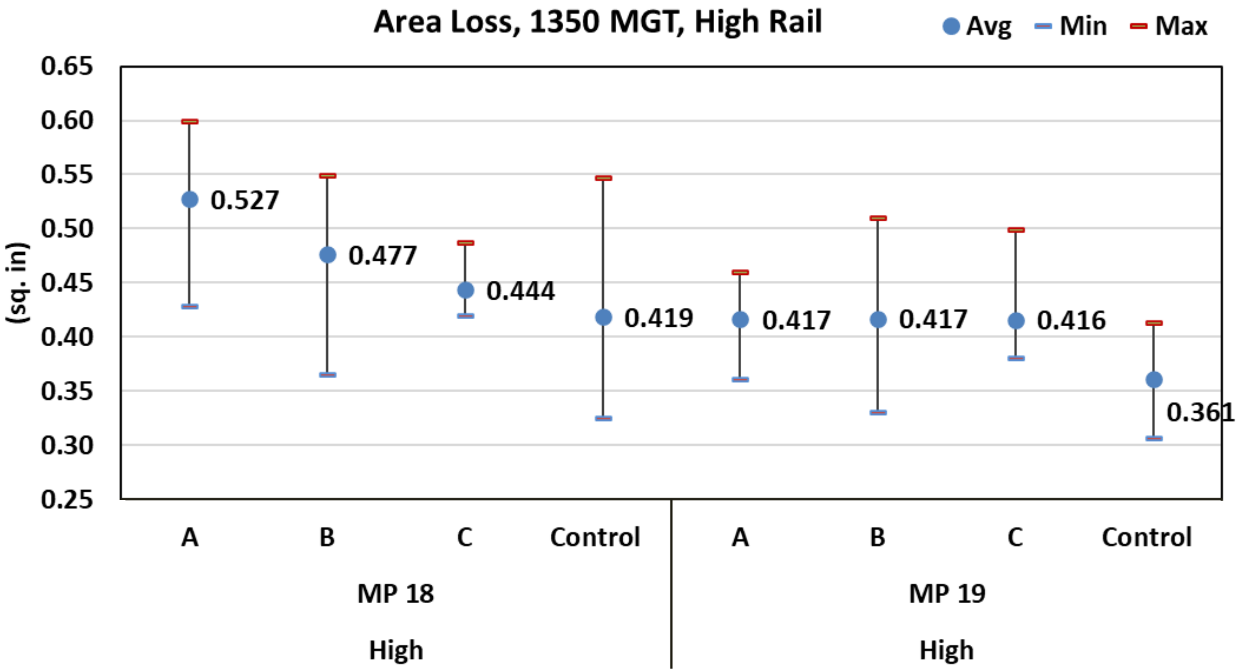
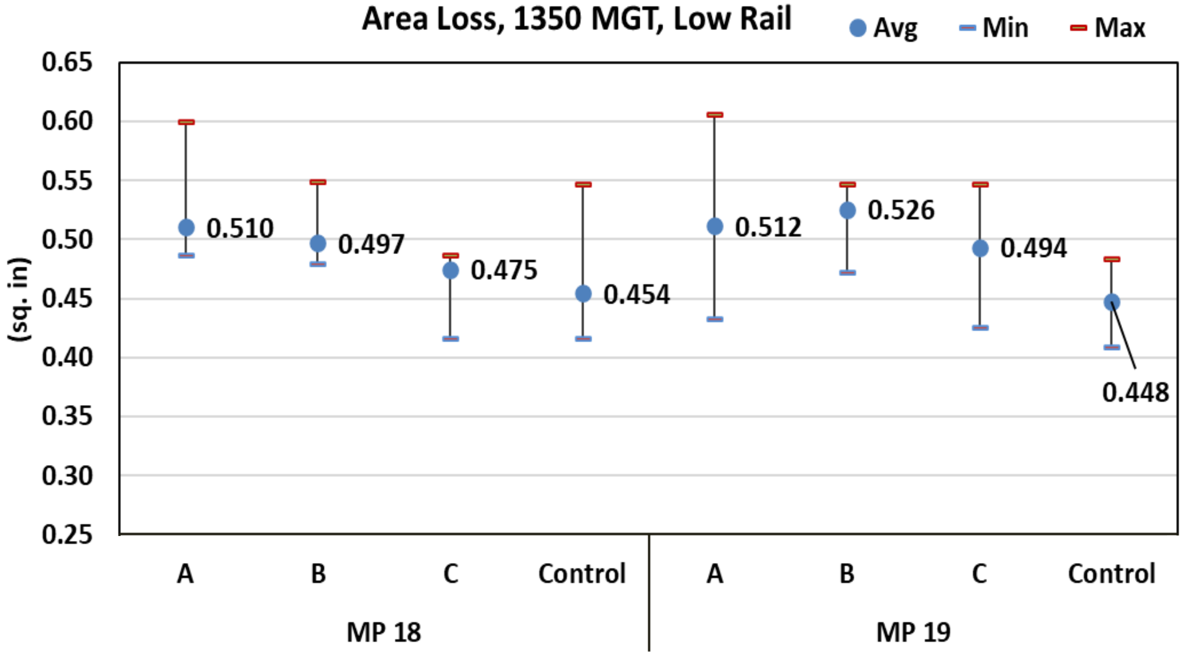
Western Megasite Rail Test

- **Small differences in wear between rail types**
  - Control rail showing overall least wear

Head area loss comparison in MP 18 and MP 19 curves for high rail (left) and low rail (right)





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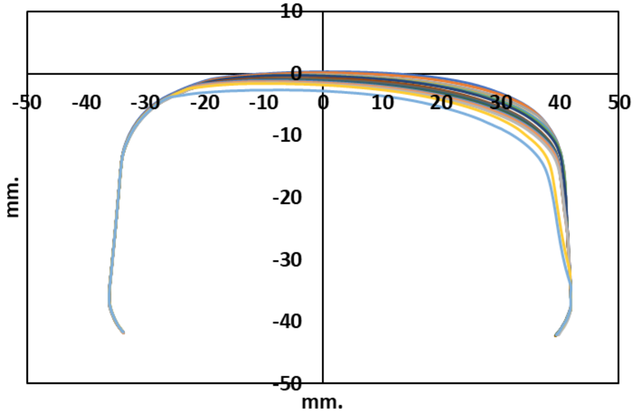
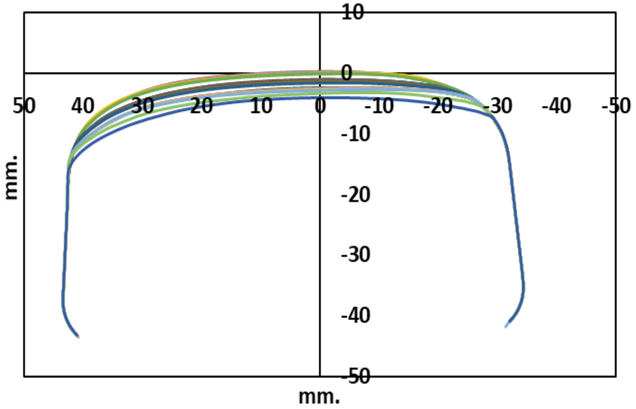
Western Megasite Rail Test

- **Multiple weld breaks, no breaks due to rail defects**
  - Tonnage changes necessitated changes in grinding schedule
    - Heavy RCF and spalls observed in rails during long intervals in between grinds

High Rail Profiles Overlay



Low Rail Profiles Overlay



Rail spalls on running surface observed at 1,350 MGT

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Conclusions

- **Both lubrication and grinding are required for rail life extension, but strategies can be different**
  - Tonnage determines grinding schedules; grinding strategies can change based on rail conditions
  - Curve orientation and distances between curves are important for lubricator placement
  - Introduction of GF lubrication improved wear rates of high rails in curves equal or higher than 2 degrees

Technology Digests reporting on this research:

- **TD25-010 -** Effects of Lubrication on Rail Wear in a High Tonnage Route: Phases I, II, and III
- **TD25-011** - Effects of Lubrication and Curvature on Wear in a Low Tonnage Route
- **TD25-016** - Updates on Western Megasite Rail and Weld Testing

Acknowledgements

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- **Rail manufacturers**
- **BNSF local crew at Canyon and El Paso Subs**
- **UP local crew at South Morrill Sub**
- **MxV Rail Instrumentation, NDE-Metallurgy, and Data Science teams**

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Back to Infrastructure Agenda

Revenue Service Evaluation of Frog Designs

Duane Otter, PhD, PE
Scientist

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Overview

- Background
- Test Lines on NS and UP
- Phase 1 – Standard vs. premium frog features
- Phase 2 – Modified heavy point frogs
- Phase 3 – Longitudinal wing slopes
- Phase 4 – Flat-top vs. conformal profiles
- Summary and Acknowledgements

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Background

- **Turnouts are a critical part of railroad infrastructure**
  - Needed for meets and passes
  - Needed for junctions
  - Needed to serve customers
- **Frogs (crossings) are critical components**
  - High cost
  - High maintenance
  - Short life

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Revenue Service Evaluation of Frog Designs

- **Evaluation in Revenue Service – Final implementation step**
- **Follows:**
  - Analytical studies
  - Lab tests
  - Tests at FAST
- **Encompasses:**
  - Variety of traffic types
  - Variety of train speeds
  - More turnouts available

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Lines Selected for Frog Evaluation

- **Norfolk Southern – Kentucky**
  - Single track with controlled sidings
  - Approximately 70–80 MGT annual traffic
  - Intermodal & mixed freight
  - Approximately equal tonnage each direction
  - 40–50 mph train speeds typical
  - Timber ties
  - RBM and WBM No. 20 frogs

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Lines Selected for Frog Evaluation

- **Union Pacific – Illinois**
  - Single track with controlled sidings
  - Approximately 20 MGT annual traffic
  - Intermodal, mixed freight, & passenger
  - Approximately equal tonnage each direction
  - 50 to 90+ mph train speeds
  - Concrete ties
  - Spring rail No. 24 frogs

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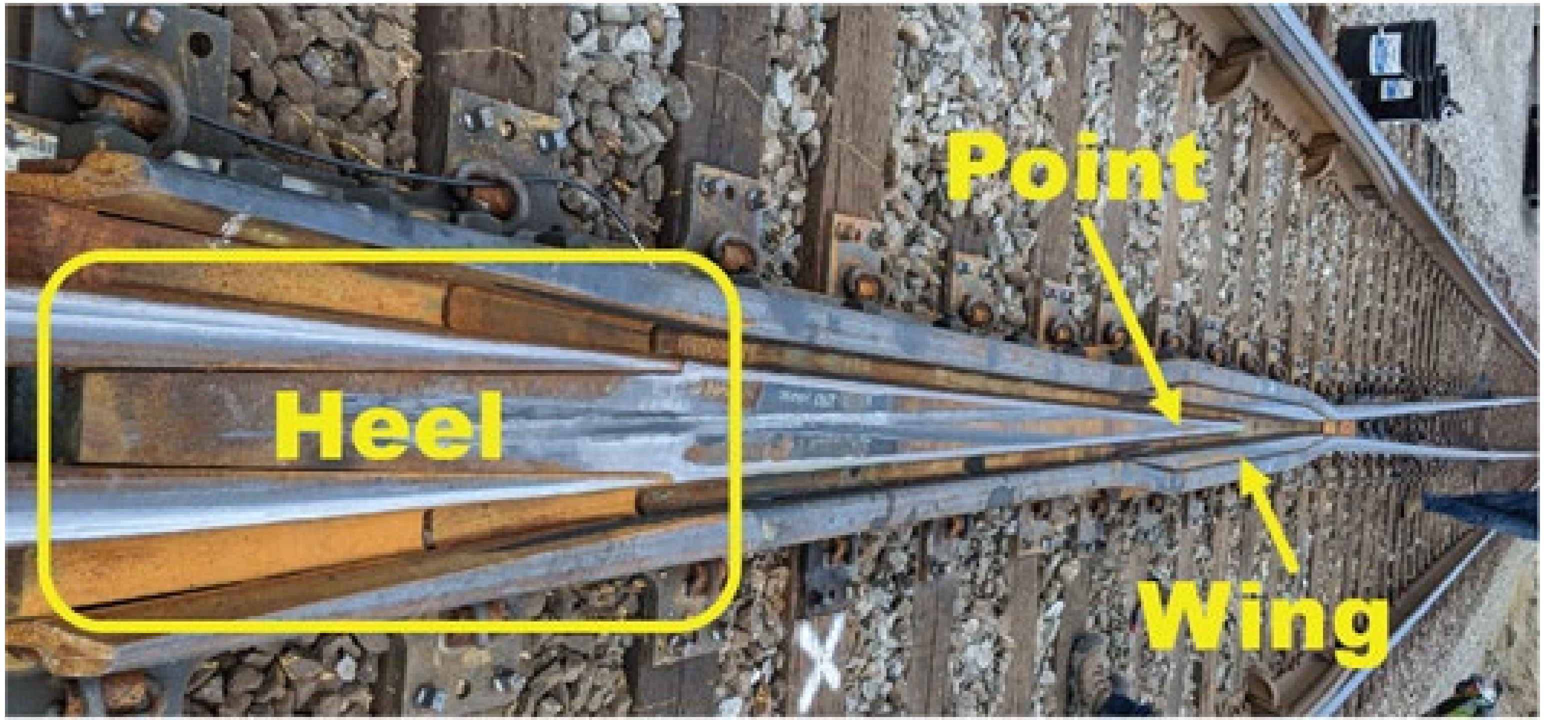
Frog Design Features Evaluated in Revenue Service Beginning in 2013

- Tapered heels vs. conventional heels
- Heavy points vs. standard points
- Modified heavy points
- Longitudinal wing slopes
- Conformal vs. flat top profiles



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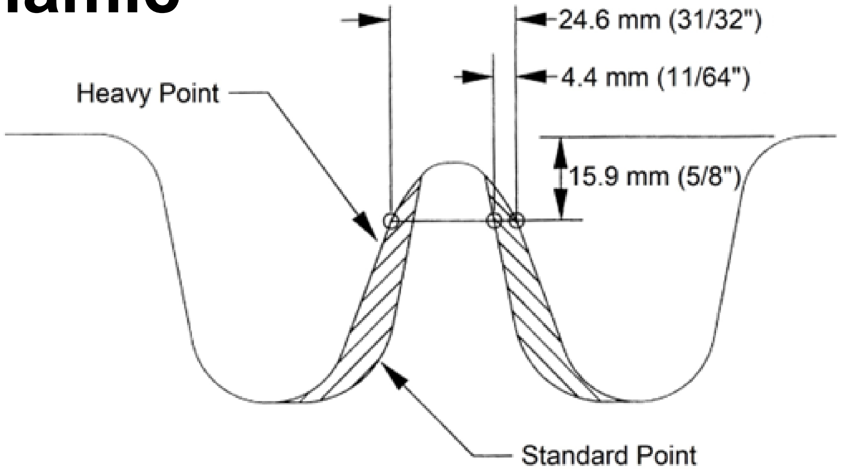
Phase 1 Testing

Designs tested included both Rail Bound Manganese (RBM) and Welded Boltless Manganese (WBM)

- **Standard Frogs**
  - Standard points
  - Conventional heels
  - Flat top profiles
  - Conventional guard rails
- **Premium Frogs**
  - Heavy points
  - Tapered or welded heels
  - Conformal profiles
  - Raised guard bars

Phase 1 Testing, con't.

- Premium frogs had about 50% less deformation in the points and 33% less deformation in the wings than standard frogs
- Tapered heels (bottom photo) had 50% less deformation than standard heels (top photo)
- Data showed the dynamic load environment was less severe for premium frogs
- 663 MGT of testing

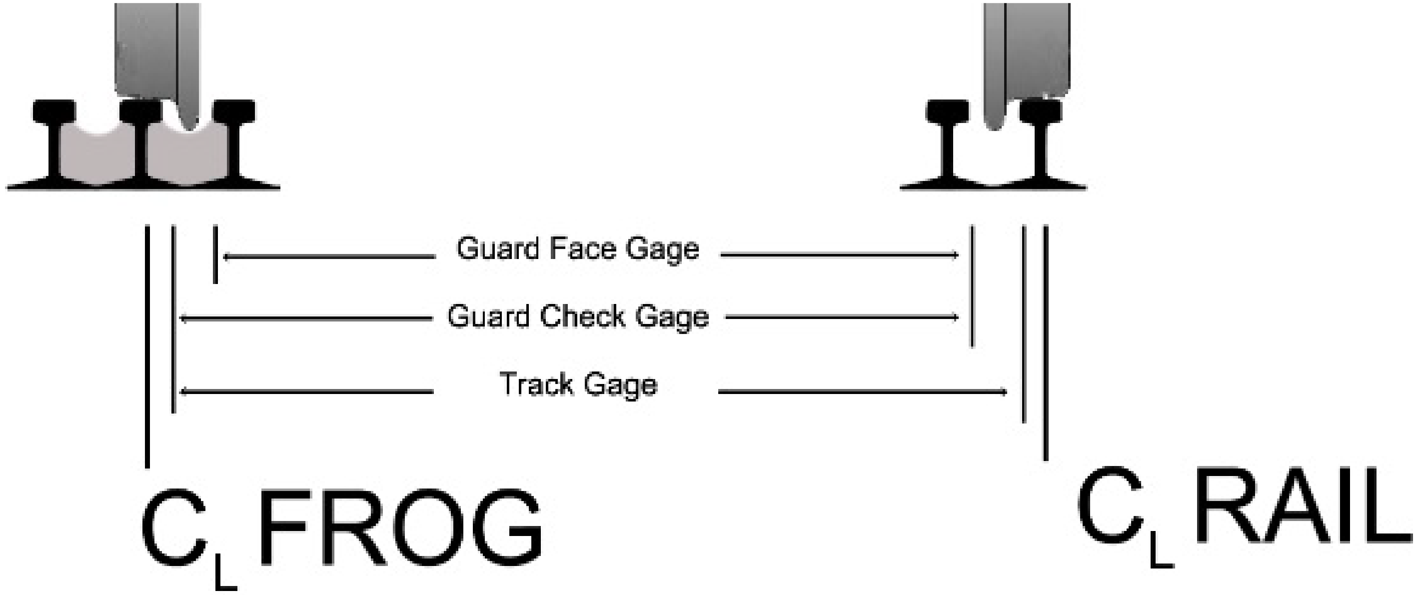


Conventional Heel

Tapered Heel

Phase 2 Testing – Modified Heavy Point Frogs

- **Motivation for modifying the heavy point frog design**
- **Potential issue with compliance to higher speed track safety standards (prior to October 2020 changes to FRA Track Safety Standards)**
- **Incompatibility of guard check gage and guard face gage**



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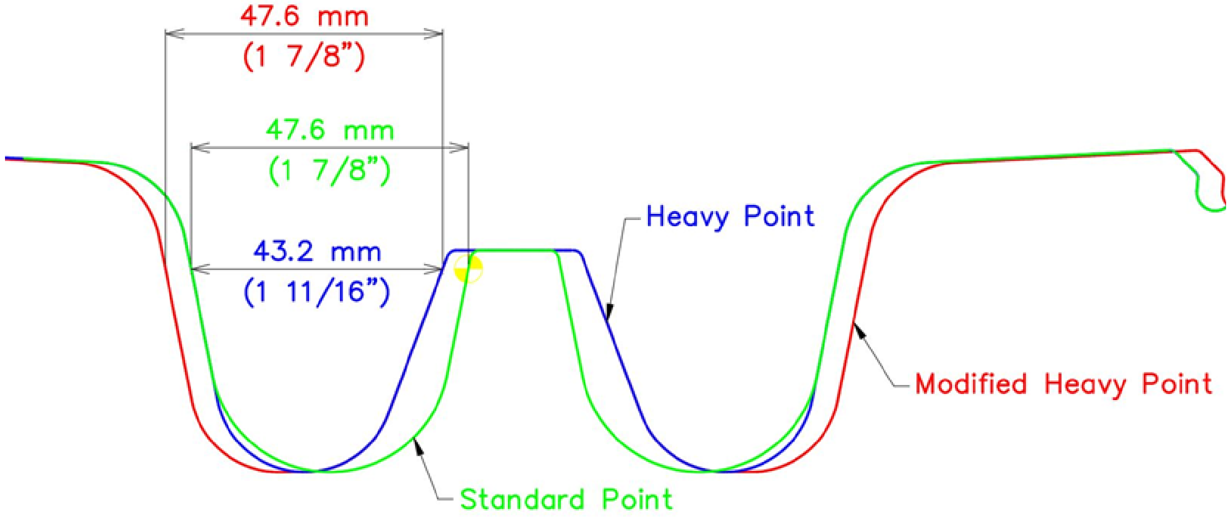
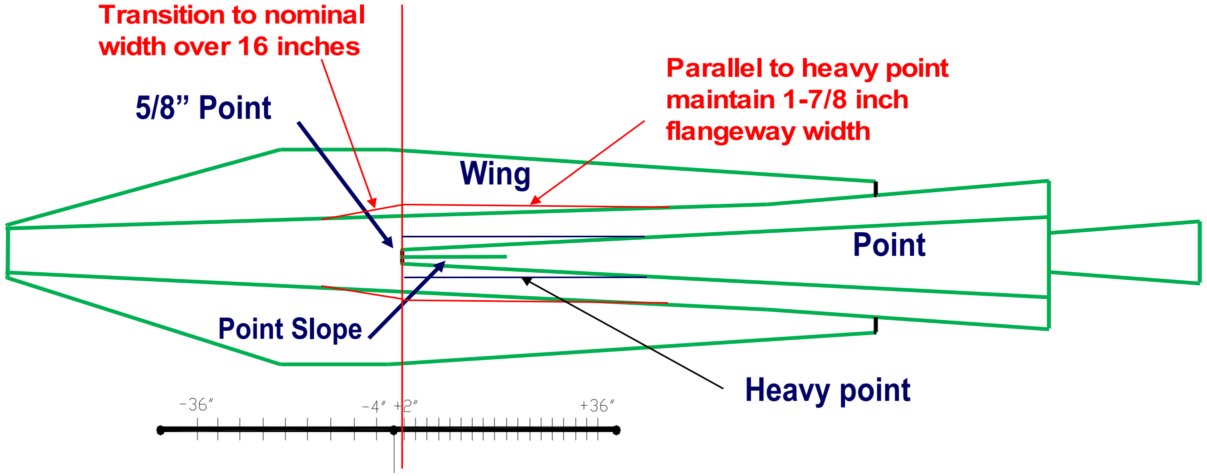
Phase 2 Testing – Modified Heavy Point (MHP) Frogs

- **Original heavy point frogs had difficulty meeting requirements for track gage, face gage, and check gage for Class 5 and Class 6 track**
- **Modified heavy point maintains a 1 7/8-inch flangeway to help meet requirements**





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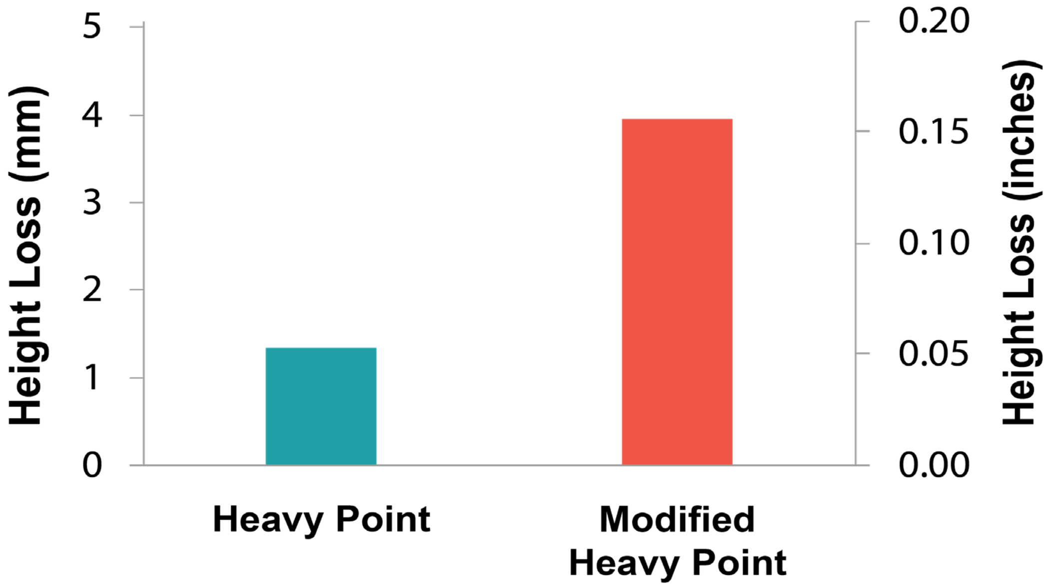
Phase 2 Testing – Modified Heavy Point No. 20 Rigid Frogs

- **Extensive NUCARS® modeling of modified heavy point design**
- **Higher impact loads predicted due to wider flangeway**
- **Concern for hollow-worn (false flange) wheels impacting the wing in trailing point moves**
- **Shorter wheel transfer zones**
- **Modified heavy point frogs had much higher average point height loss for No. 20 rigid frogs tested**
- **Original HP frogs performed better**



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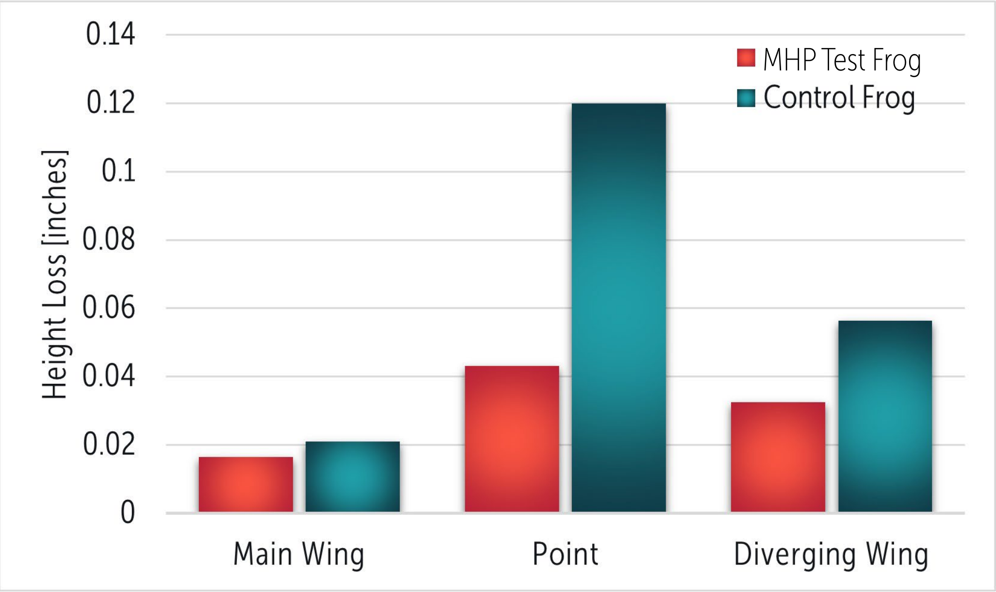
Phase 2 Testing – Modified Heavy Point No. 24 Spring Rail Frogs

- No flangeway gap for mainline movements
- Point height loss much lower for modified heavy point No. 24 spring rail frog tested



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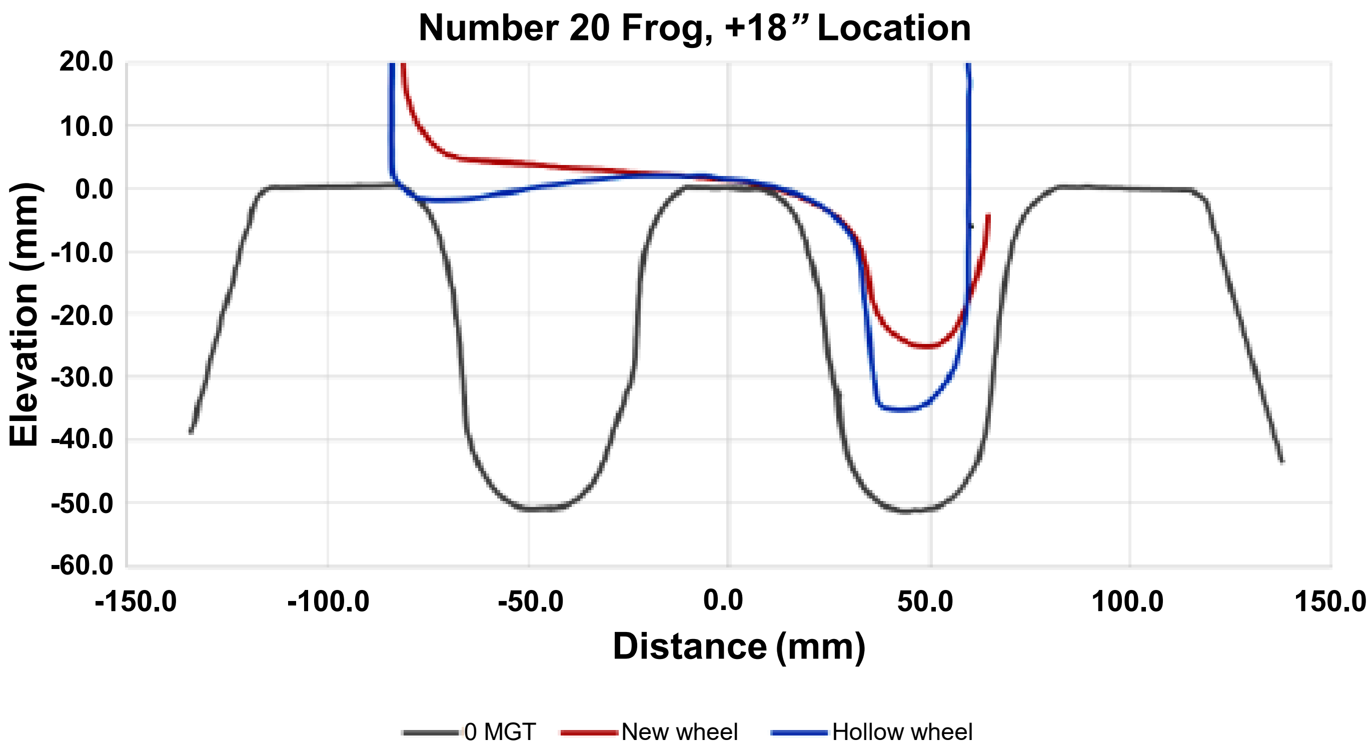
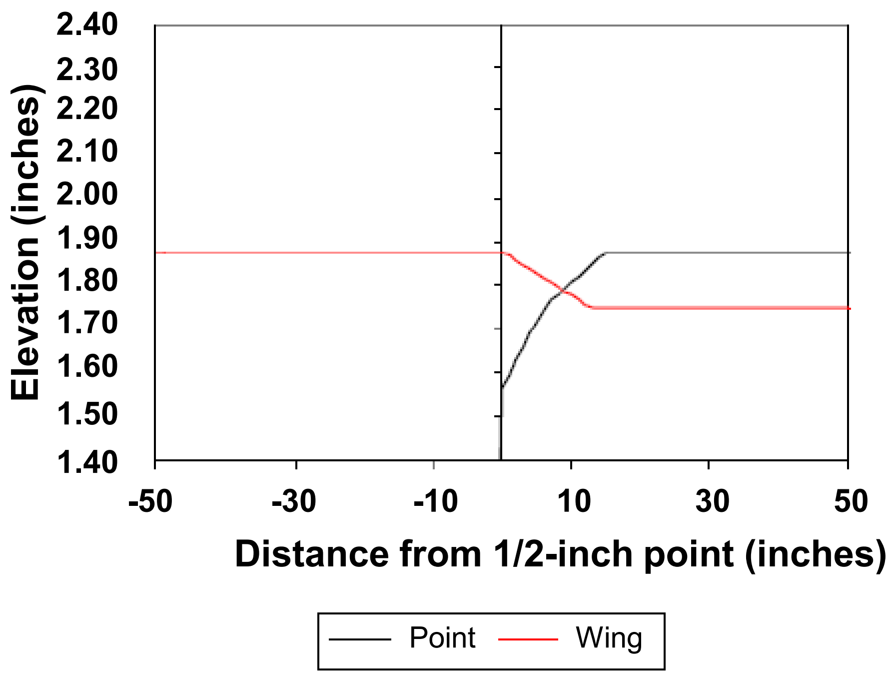
Phase 3 Testing – Longitudinal Wing Slopes

- **Reduce detrimental effects of hollow-worn (false flange) wheels**





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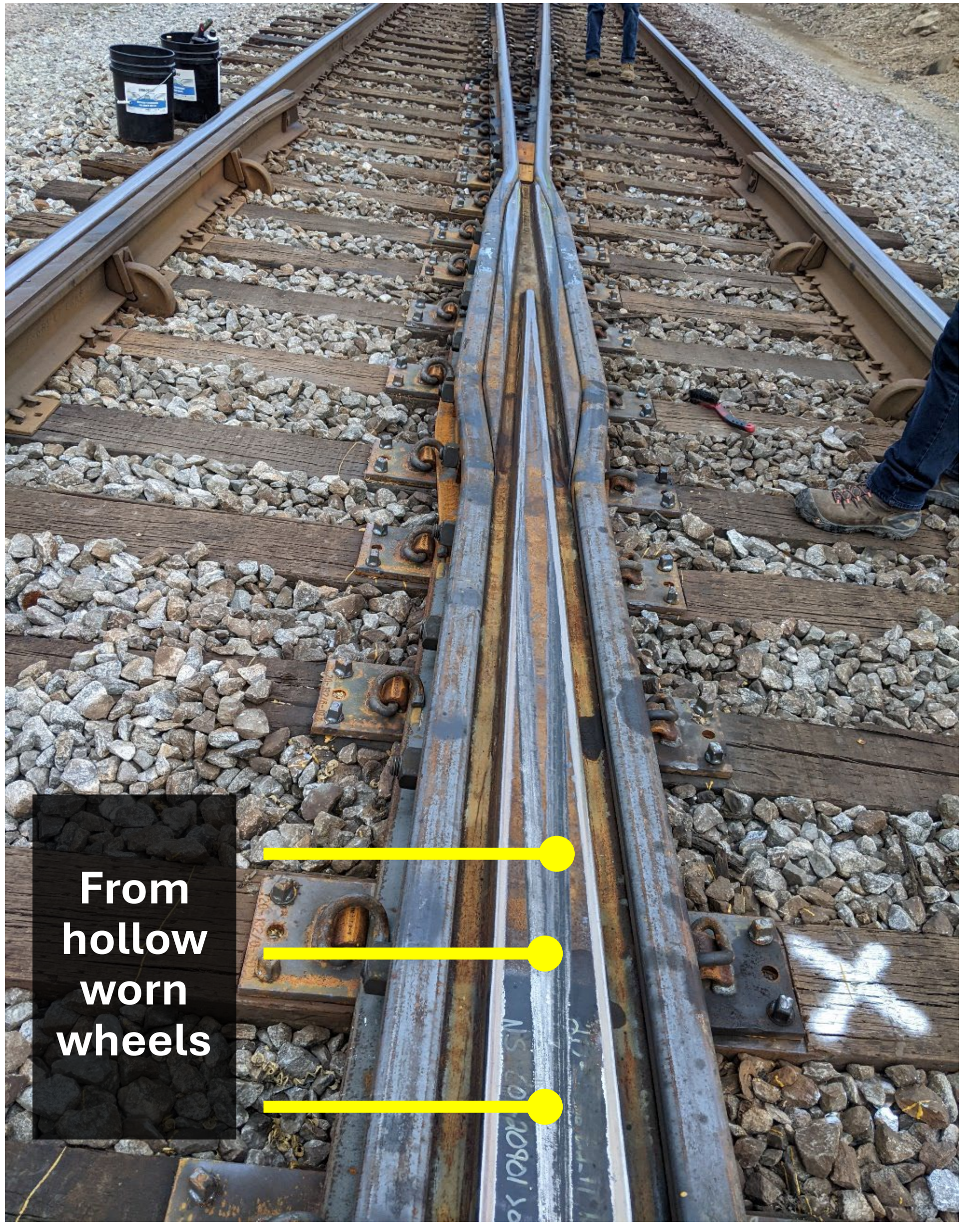

Phase 3 Testing – Longitudinal Wing Slopes

- NS line with test frogs carries plenty of traffic with hollow-worn (false flange) wheels
- Note wheel wear paths on almost-new frog

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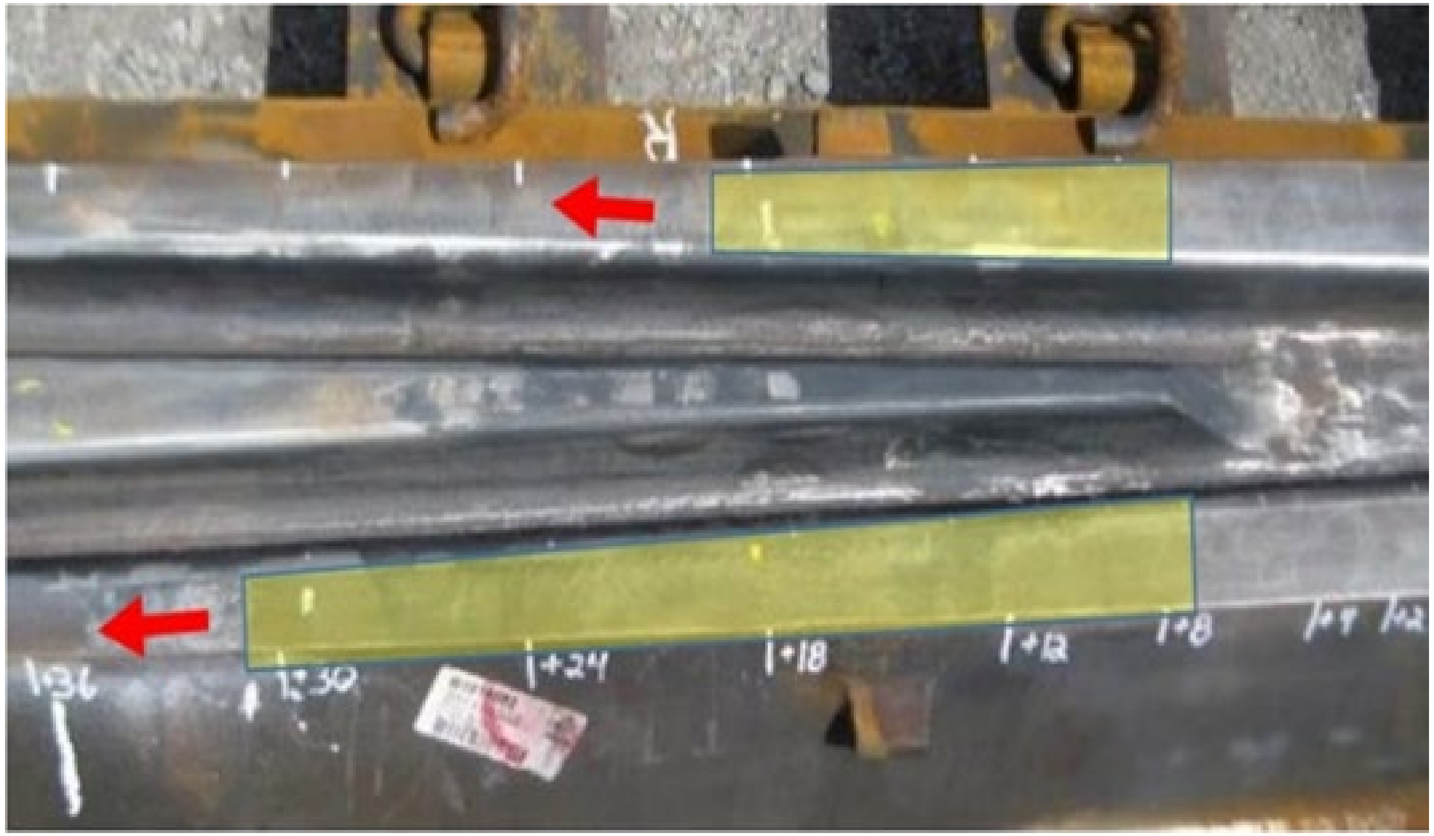
Phase 3 Testing – Longitudinal Wing Slopes

- **Two test frogs**
  - **RBM frog**: 1/8 inch over 24-inch slopes on both wings
  - **WBM frog:** 1/8 inch over 24-inch slope on main wing 1/8 inch over 12-inch slope on diverging wing



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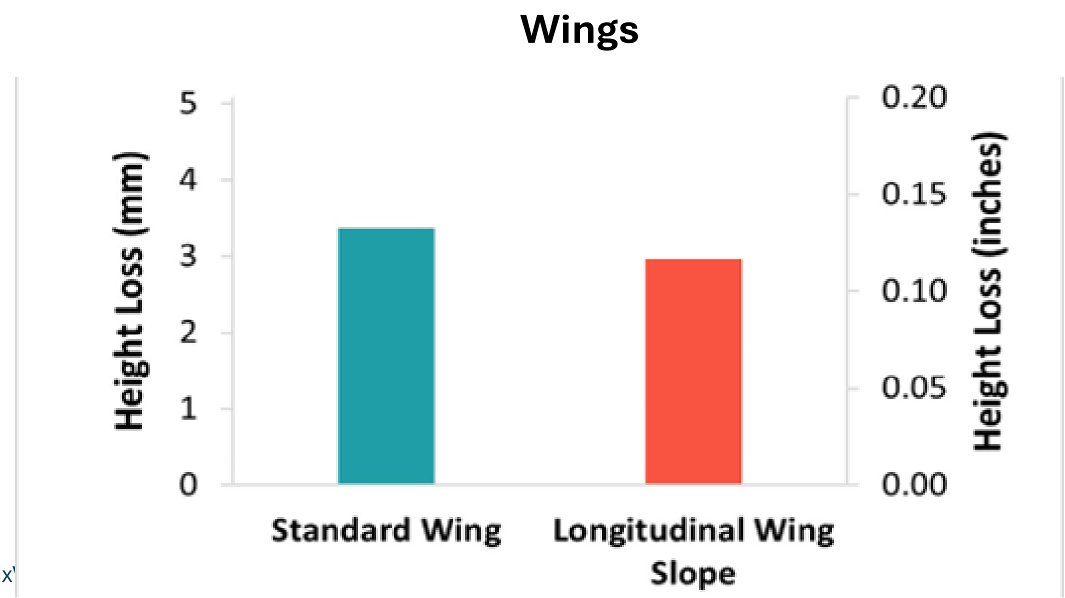
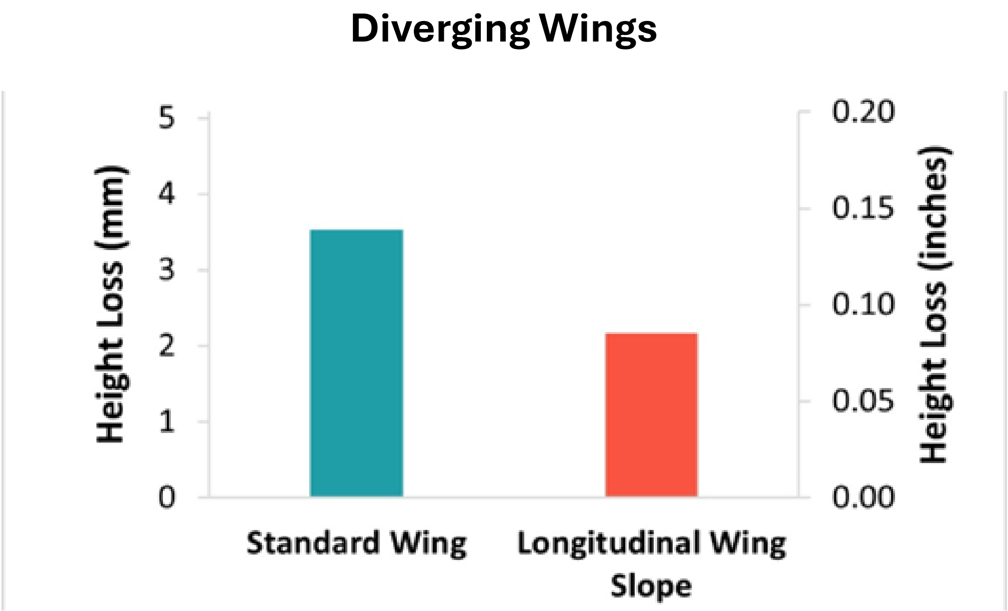
Phase 3 Testing – Longitudinal Wing Slopes

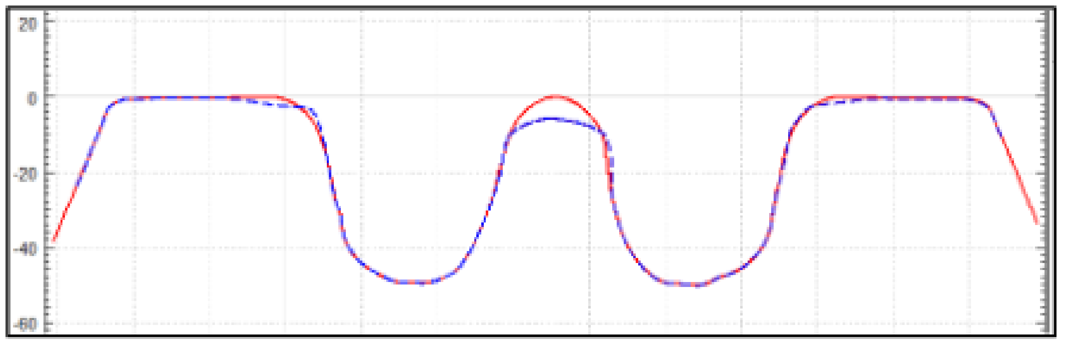
- Test results: Wing slopes performed better
- Main wings: Slight reduction in height loss
- Diverging wings: Greater reduction in height loss
- No weld repairs needed for wings of either frog





Phase 4 Frog Testing (Ongoing)

- **NS new standard**
  - Heavy points
  - Flat top profiles
- **Test frogs**
  - Two RBM frogs
  - One WBM frog
- **Measurements**
  - Profile wear
  - Hardness
  - Maintenance performed



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Summary of No. 20 Rigid Frog Test – Phase 4 ongoing

	MP	Location	Type	Point	Long. Wing Slope	Running Surface Profile	Installation Date	Removal Date	Total MGT
Phase 1	95.7	Corman - 2013	RBM	Standard	No	Flat	03/2013	12/2018	398
	85.6	Bishop - 2013	RBM	Standard	No	Flat	04/2013	Late 2017	325
	139.2	Kings Mountain - 2013	WBM	Heavy	No	Conformal	08/2013	12/2017	342
	134.8	South Fork - 2013	RBM	Heavy	No	Conformal	08/2013	12/2021	663
Phase 2	139.2	Kings Mountain - 2017	WBM	Modified	No	Flat	12/2017	09/2022	378
	130.2	Palm - 2017	WBM	Modified	No	Flat	12/2017	10/2022	381
Phase 3	32.0	Reid - 2019	WBM	Heavy	Yes	Flat	10/2019	06/2025	380
	22.0	Bracht - 2019	RBM	Heavy	Yes	Flat	10/2019	01/2025	354
Phase 4	134.8	South Fork - 2021	WBM	Heavy	No	Flat	12/2021		283
	139.2	Kings Mountain - 2022	RBM	Heavy	No	Flat	09/2022		225
	130.2	Palm - 2022	RBM	Heavy	No	Flat	10/2022		222

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Results Summary

- **Heavy point frogs performed much better than standard frogs**
- **Tapered heels had less deformation than conventional heels**
- **Modified heavy point frogs**
  - Did not perform as well for rigid No. 20 frogs
  - Performed better for No. 24 spring rail frog
  - FRA rule change in Oct 2020 helped
- **Longitudinal wing slopes provided wear and maintenance benefit with no welding required on the wings**

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- **Norfolk Southern Railway**
- **Union Pacific Railroad**
- **Suppliers – voestalpine Nortrak and Progress Rail**
- **AAR Revenue Service TAP and Special Trackwork TAG**
- **MxV Rail Instrumentation Team**
- **Ben Bakkum, Ekrem Koc, David Davis (retired), Rafael Jimenez (retired)**

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Tie and Fastener Systems

Yin Gao, PhD

Principal Investigator I

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Presentation Overview

- **Background**
- **Tests and Measurements Update**
  - Laboratory characterization of rail anchor performance
  - Modeling of loading environment of screw spikes
  - Concrete ties interspersed with wood ties
- **Summary**

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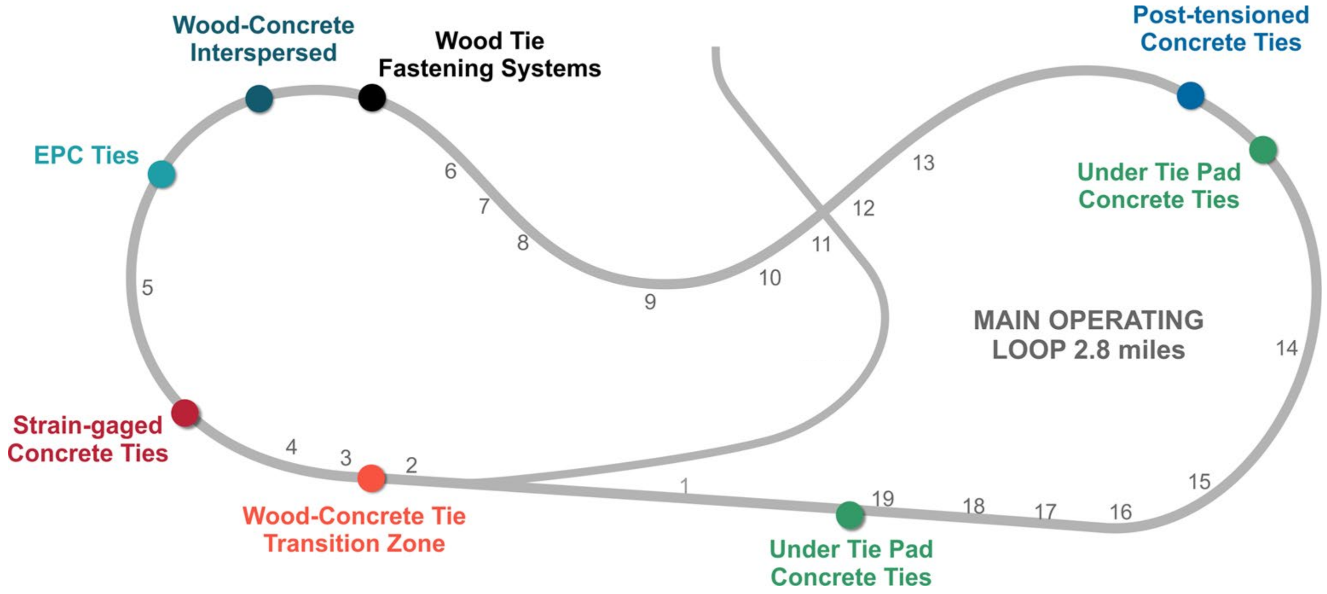
Background: Crosstie & Fastener Test Program

- **Tests at Various Locations at FAST®**
  - Mainly on two curves (5- and 6-degree)
  - More than 335 million gross tons (MGT) by late April 2026
  - Concrete tie tests
  - Wood tie fastening systems
  - Engineered polymer composite (EPC) ties
- **Laboratory Testing**
- **Computer Modeling**



FAST® is a registered trademark of MxV Rail

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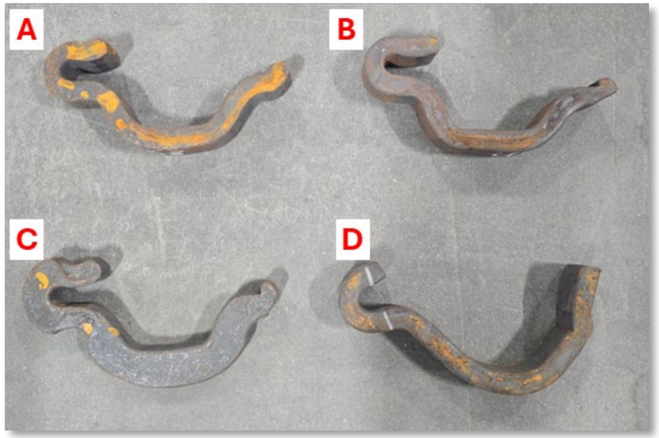
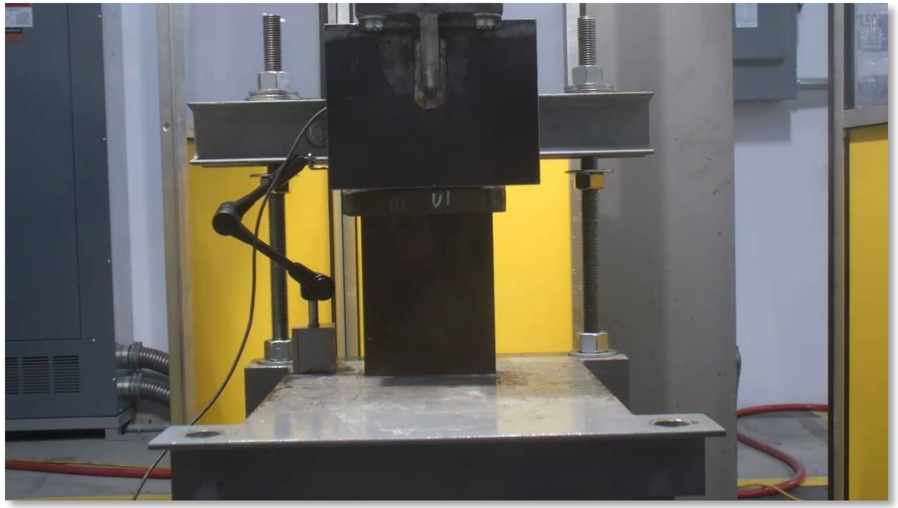
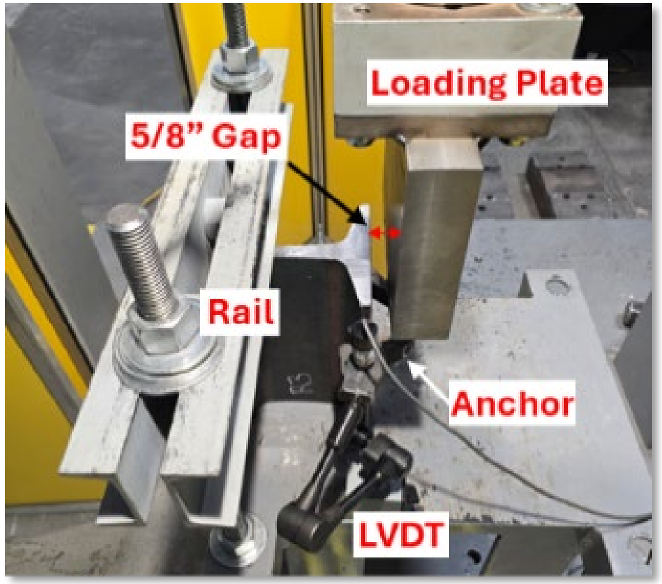
Characterization of Rail Anchor Performance

- **Laboratory Testing**
  - Modified anchor slip test, AREMA Chapter 5, Part 7.1.4
    - A preload of 500 lbs. used to take the initial set
    - Test stopped when 12,000 lbs. reached or when anchor slipped more than 1/16-inch on the rail
  - Four types of anchors included:
    - Drive-on anchors (Type A, B, C)
    - Wrench-on anchors (Type D)
  - Test Scenarios:
    - New anchors
    - Number of applications
    - Loading rate
    - Loading location







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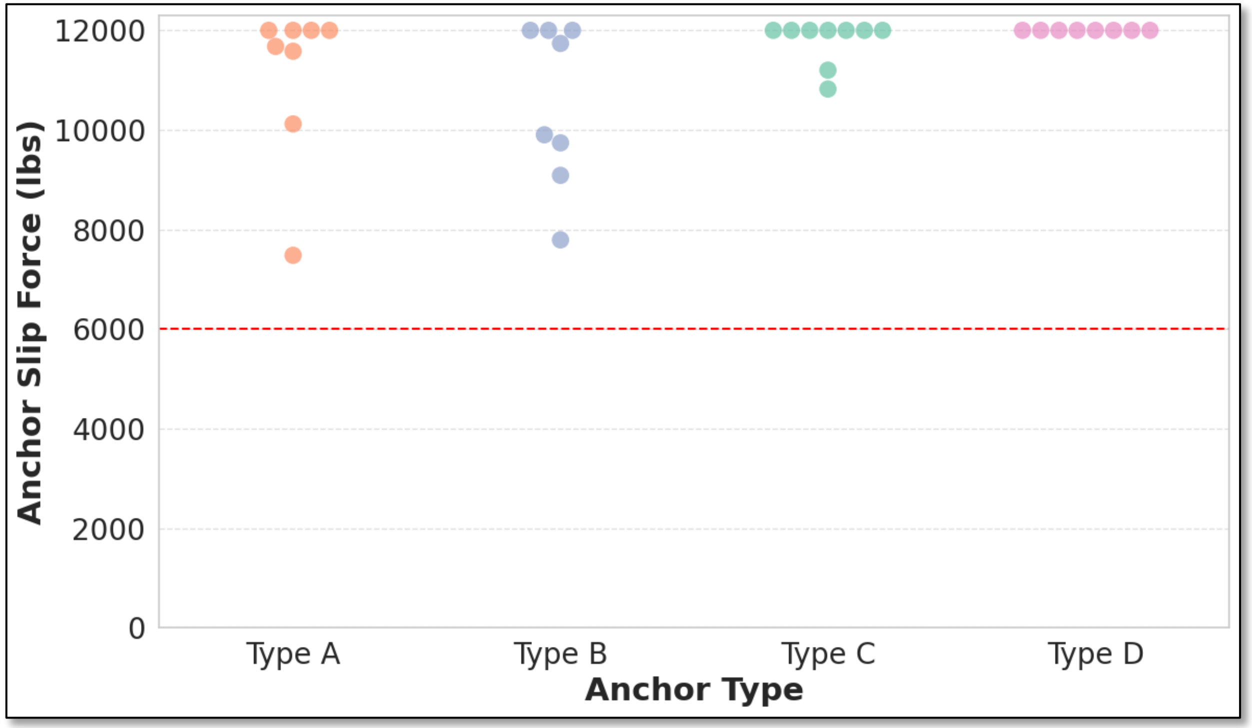
Characterization of Rail Anchor Performance



- **At least eight anchors of each type were included in the test**
- **The AREMA *Manual for Railway Engineering* recommends a minimum of 6,000 lbs. for a new anchor**
- **All the test anchors met the test criterion**

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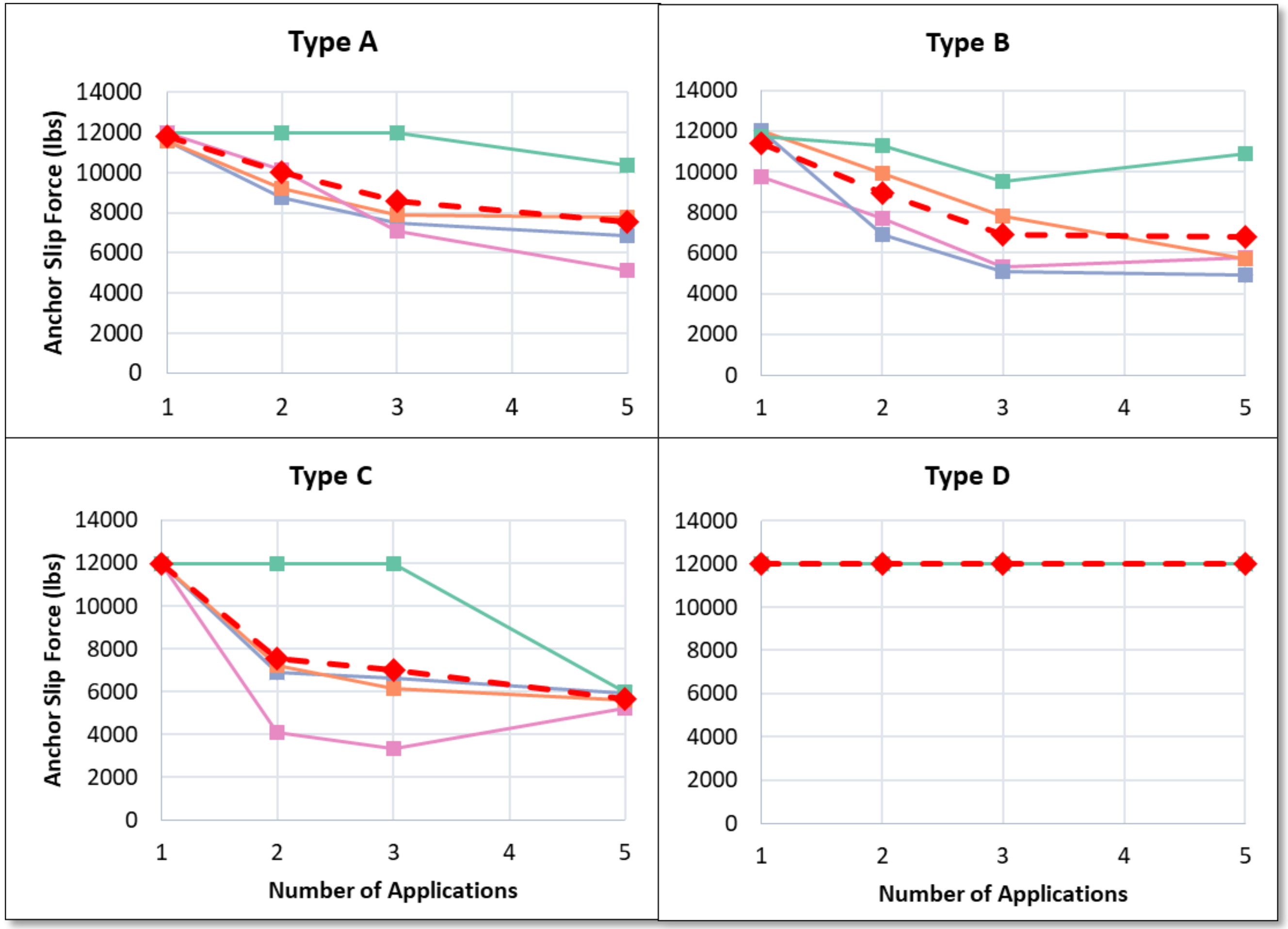
Characterization of Rail Anchor Performance

- **Number of Applications**
  - The percent of reduction in slip strength on the second application was 15%, 21%, and 37% for Types A, B, and C, respectively.



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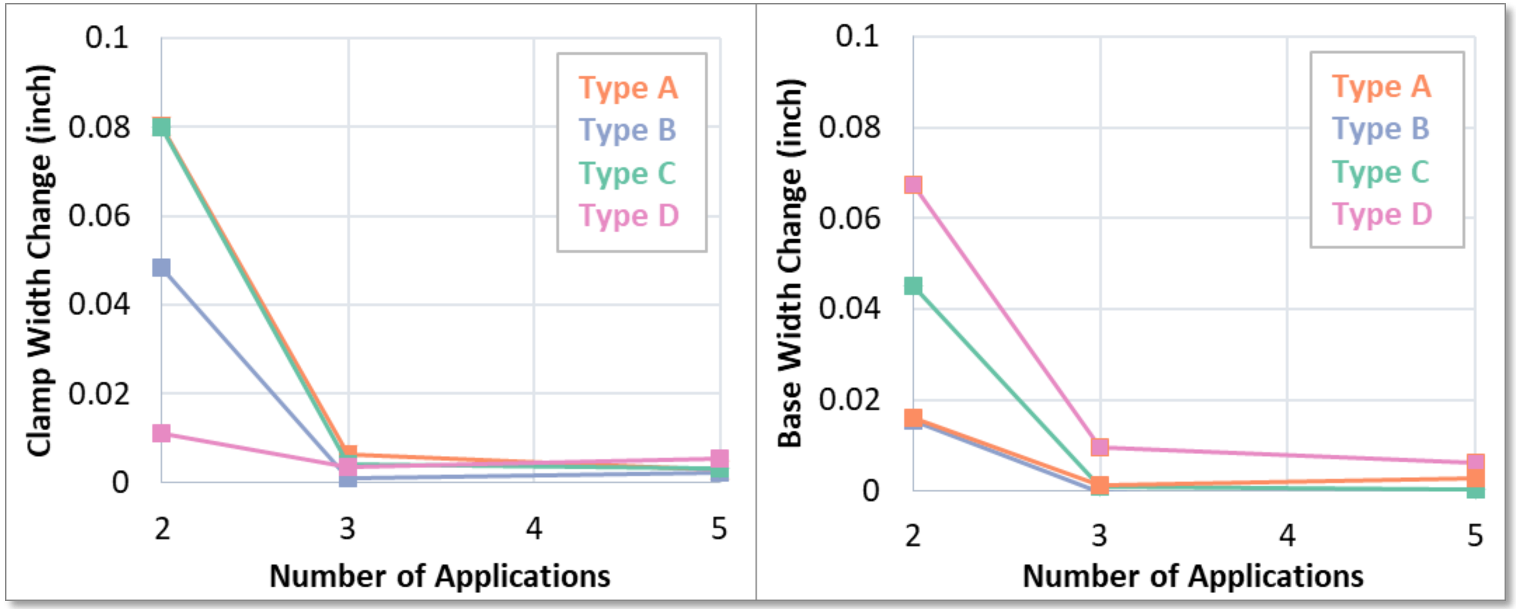
Characterization of Rail Anchor Performance

- **Anchor Geometry Change**
  - Clamp width and base width measurements
  - The largest change occurred during the second application



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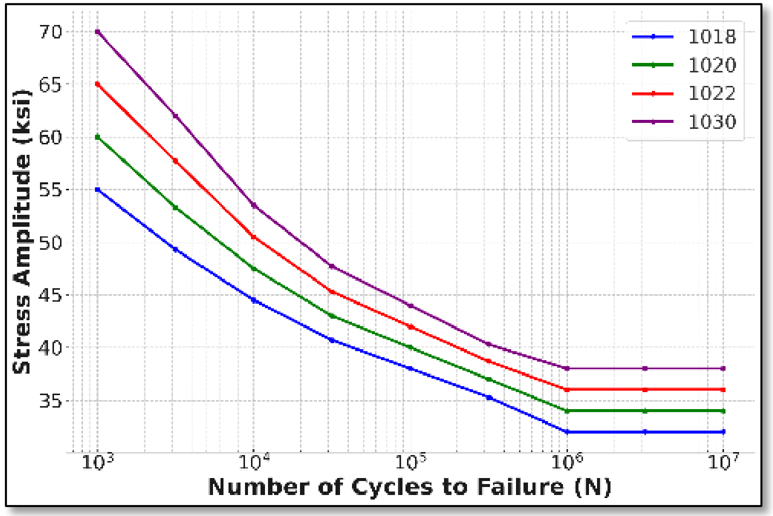
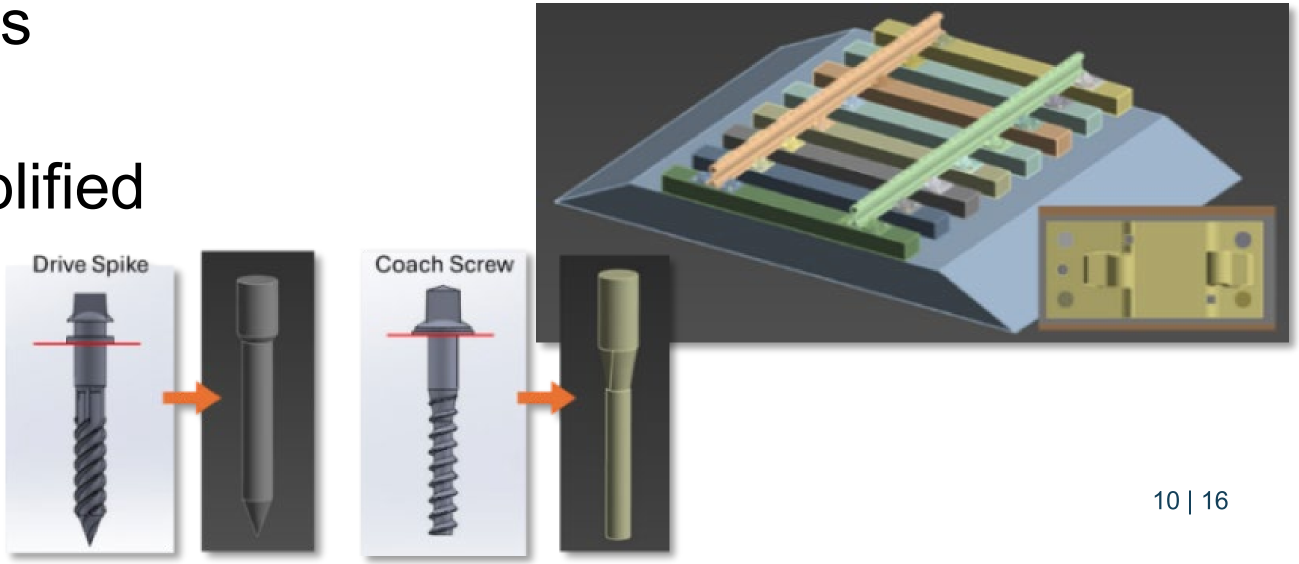
Characterization of Rail Anchor Performance

- **Other Influential Factors**
  - Rail Base Width
    - The AREMA Manual recommends the section tolerances of ±0.04 inch for a 6-inch rail base
  - Loading Rate
    - Applied cyclic loading (2 to 3 Hz) on the anchors
    - The repeated load required to move anchors was 20 to 40% lower than the static load due to progressive slippage
  - Loading Location
    - Loading plate was moved as close as possible to the rail base to simulate severe plate cutting or uncentered tie plates
    - Slip forces also decreased 20 to 40% compared to the results from the standard test setup

Loading Environment of Screw Spikes

- **Both cut and screw spikes break on elastic fasteners on high-degree curves**
- **Typical spike materials**
- **Finite element analysis**
  - Eight-tie track panel with rails, elastic fastener tie plates, wood ties, and screw spikes
  - Vertical and lateral wheel loads
  - Four-screw-spike pattern and simplified spike model





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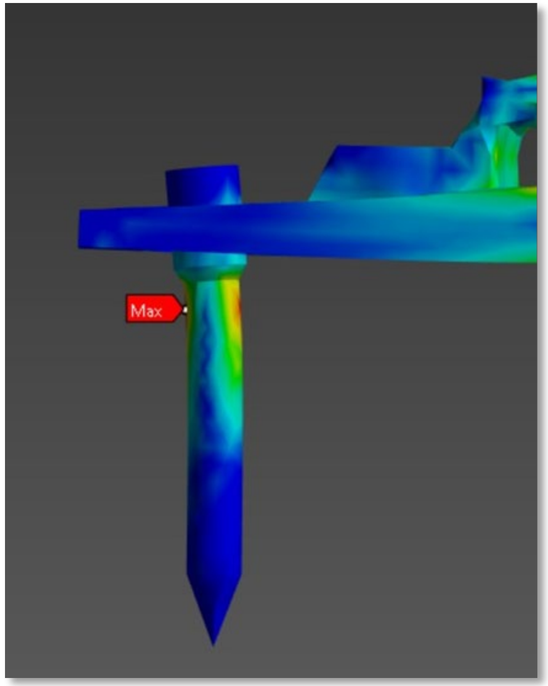
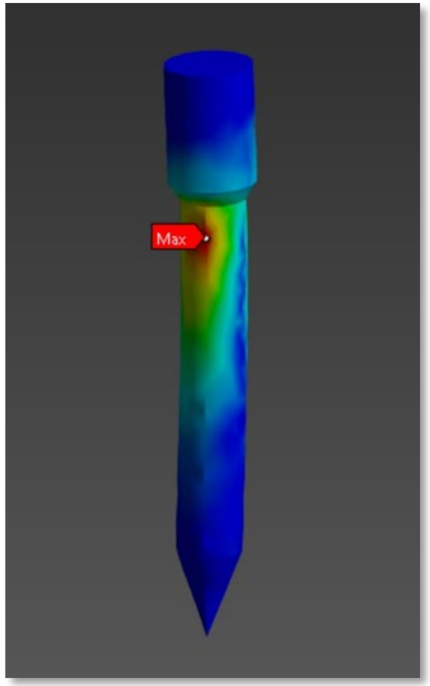
Loading Environment of Screw Spikes

Four modeling scenarios:

Model Scenario	# of Spikes Contacting Plate	Spikes Providing Hold Down Force	Peak Stress in Spike (ksi)
Case 1	4	Yes	23.2
Case 2	4	No	41.3
Case 3	1	Yes	47.8
Case 4	1	No	61.9
Fatigue Limit	32 to 38		





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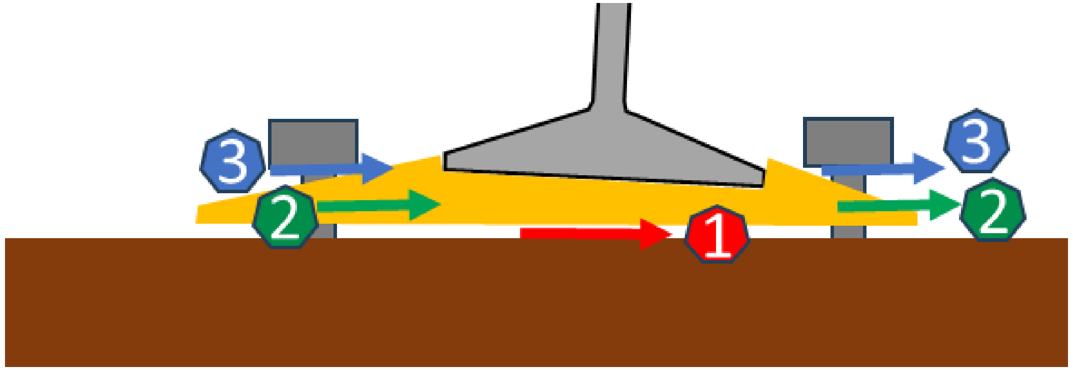
Loading Environment of Screw Spikes

- **Analysis and Discussion**
  - Loading interface
    - Two frictional forces and one shear force
  - Hold down force and load distribution
    - Maintaining hold down force helps reduce spike load and improve spike load distribution
    - Even spike load distribution is also needed to reduce spike breakage
  - Spike materials
    - Increase diameter: 1/16 inch vs. 13% reduction
    - High strength material



Model Scenario	Peak Stress in Spike (ksi)
Case 1	23.2
Case 2	41.3
Case 3	47.8
Case 4	61.9
Fatigue Limit	32 to 38

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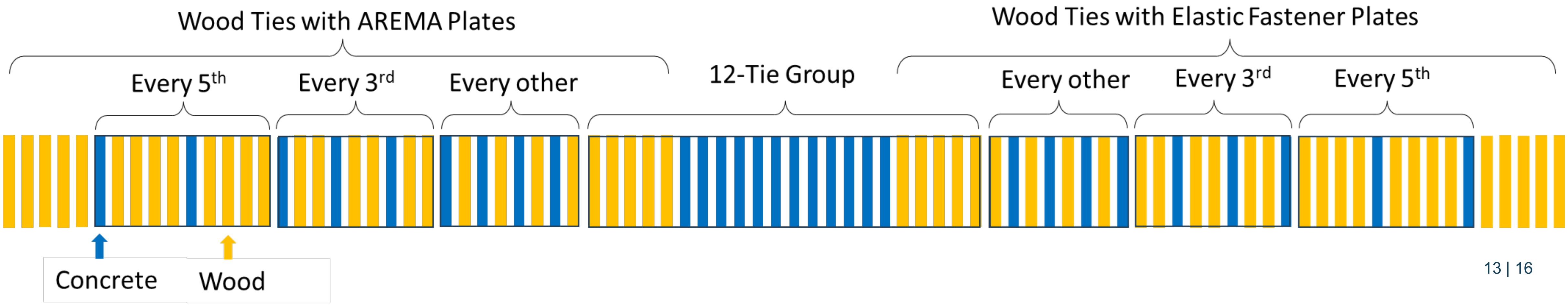
Concrete Ties Interspersed with Wood Ties

- **76-tie Interspersed Section**
  - Different tie configurations
  - Standard AREMA plates
  - Elastic fastener plates with cut spikes
  - A 12-tie consecutive concrete tie zone



Wood Ties with AREMA Plates

Every 5th

Every 3rd

Every other

12-Tie Group

Wood Ties with Elastic Fastener Plates

Every other

Every 3rd

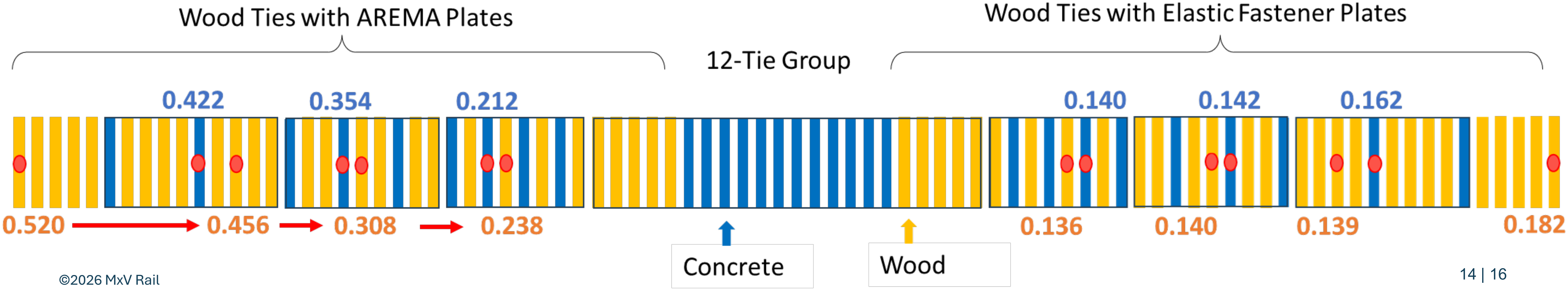
Every 5th

Concrete

Wood

Concrete Ties Interspersed with Wood Ties

- **Gage strength test using Lateral Track Loading Fixture performed every 50 MGT**
  - During the 335 MGT period, concrete ties showed improved gage strength on wood ties with cut spikes but not much improvement on wood ties with elastic fasteners



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Summary

- All four rail anchor types exceeded AREMA anchor slip recommendations; however, slip strength can decrease with repeated applications, rail size, and loading conditions.
- Modeling suggests screw spikes may not solve spike breakage permanently; proper hold-down force management and even load distribution are critical.
- Concrete ties interspersed with wood ties improved gauge-holding strength compared to wood ties with AREMA tie plates.

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Rail Neutral Temperature Research

Stephen Wilk

Principal Investigator II

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Track Buckle Prevention

- **Thermal misalignments/track buckles can be highly disruptive during summer months**
- **Combined effort between track and vehicle perspectives**
- **Long-term goals:**
    - Improve rail neutral temperature (RNT) management
    - Improve track buckle strength and identify high-risk scenarios
    - Optimize speed restrictions policies

Track Buckle from 2022 MxV Rail/BNSF Test

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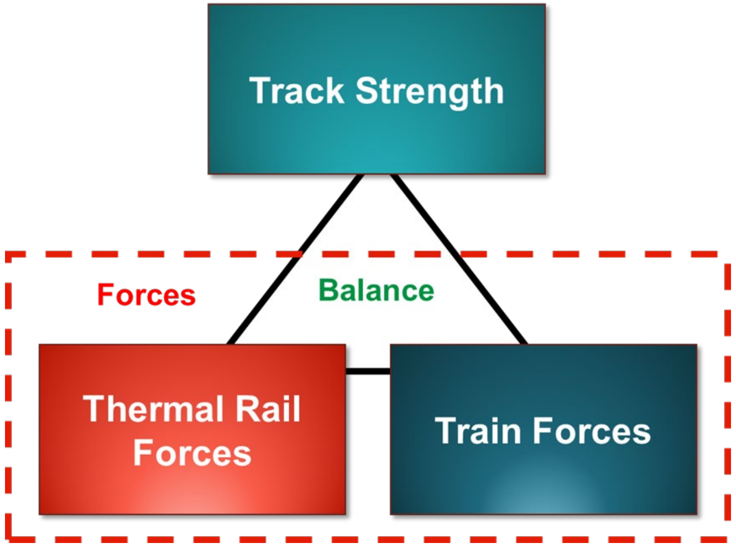
Outline

1 Background



Track Strength

Forces

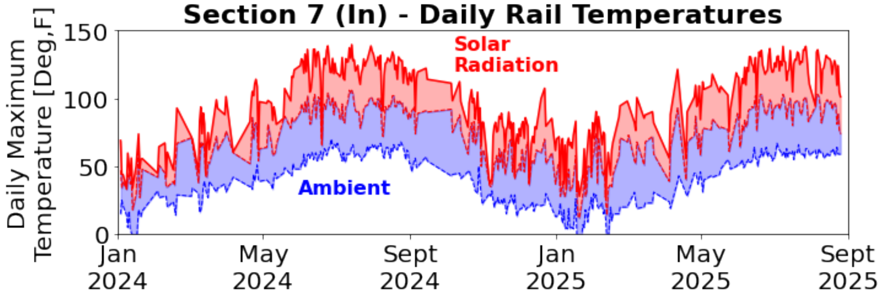
Balance

Thermal Rail Forces

Train Forces

2 FAST RNT Monitoring

3 FAST Rail Temperatures



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Topic 1: Background

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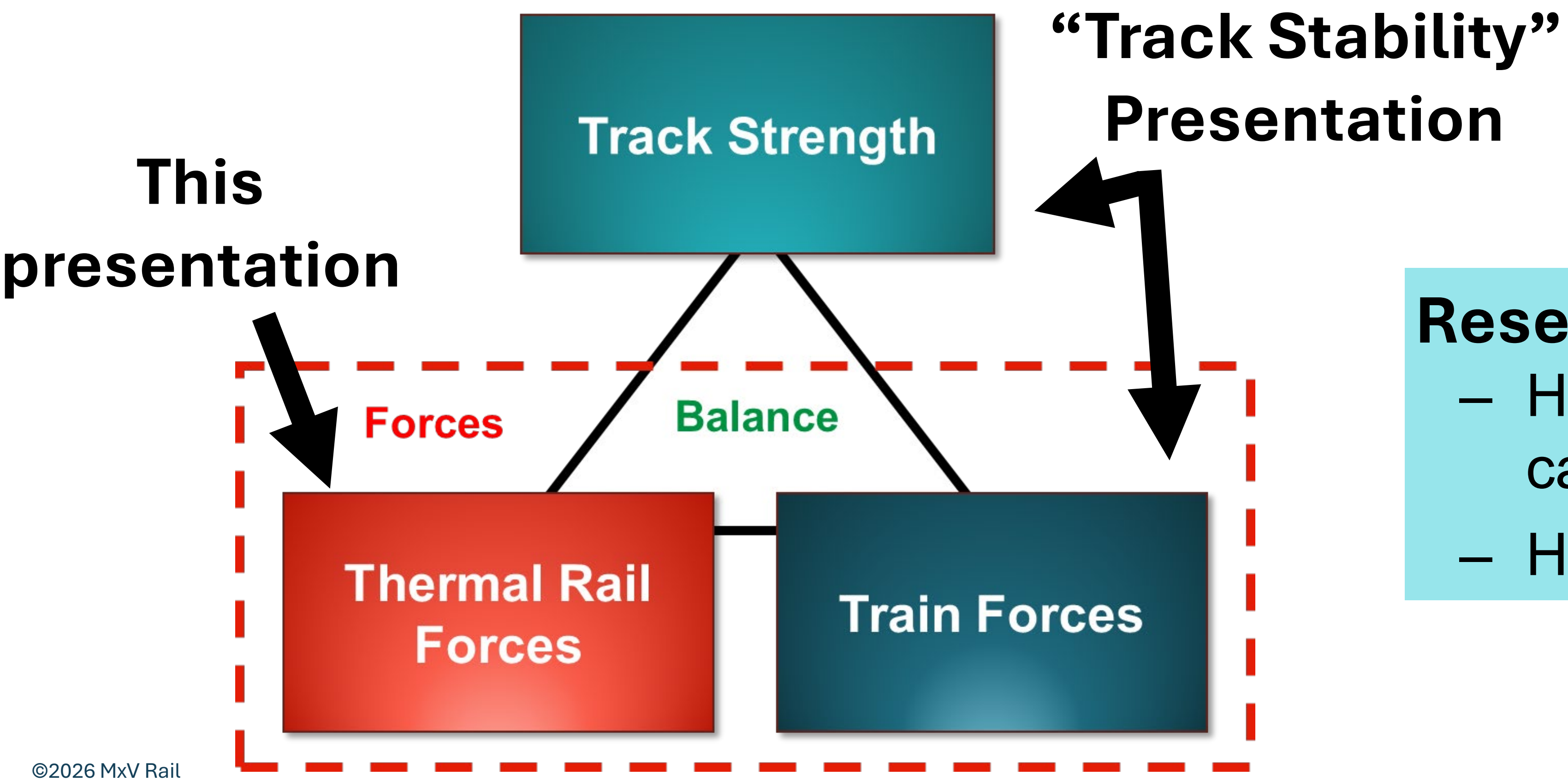
Thermal Forces and Track Stability

$$\mathit{Track\ Strength} > \mathit{Forces}\ (\mathit{Thermal\ and\ Train})$$



This presentation

“Track Stability” Presentation

Track Strength

Forces

Balance

Thermal Rail Forces

Train Forces

Research Items:

- How do we measure each category?
- How do they interact?

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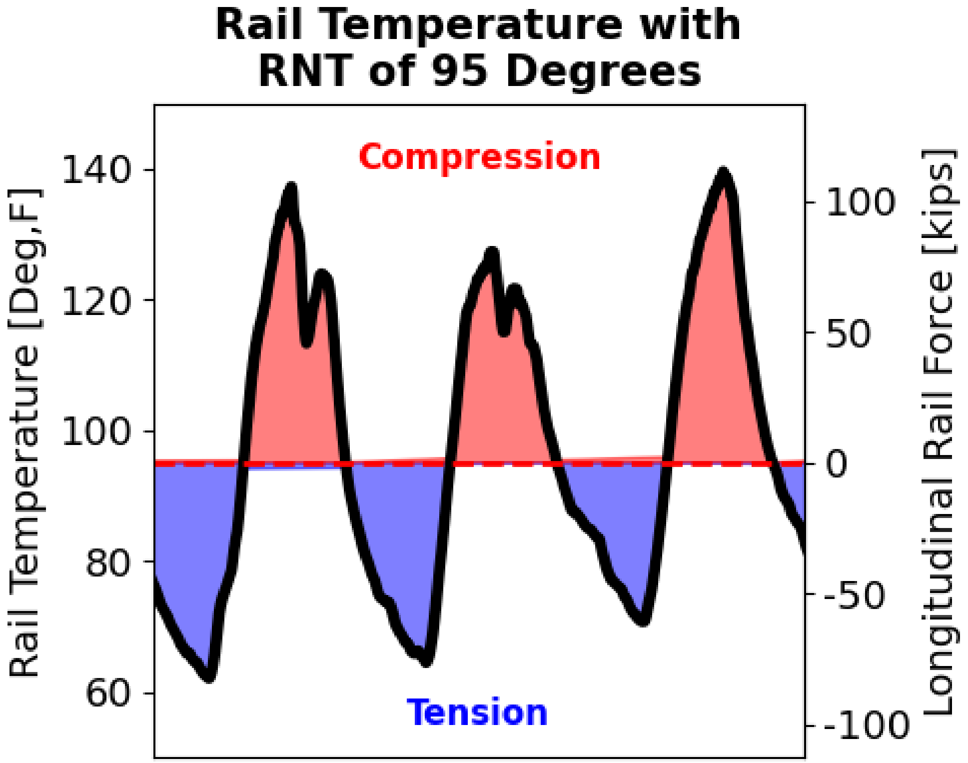
Thermal Forces Definitions

- **In Continuous Welded Rail (CWR) track, thermal forces occur when rail temperature deviates from RNT**
  - RNT is defined as the rail temperature at which there is no longitudinal rail force
- **Avoid large longitudinal rail forces:**
  - Too high compressive → Track buckles
  - Too high tensile → Large gaps during rail breaks



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Thermal Force Management

RNT Measurement

- No scalable direct RNT measurement method
- Reliant on procedures and indirect indicators

RNT Establishment

- Setting RNT to desired temperature
- Examples: Welding or lining
- Well understood

RNT Change

- RNT changes after establishment
- Examples: curve breathing, longitudinal rail movement
- Not well understood

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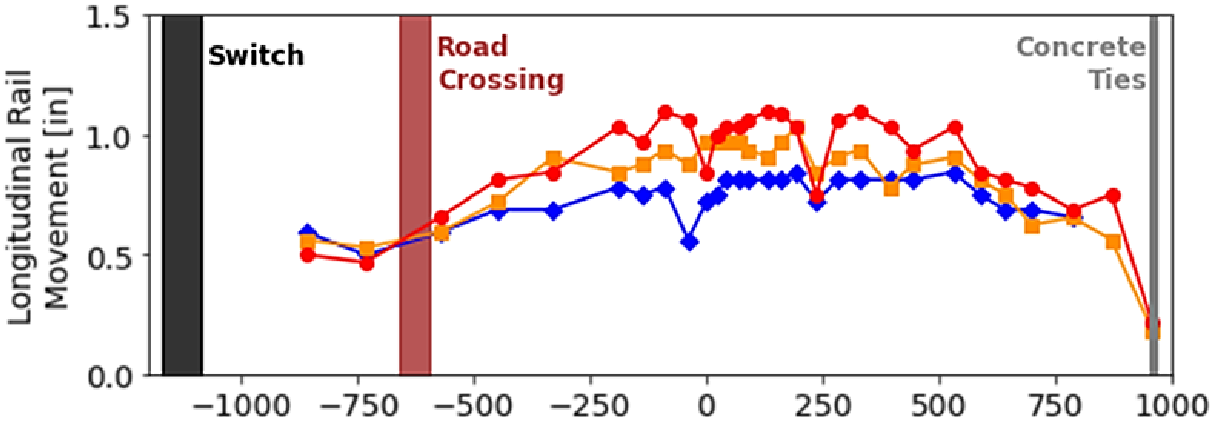
RNT Changes: SRI Goals and Objectives

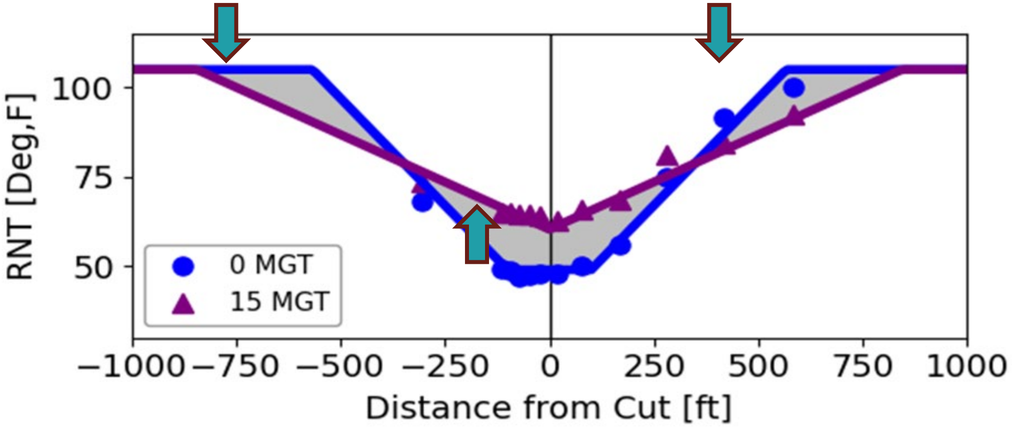
- **Understand situations prone to RNT changes**
- **Start with field testing and use data for numerical modeling and simplified guidance**

RNT “Bunching” Near Fixed Objects

Typically do not lift through turnout



RNT “Smoothing” with Train Operations



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Topic 2: Facility for Accelerated Service Testing (FAST®) RNT Measurements

---

TD25-019 “Longitudinal Rail Force Monitoring at FAST®”

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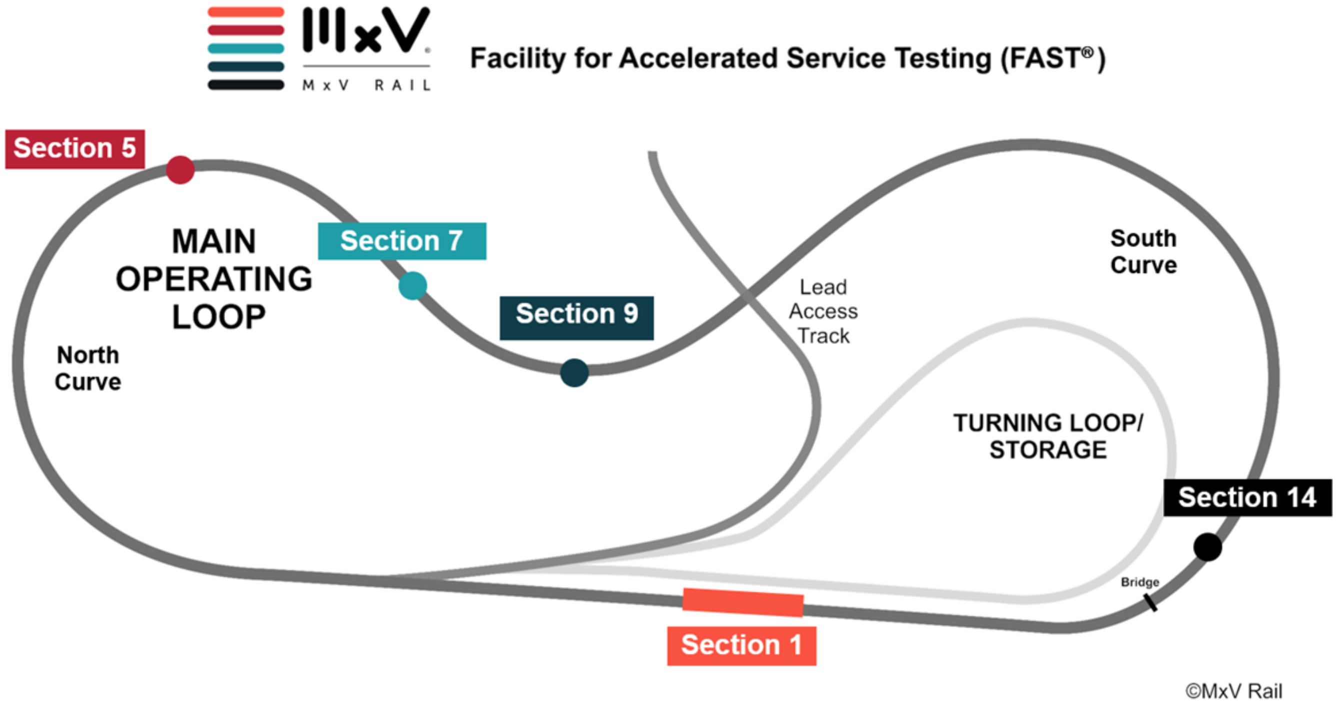
Objectives, Locations, and Operations

- **Five monitoring locations**
  - Safe FAST operations
  - Passive measurements due to large amounts of trackwork
- **Target RNT: 100°F**
- **High number of weld/rail breaks in curves**
- **April 2024 to June 2025**
  - Two full operating seasons
  - Two non-operating seasons



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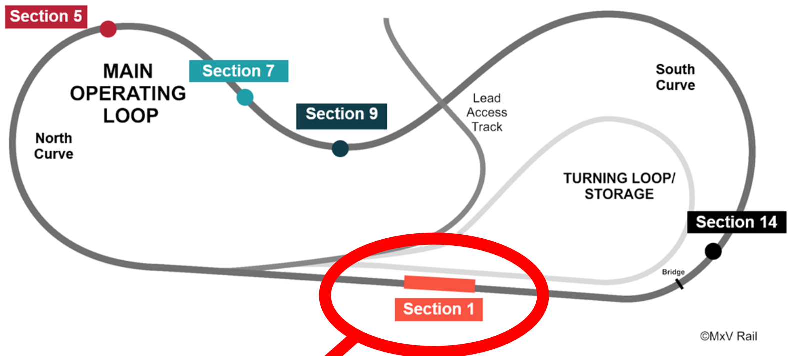
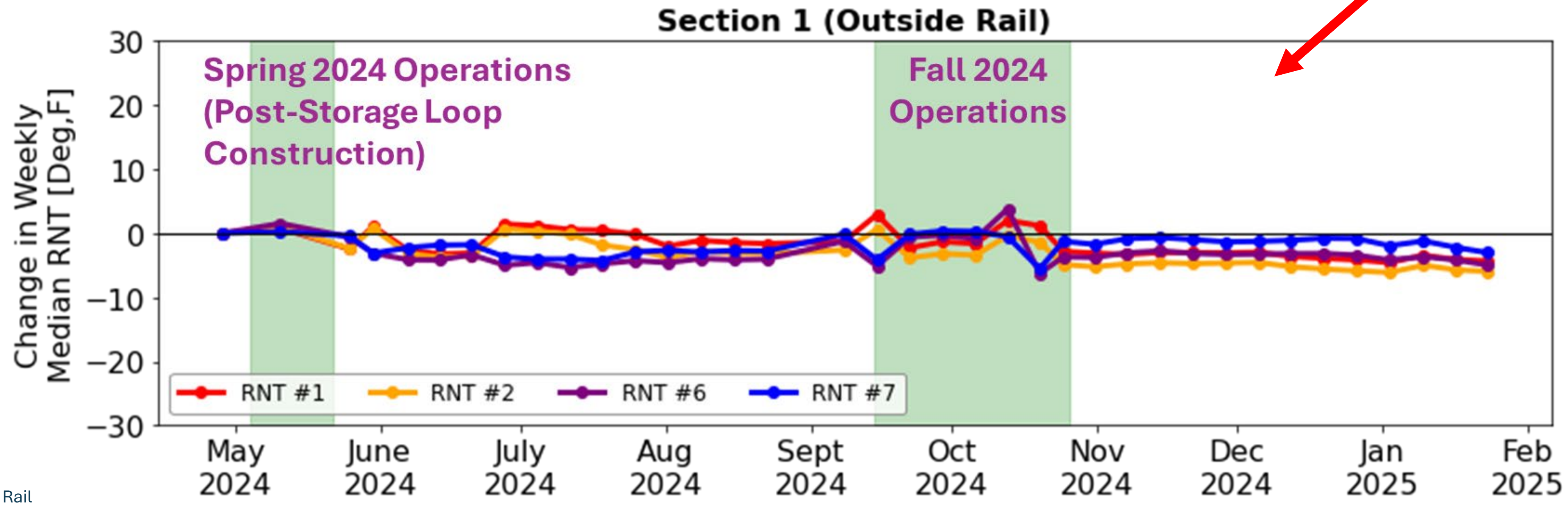
Stable RNT

- **Majority of track stayed within 10°F of target**
- **No single RNT degradation rate or trend**
  - RNT changes that occurred were typically associated with a particular mechanism unique to location





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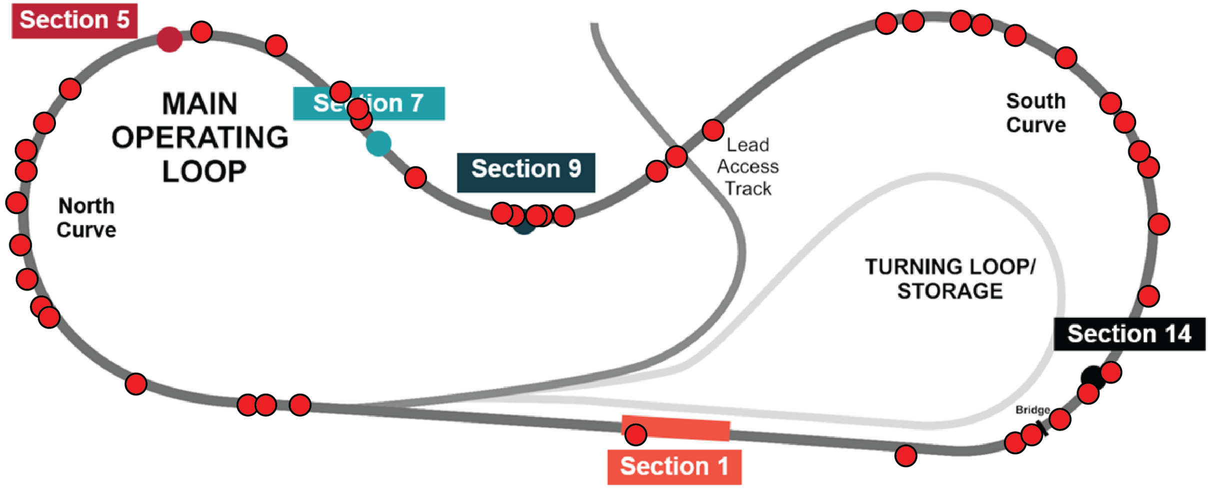
RNT Changes: Weld/Rail Breaks and Maintenance

- **Weld/rail breaks common in curves**
- **FAST RNT management generally keeps RNT near target**

Locations of Weld/Rail Breaks



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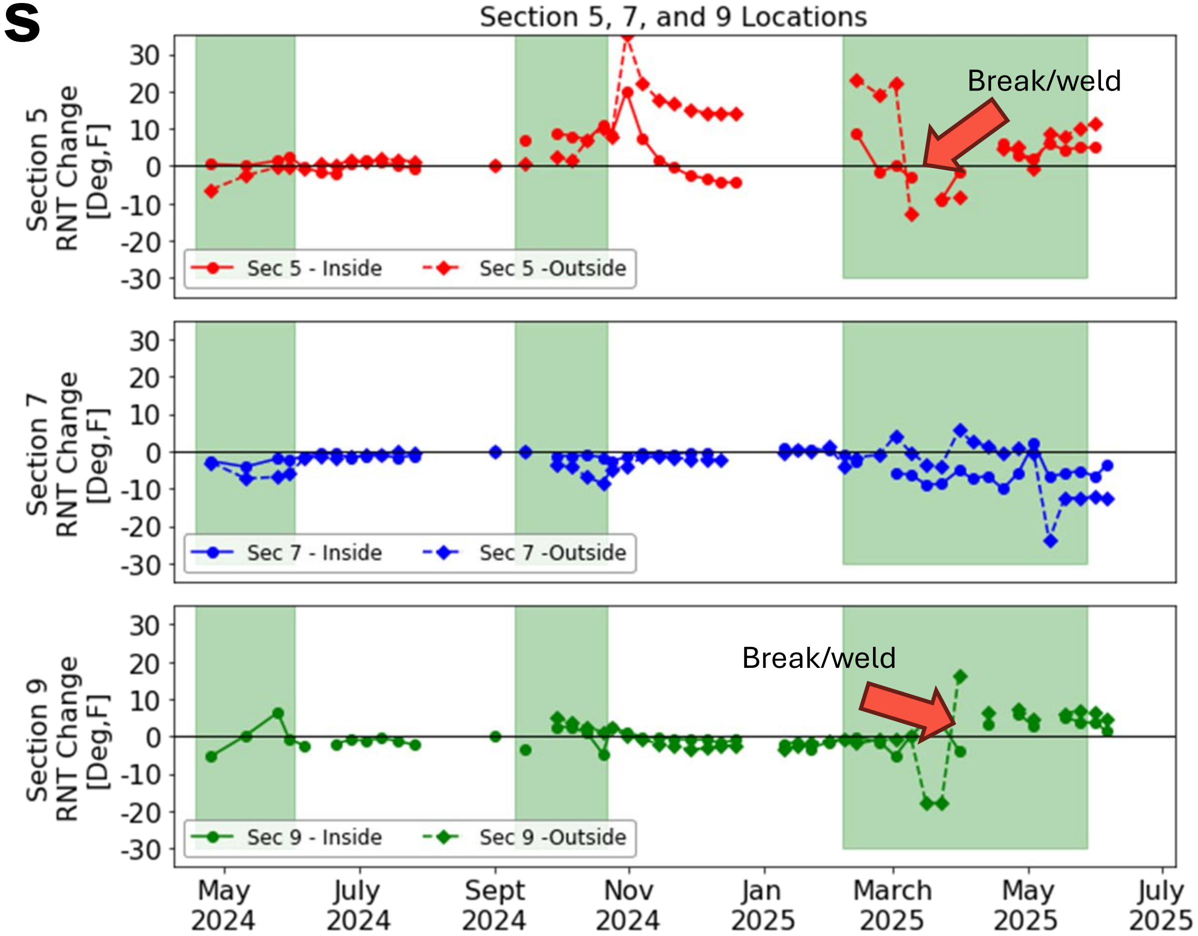
Section 5, 7, and 9 Locations

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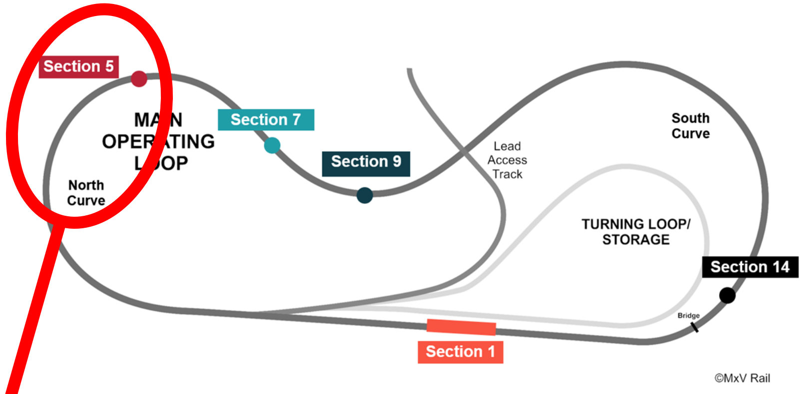
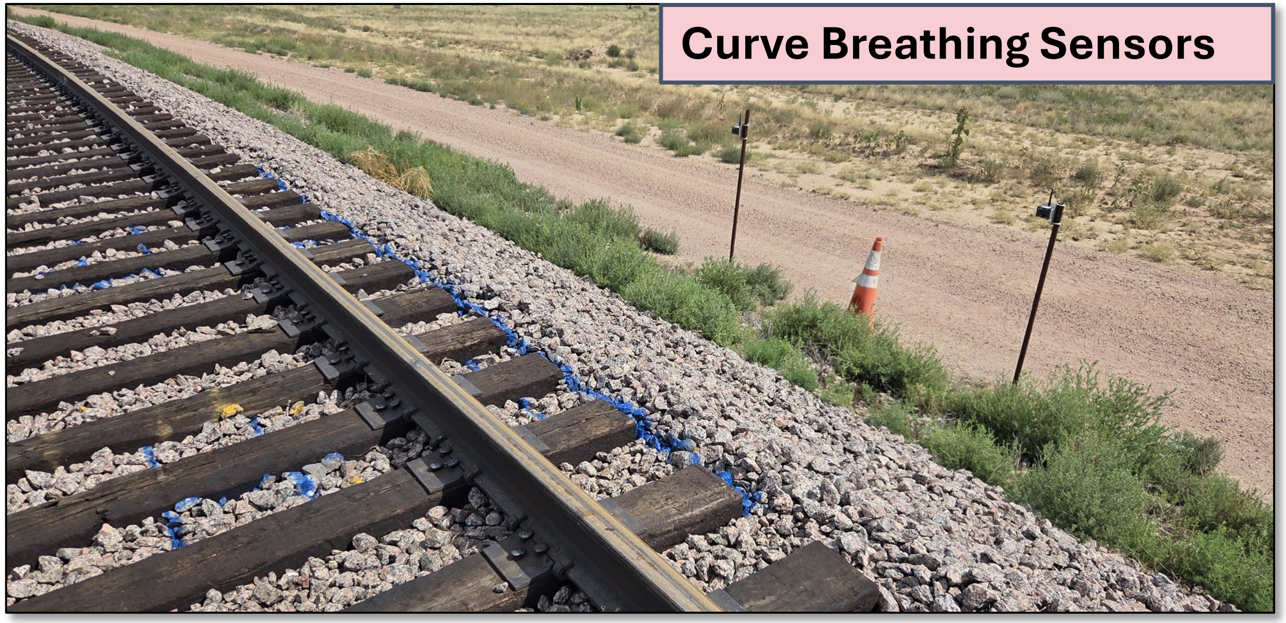
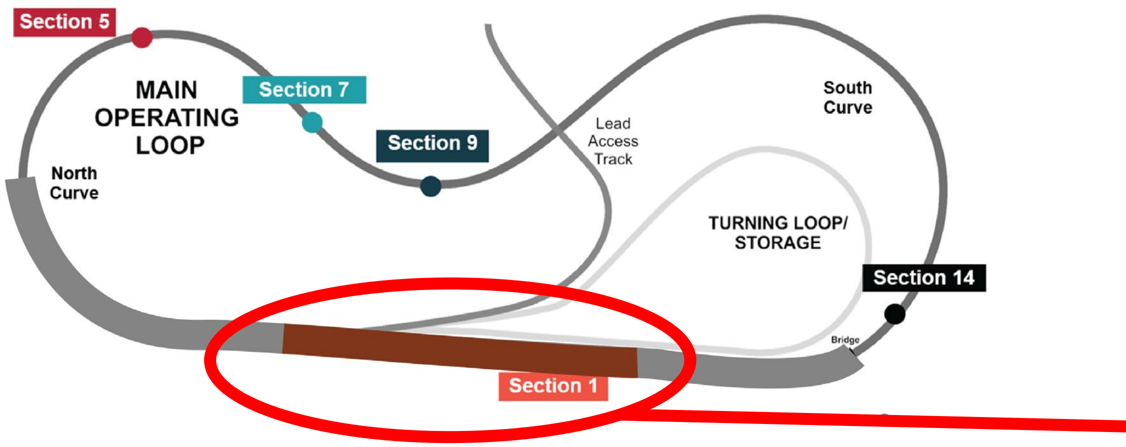
RNT Changes: Curve Breathing

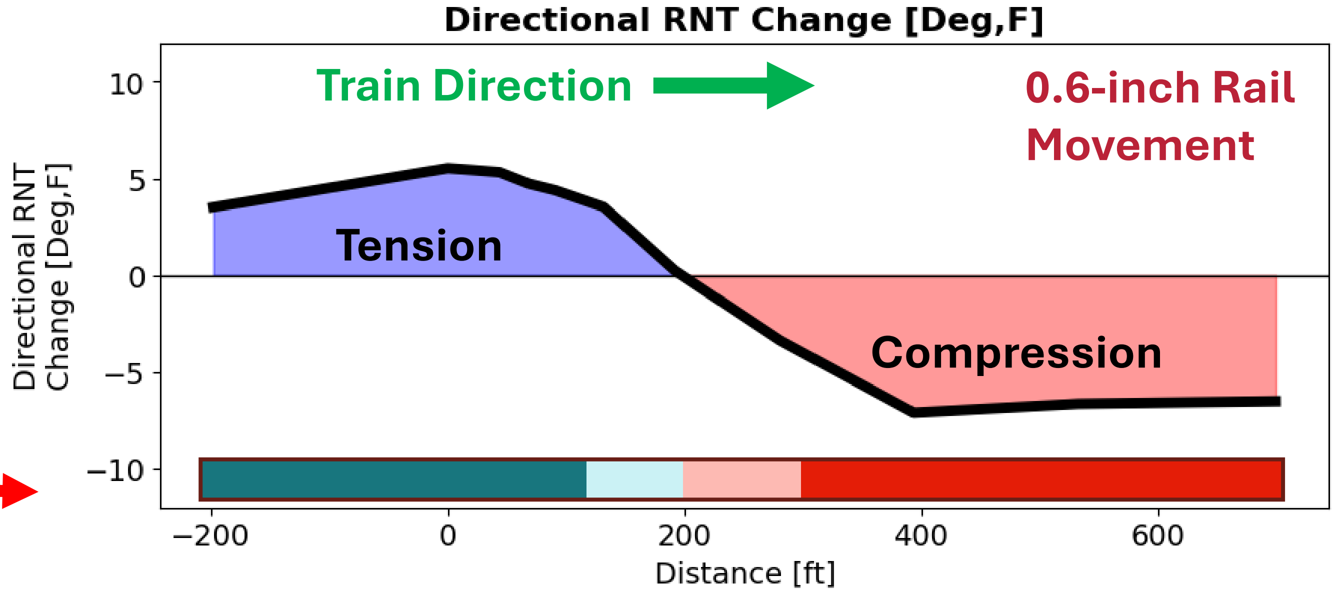
- **North curve shows evidence of curve breathing**
- **Difficult to isolate RNT changes because rail breaks**
  - 6°F RNT drop from 0.4-inch inward movement (6-degree curve)
- **More effort on quantifying curve movement**





RNT Changes: Train Operations





- **Train directional rail movement in Section 1**
    - Rail can move between loose anchors or from tie moving through ballast
- **Occurs within stiffer structures (turnout and concrete ties)**

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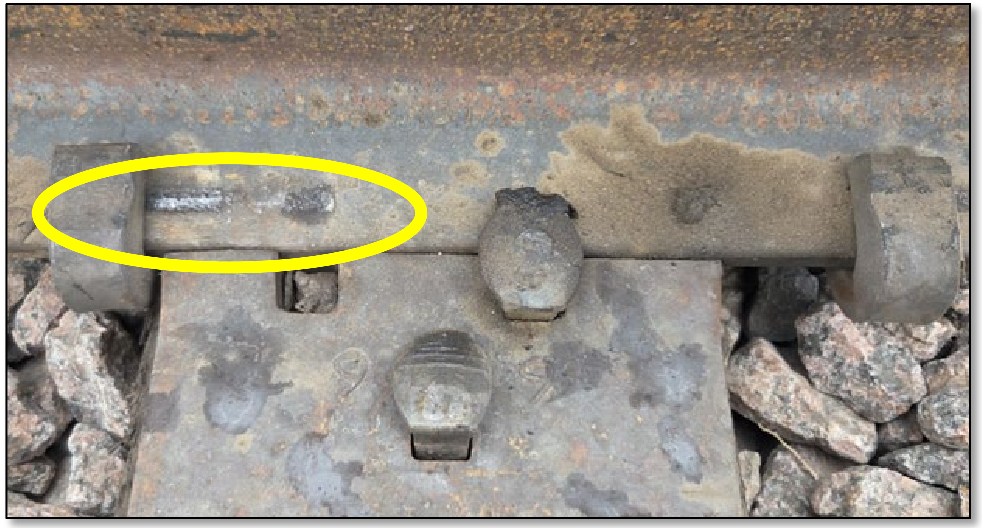
RNT Changes: Proxy Measurements

Key Questions:

- Without direct measurements, how do we identify track locations where RNT changes are anticipated?
- What do these measurements tell us? False positives? Potential RNT change? Actual RNT changes?

Rail slide through anchors



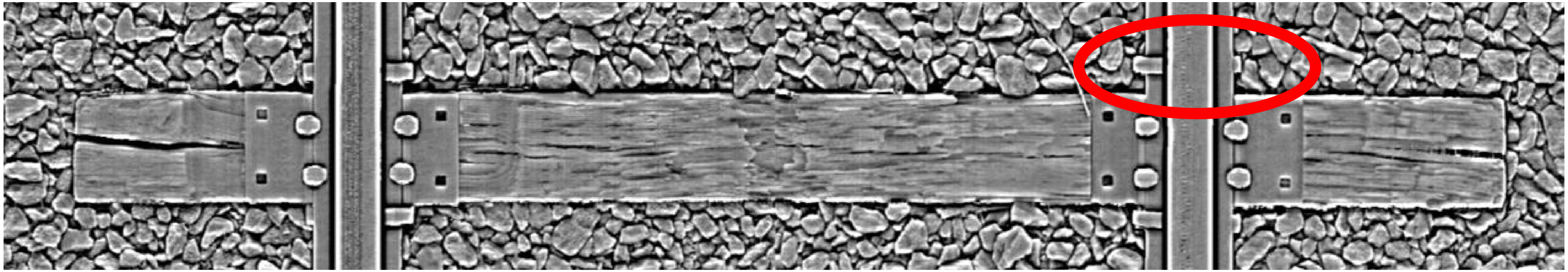


Photo credit: University of Illinois at Urbana-Champaign – RAILTEC

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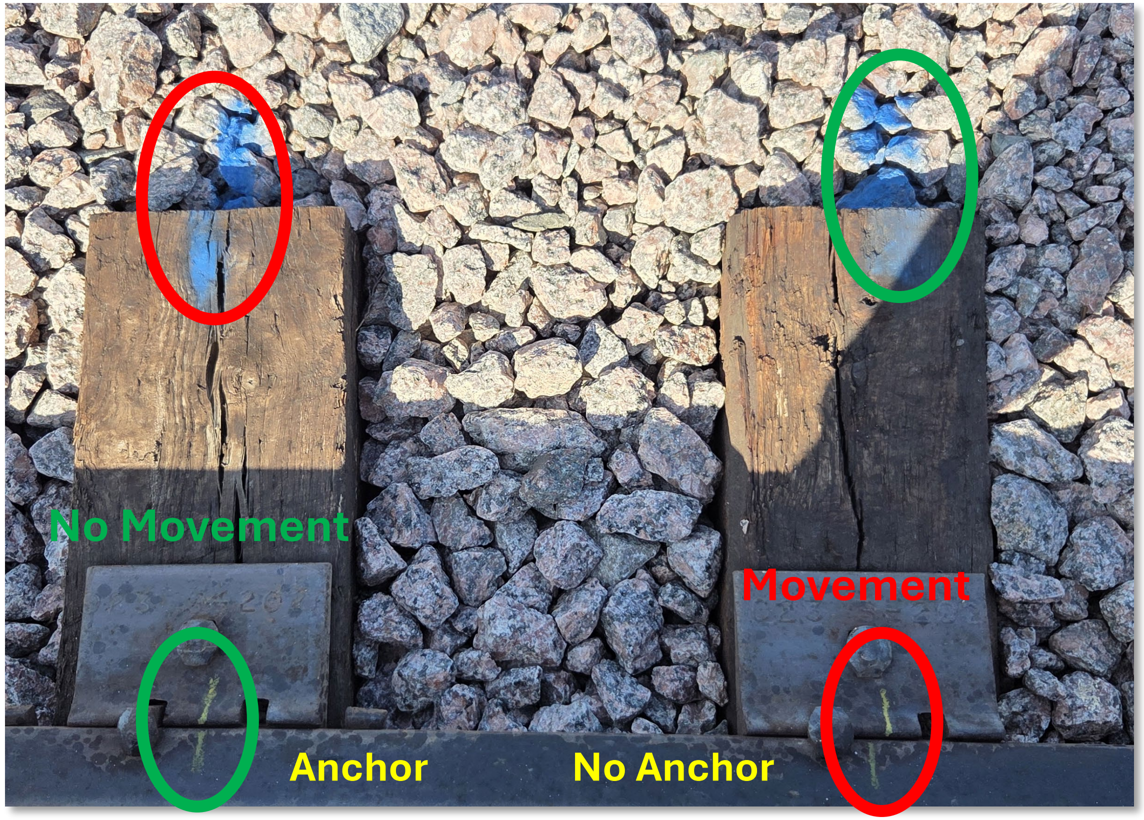
FAST RNT: Continuing Research

- **More RNT variation at FAST anticipated as track gets disturbed and loosens up**
- **More measurements in regions where RNT is changing**
- **Use field data as validation for numerical modeling**
- **Provide simplified guidance**

Rail and Ties moving through ballast



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Topic 3: FAST Rail Temperature Measurements

TD25-029 “Rail Temperature Monitoring at FAST®”

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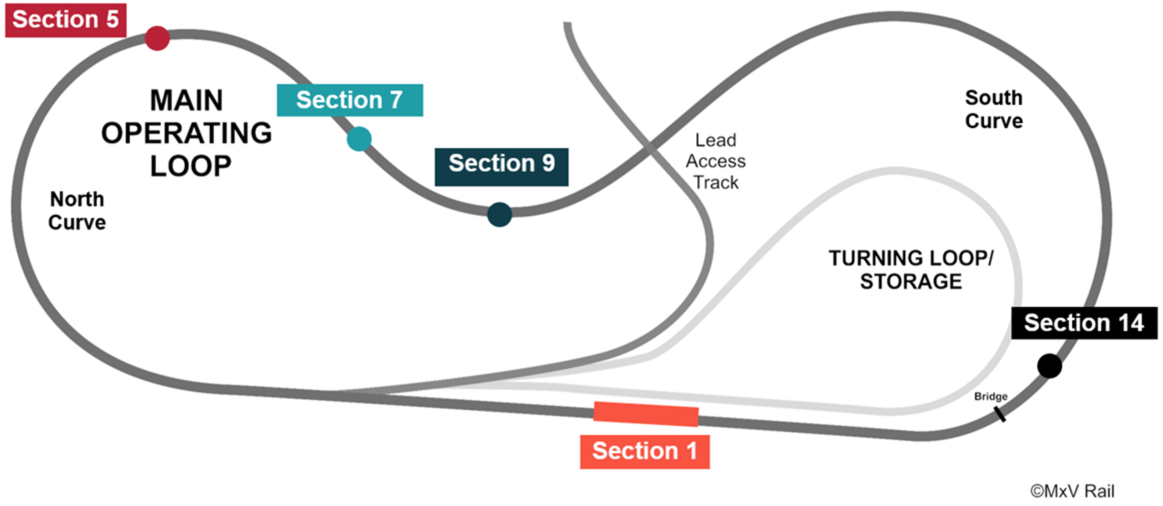
FAST Rail Temperature

- **Rail temperatures same locations as RNT**
  - Measured on web
- **Unique operating environment**
  - Loaded unit train pass every four minutes
  - Monitor rail temperatures at night and slow train down to cool rail if needed
- **Better understand how solar radiation and other factors affect rail temperatures**
  - +30°F is historical guidance, but newer tools and understanding can improve rail temperature predictions



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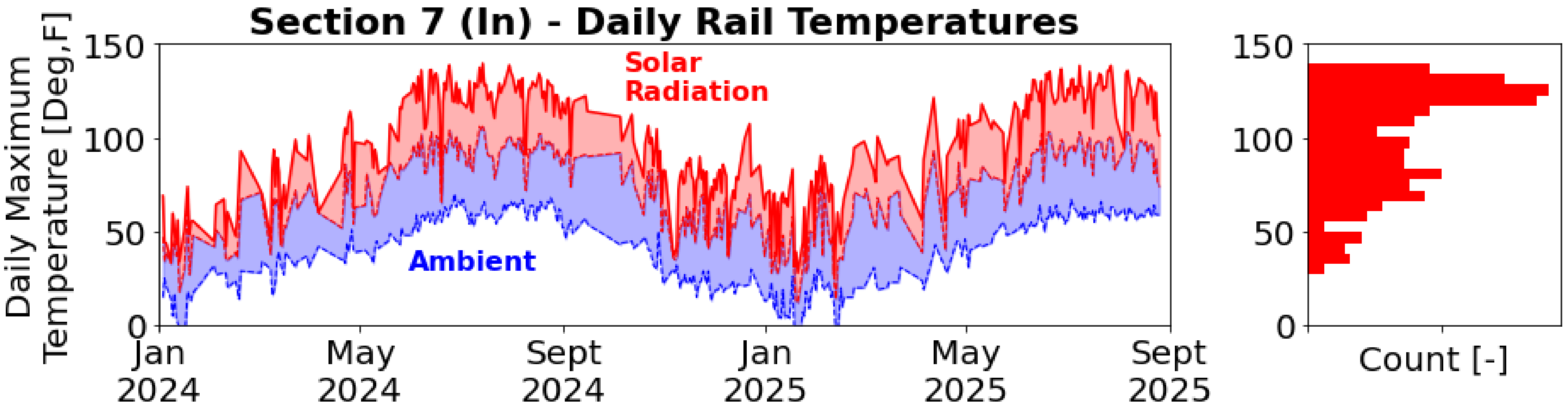
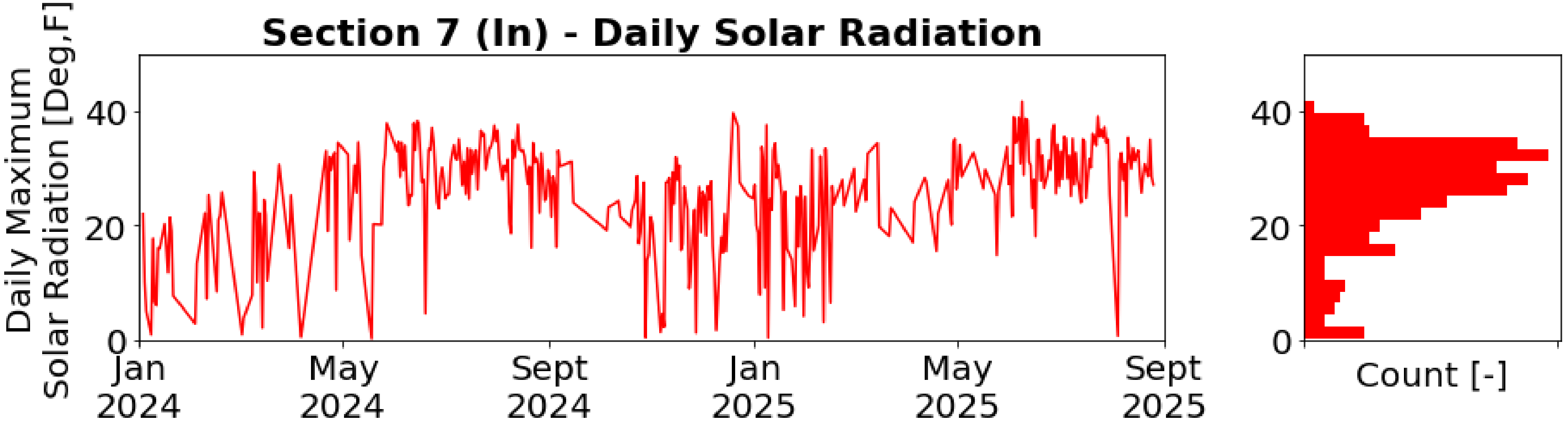
Maximum Rail Temperatures (No Train Operations)



Section 7 (In) - Daily Rail Temperatures

Up to 142°F



Section 7 (In) - Daily Solar Radiation

Up to 41°F but in specific weather conditions

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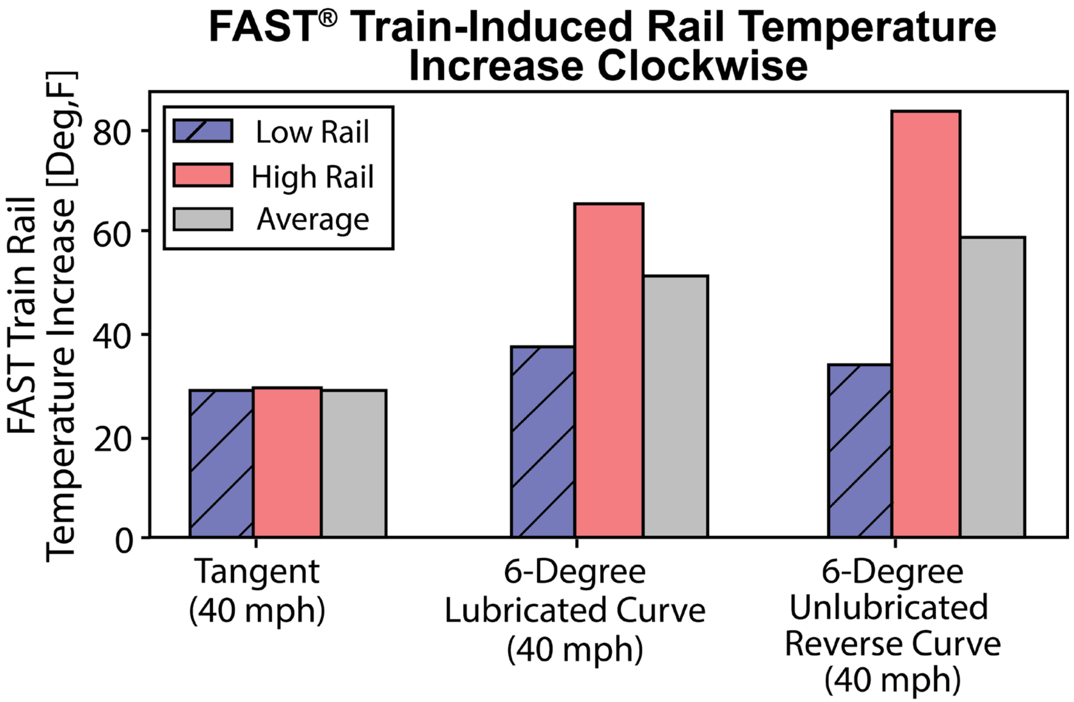
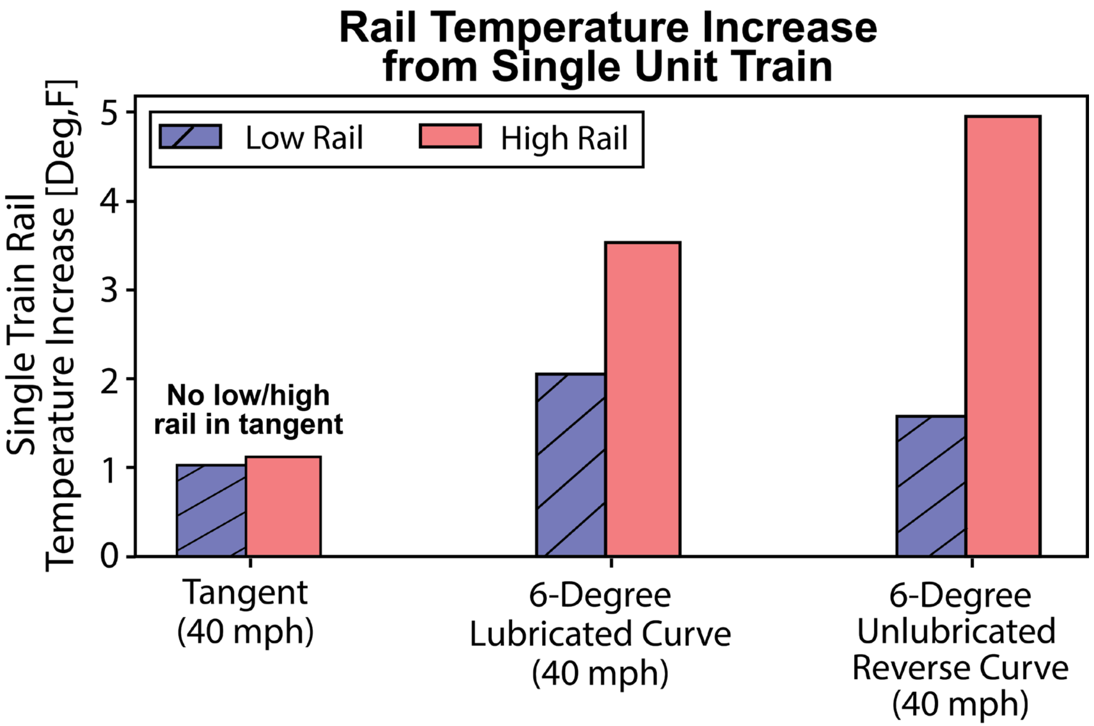
Train Operations (Rolling Friction Only)





FAST train operations can increase rail temperatures by up to 80°F

Typical loaded unit train increase rail temperatures between 1°F to 5°F

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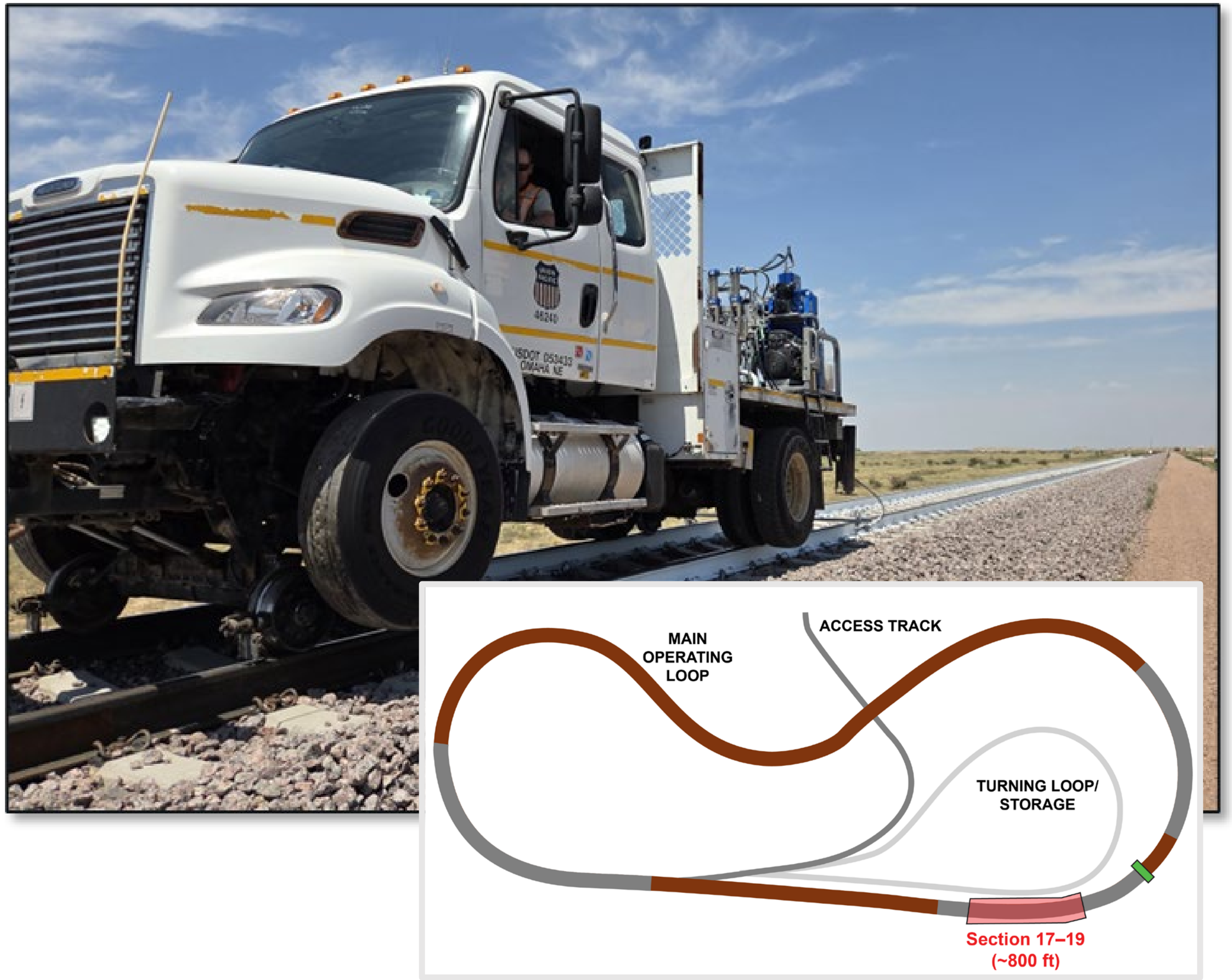
Continuing Research

- **Improve from assumption that solar radiation increase rail temperatures +30°F**
  - More accurate rail temperature predictions
  - Validate and improve rail temperature prediction models
  - Identify situations greater than 30°F
- **Methods to reduce rail temperature (painting rail)**



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Summary and Acknowledgements

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Key Findings

- **Rail Neutral Temperature (RNT) can change after establishment from a range of factors, often associated with train operations**
- **RNT tends to degrade but does not appear to have a generalized degradation rate**
- **Rail temperatures in Pueblo reach up to 142°F with influence from solar radiation reaching 41°F**
- **FAST unit train adds approximately 1 to 5°F per train pass**

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- **Track Buckling Prevention and Heat Speed Restriction Technical Advisory Groups**
- **MxV Rail Engineering Teams (Track Infrastructure, Vehicle, and Data Science)**

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Agenda | Technical Sessions

Wednesday, April 29, 2026

Mechanical (AM) | Fortino Ballroom C

Wheel Performance and Integrity	Corey Pasta
Autorack Loading Test	Stan Gurulé
Brake Systems Research	Yi Wang
Q&A	

Mechanical (PM) | Fortino Ballroom C

Axle Inspection Technologies	Anish Poudel
Bearing Performance & Integrity	Matt Wenger
Water Ingress Bearing Testing	Matt Wenger
Q&A	

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Wheel Performance & Integrity

Corey Pasta
Scientist

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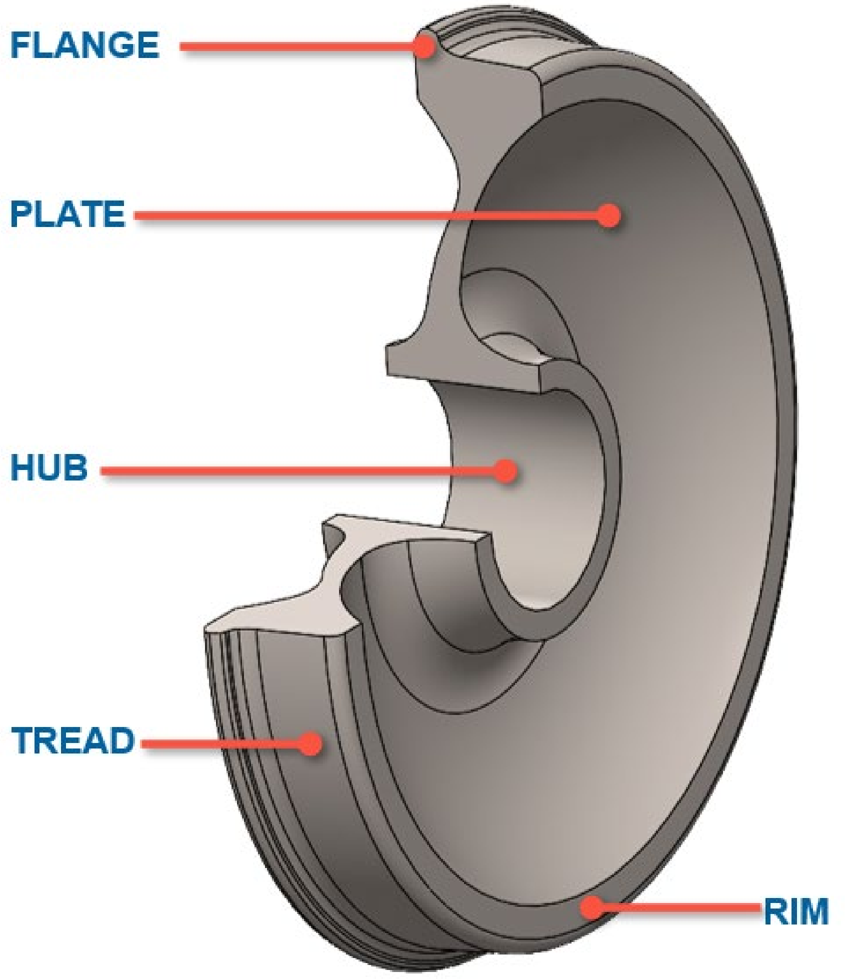
Research Objectives

1. **Identify and mitigate root causes of wheel failure**
2. **Evaluate wear and fatigue performance of new wheel materials**

Presentation Focus Areas:

- Recent wheel life trends
- High performance wheel testing

Wheel Section View with Key Nomenclature



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Wheel-Related Replacements

- **Most significant maintenance cost**
- **Interchange car repair**
  - AAR Car Repair Billing (CRB) data
  - AAR Rule 41 – Why Made Codes (WMC)
  - Extensive, not comprehensive
- **Wheel-related replacements only**
  - No WMC 11 – “Removed in good condition”
- **Bulk commodity cars only**
  - Hopper, gondola, and tank car types
  - Four-axle, 143-ton gross rail load

Hopper

Gondola

Tank

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Ranking Wheel Replacements

Tread Damage **~75% of wheel replacements in 2024**

- Most common replacement cause
- Wheel impact, thermal cracks, shelled/built-up/grooved tread and slid flats

Wear **~25%**

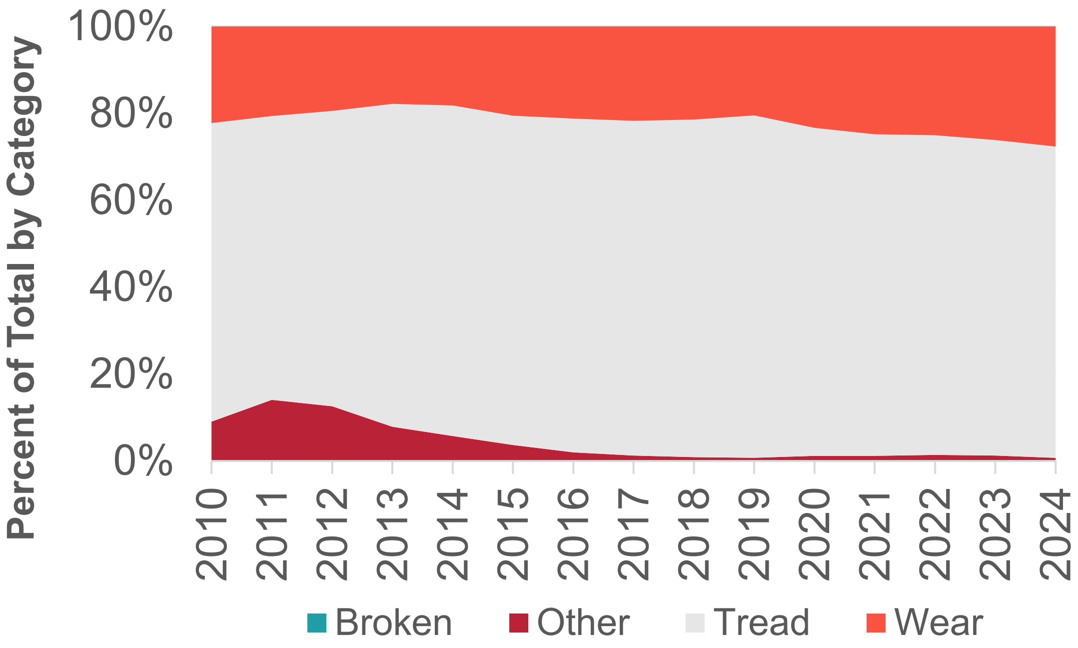
- Preferred replacement cause
- Slight increase over last 5 years

Other **~0.5%**

- Example: WMC 7 “Obsolete material”

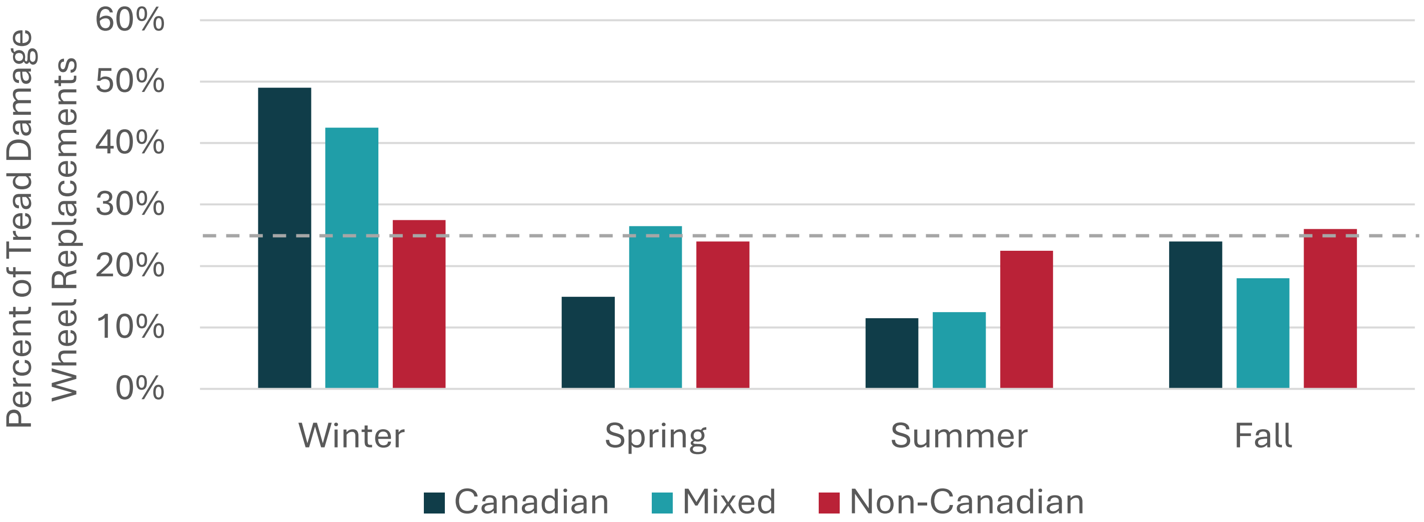
Broken **~0.2%**

- Very rare
- Significant research focus



Tread Damage and Wheel Impacts

- **Over 90% of tread-damage-related replacements are associated with high impact wheels (HIW)**
- **High seasonality for wheels operating in northern latitudes**



Sample High Impact Wheel

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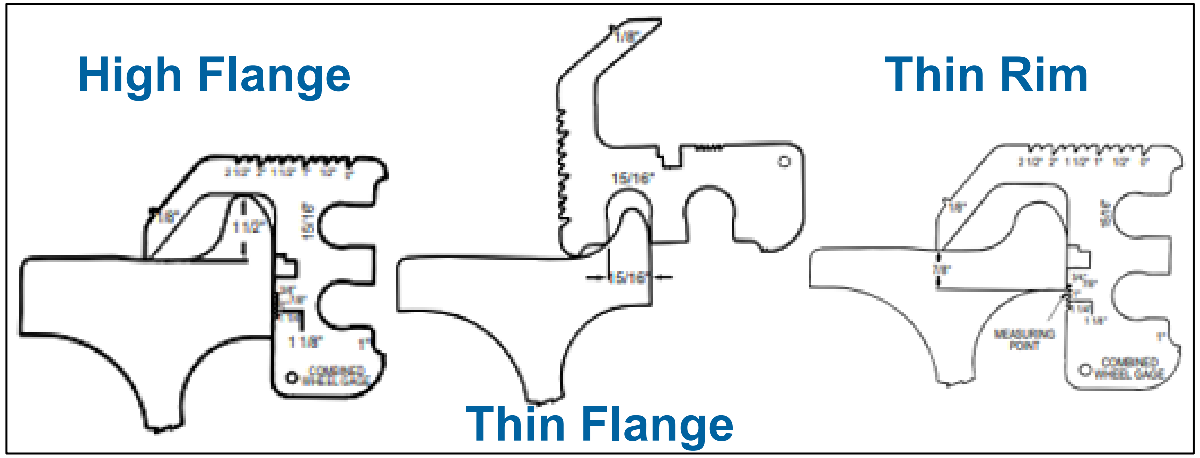
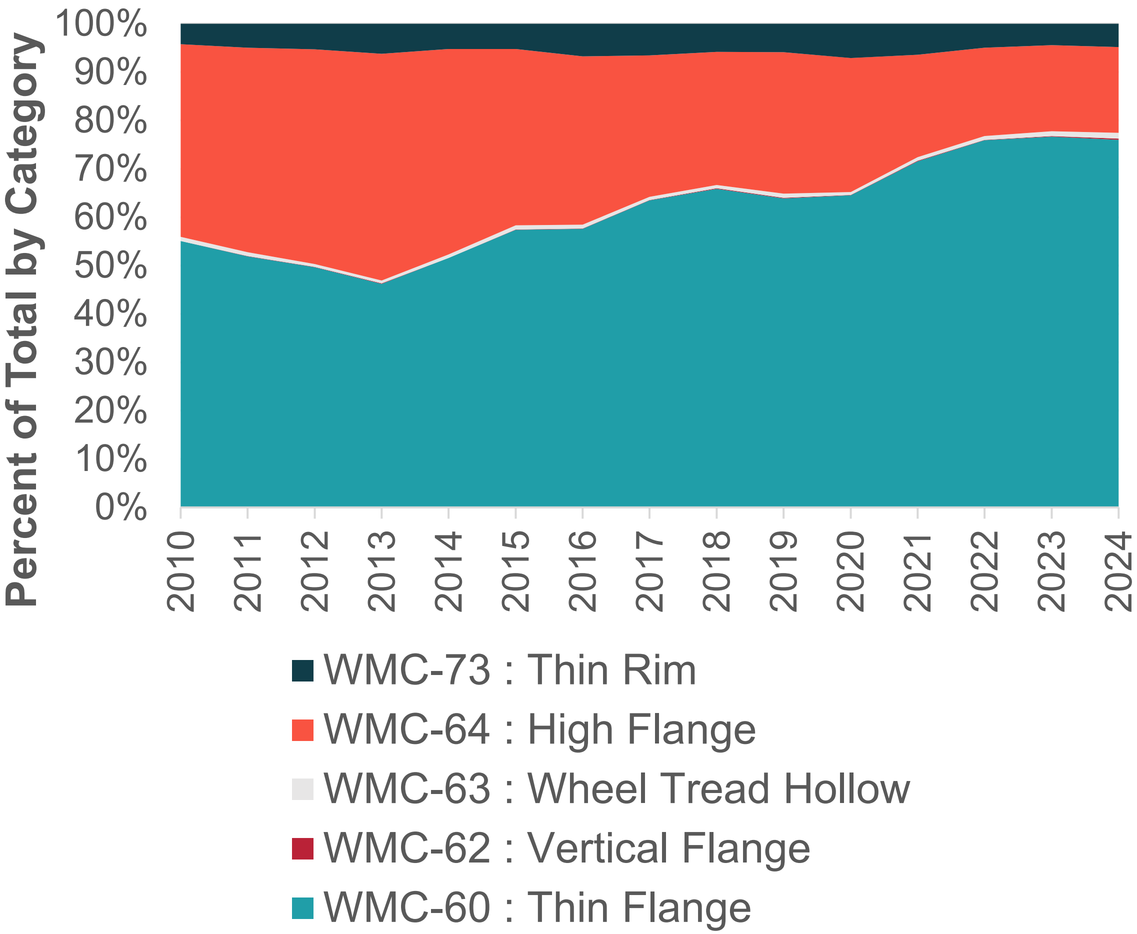
For the Wheels that Wear Out…

- **Thin flange is now the most common wear replacement**
  - Shift from 2013 when high flange was most common
- **Thin rim steady at ~5%**





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Wear Shift from Tread to Flange

- **Root Cause(s) Unknown**
  - Introduction of Specification M-976* Trucks (2004)
    - Demonstrated to provide improved steering performance
    - ~80,000 cars equipped in 2010 increasing to ~300,000 by 2015
    - 2.8 - 3.5 X reduction in removals for tread damage
    - 6.5 - 6.6 X increase in thin flange removals
  - Introduction of AAR-2A profile for all new/reconditioned wheels – 2020
    - 1/8-inch-thinner flange
    - Large-scale service testing in 2018 did not show a negative impact on service life

* Association of American Railroads, *Manual of Standards and Recommended Practices, Section D,* Washington DC, 2025.

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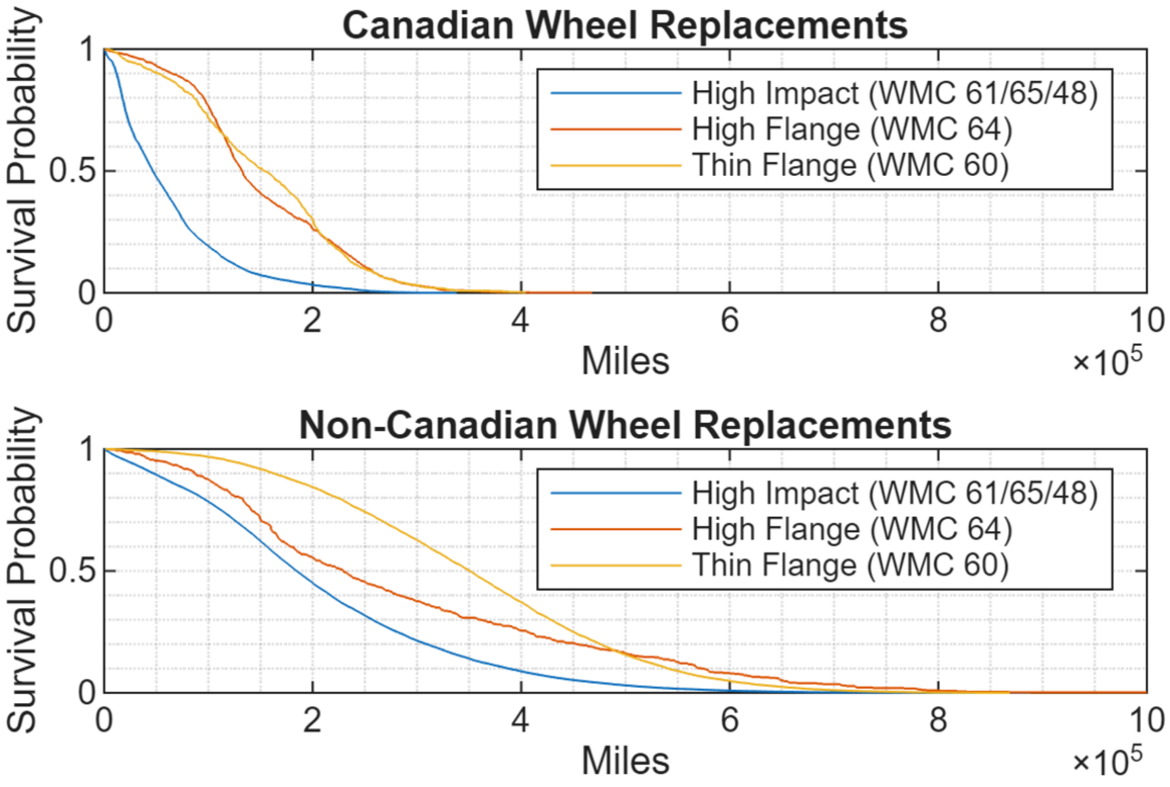
Mileage Data



- **No censored observations**
- **Large variation**
  - Operating environment
  - Removal cause
- **50% of wheels removed within 100,000 miles for HIW in Canadian service**
- **50% of wheels removed within 350,000 miles in non-Canadian service for thin flange**

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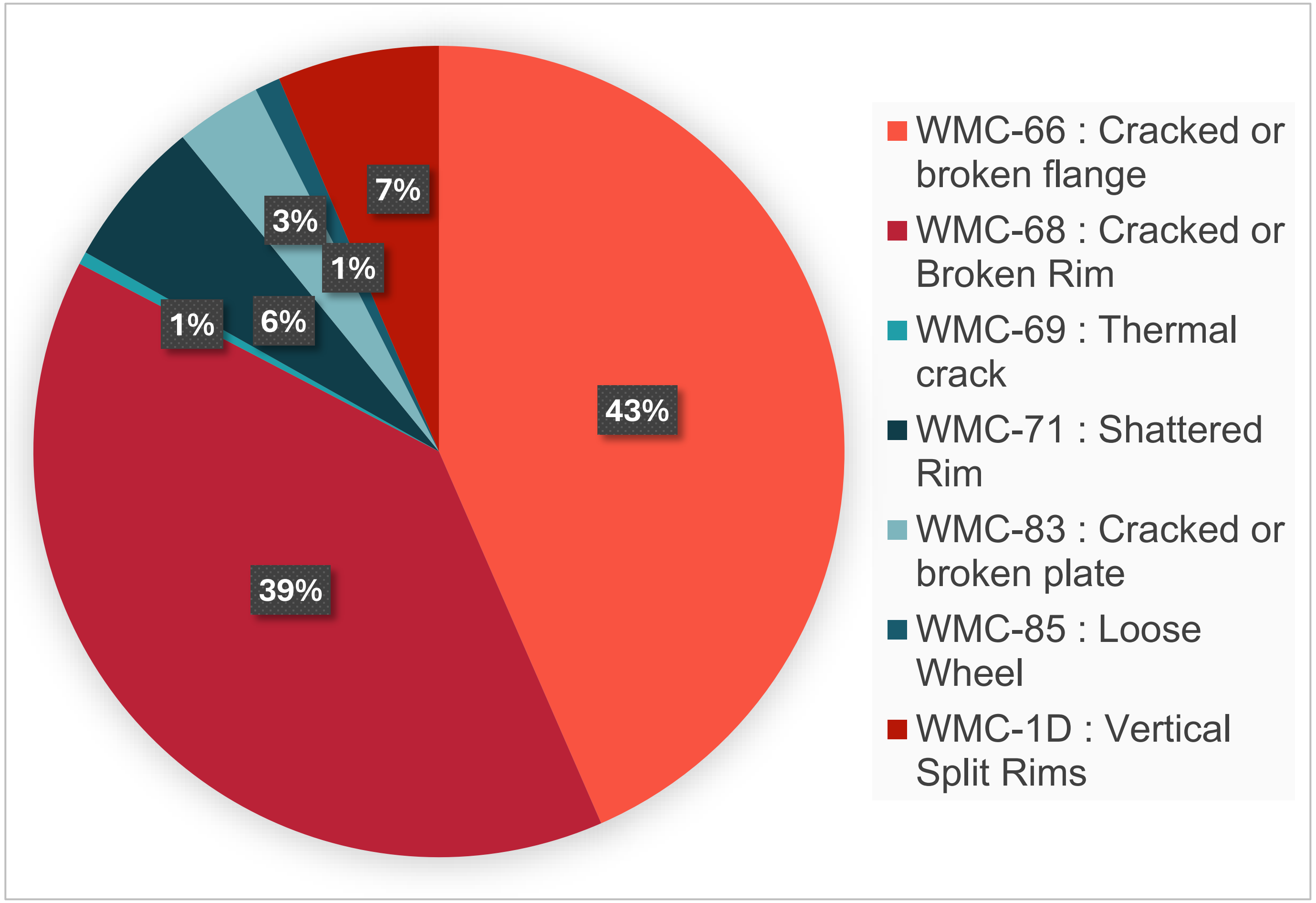
Broken Wheel Categories and Breakdown

- **Many cracked broken wheels found by wayside detectors**
- **AAR Mechanical Directive MD-115 report**
    - Select failure modes reviewed routinely by industry experts
    - Subcategories outside of AAR WMC emerging and documented over time



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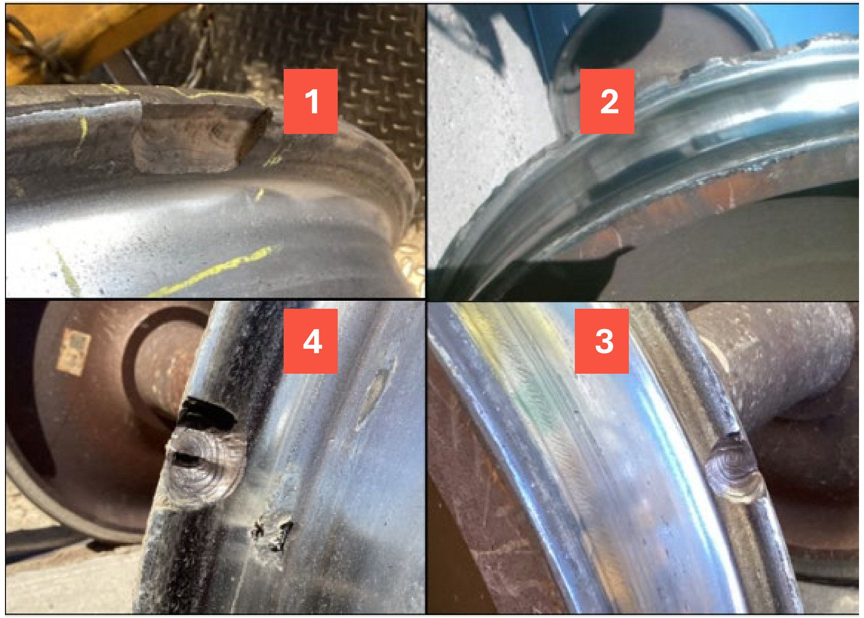
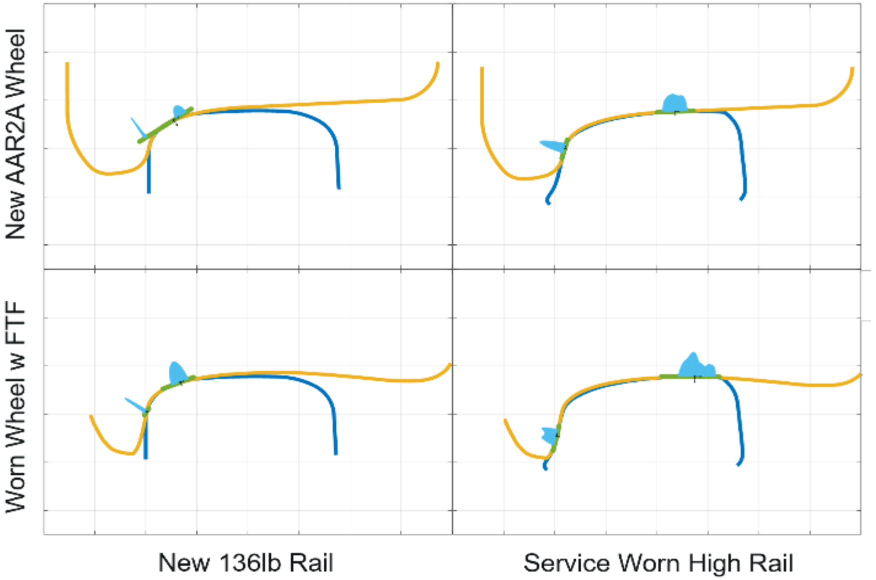
Cracked/Broken Flange

- **Flange failure subcategories:**
  1. Vertical flange fatigue
  2. Chipped (not fatigue related)
  3. “Eye”
  4. “Butterfly”
- **Investigating wheel (and rail) profile and related subsurface stresses**





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High Performance Wheel (HPW) at FAST®

- **HPW 2: Commenced September 2017**
  - 40 wheelsets, 14 wheel types
  - 36-inch wheels under 286,000-lb. GRL gondolas
  - 130,000 average accumulated miles through 2024
  - 11 wheel replacements (28% of test population)
    - 8 due to subsurface fatigue cracks
    - 1 shattered rim, 1 with shelling, 1 due to flange wear
- **HPW 3: Commenced Aug 2024**
  - 12 wheelsets, three wheel types
  - 38-inch wheels under 315,000-lb. GRL gondolas
  - 23,000 miles and no replacements

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HPW 2 Revenue Service Update

- **Grain service**
    - 6 suppliers: 140 HPW wheelsets
    - 44 Class C wheels
- **Average mileage at removal: 353,000**
    - Some wheelsets have reached 500,000 miles

Supplier Number	Wheelsets Removed for Cause	Wear	High Impact	Shelling	Average Mileage at Removal
3	10	3	2	0	481,400
6	3	2	0	1	326,900
10	9	0	5	0	264,300
11	5	1	3	0	410,600
13	9	3	3	0	313,900
16	3	1	0	1	399,900
Class C	2	1	0	1	273,400
Total % of Pop	**41 (22%)**	**11 (6%)**	**13 (7%)**	**3 (2%)**	

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HPW 3 Revenue Service Test – 2026 Kickoff

- Three suppliers, 20 wheelsets each
- HPWs and Class C control wheels in same articulated truck
- Higher mileage cars → estimated three-year test

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Acknowledgements

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RESEARCH
REVIEW

ASSOCIATION OF AMERICAN RAILROADS

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- **Wheel Suppliers**
- **Union Pacific and TTX**
- **Kerry Jones, Brian Lindeman, John Krasovic, MxV Rail NDE-MET Team**

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Back to Mechanical Agenda

Top-Deck Loading of Bi-level Autorack Test

Stan Gurulé

Scientist

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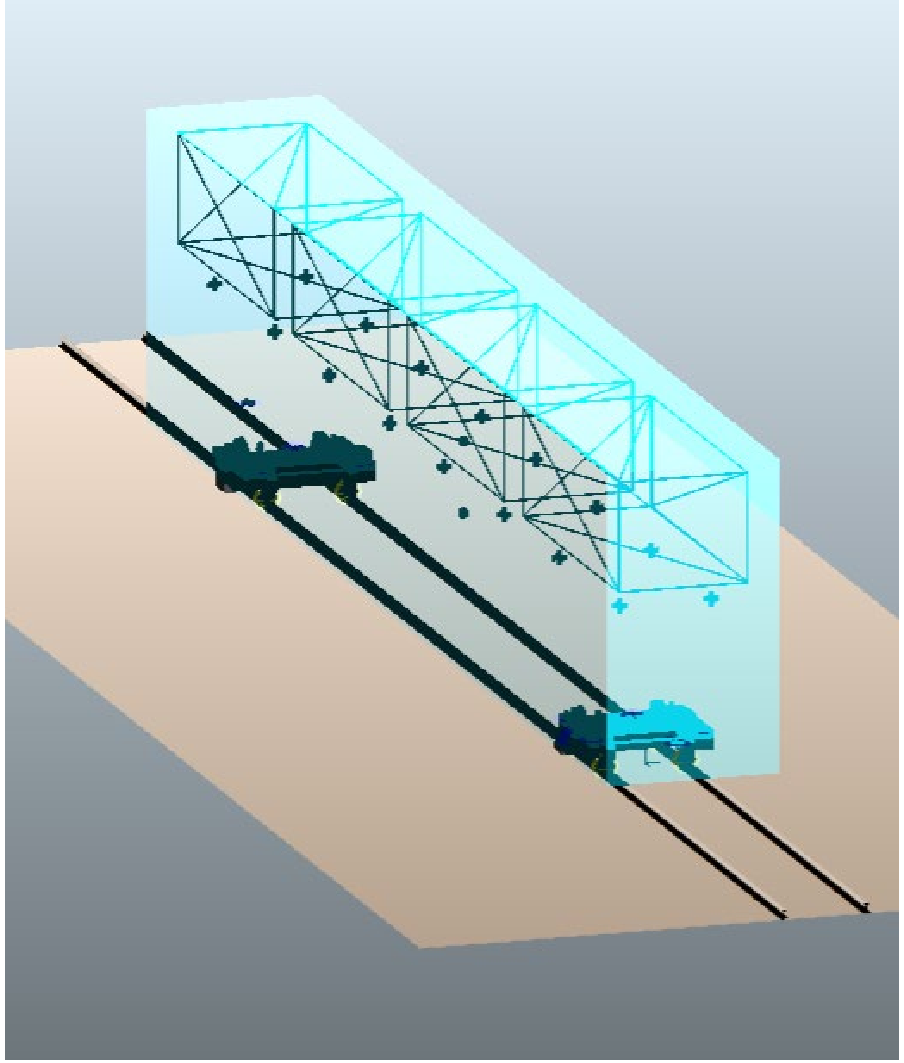
Background

- **Autorack Loading Task Force**
  - Formed to address concerns related to top-deck-only loading configurations.
    - High-profile vehicles loaded on upper deck only prompted evaluation of stability and performance.
- **Equipment Engineering Committee (EEC)**
  - Modeling results were presented to EEC.
- **Mechanical Committee**
  - Requested that testing be conducted to verify modeling.



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Test Program at MxV Rail

- **Testing was conducted by MxV Rail under the AAR Strategic Research Initiatives (SRI) Car and Truck Systems Program.**
  - Support from:
    - Greenbrier
    - TTX
    - Ford Motor Company

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Test Matrix

- **The task force defined a limited set of Chapter 11 regimes and load conditions:**
  - Chapter 11 regimes
    - Twist & Roll
    - Pitch & Bounce
    - Dynamic Curving
    - Limiting Spiral
  - Load Configurations (Plate K car)
    - Empty (baseline)
    - Top-only load (4 units on upper deck/lower deck empty)
    - Full load (4 units on upper deck/4 units on lower deck)

Image courtesy of Greenbrier

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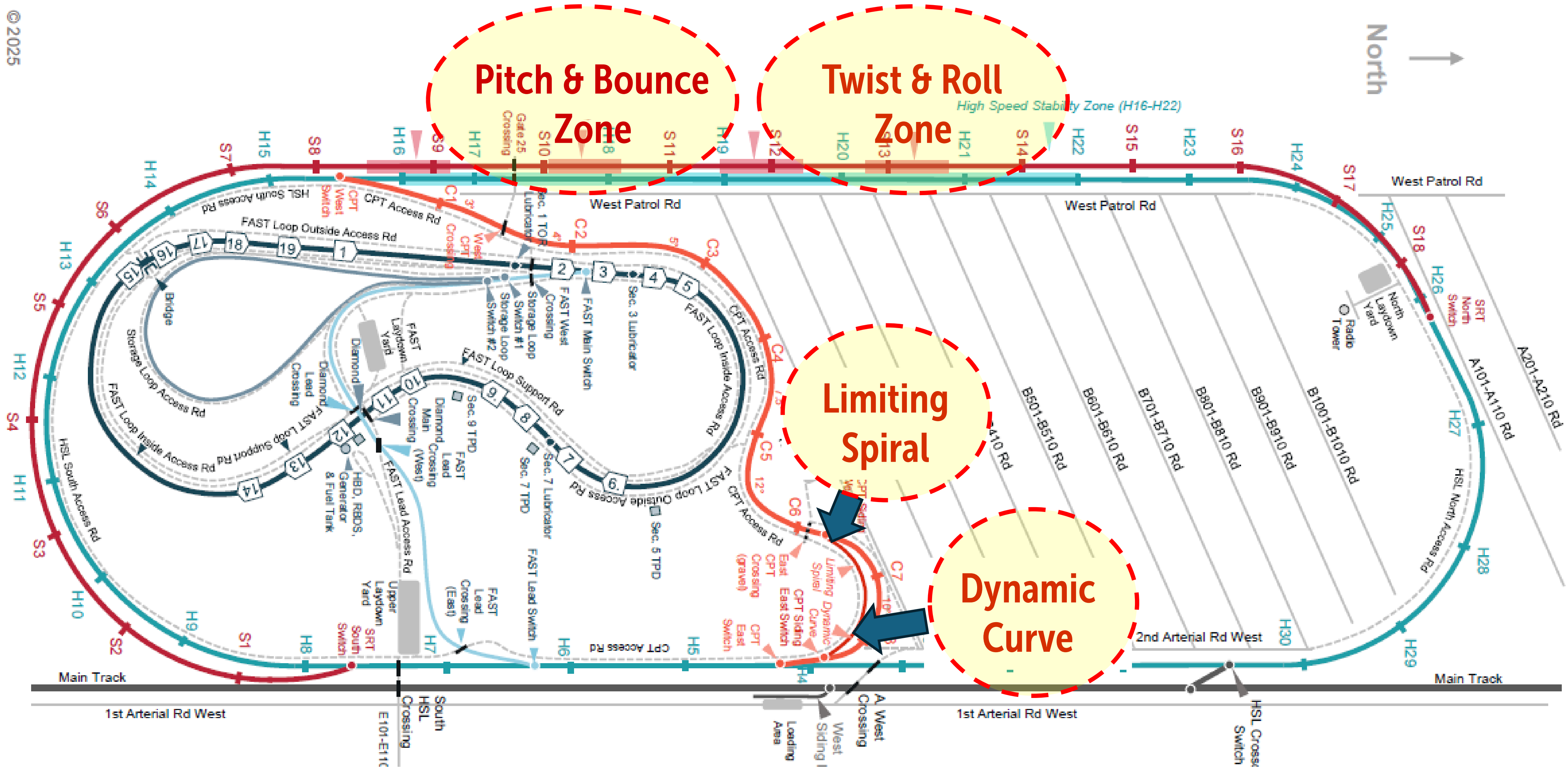
MxV Rail Test Track Layout Test Zones



Pitch & Bounce Zone

Twist & Roll Zone

Limiting Spiral

Dynamic Curve

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What is Chapter 11?

- AAR *Manual of Standards and Recommended Practices*, Section C-II, Specification M-1001
- Industry standard used to verify that new or modified freight cars are safe, stable, and service ready.
- Defines the modeling and performance tests railcars must undergo before entering interchange service.
- Ensures railcar designs maintain operational reliability, reduce risk, and meet AAR compliance requirements.

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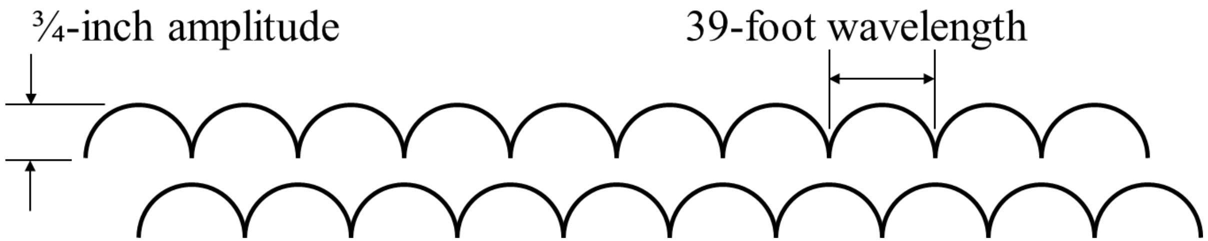
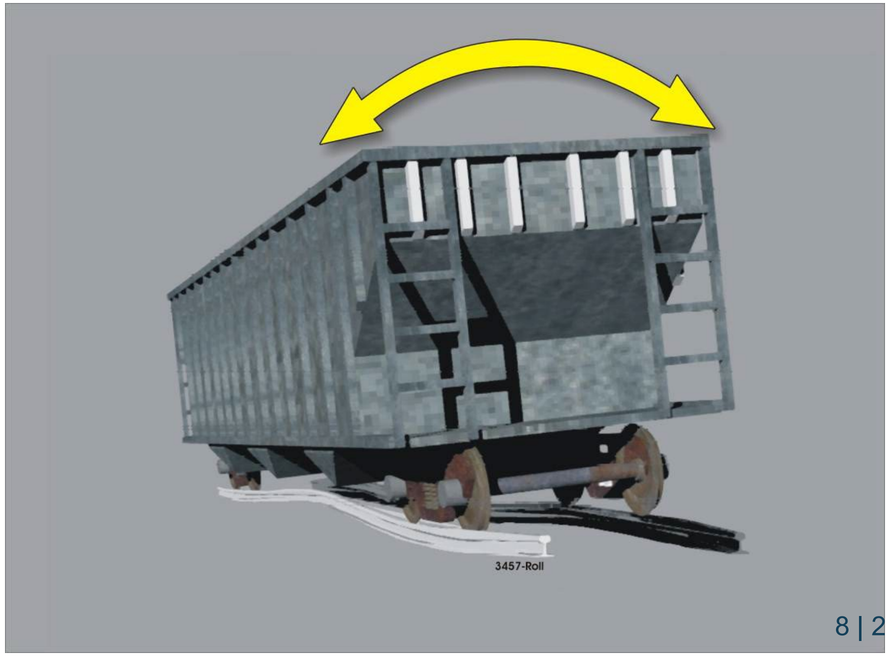
Chapter 11 Regimes Evaluated

- Twist & Roll
  - Testing of a railcar on a series of vertical perturbations that are staggered on each rail to excite the railcar in a roll mode of vibration.
  - Testing starts at 10 mph and increases in 2-mph increments until lower center roll resonance is passed, then in 5-mph increments up to 70 mph.





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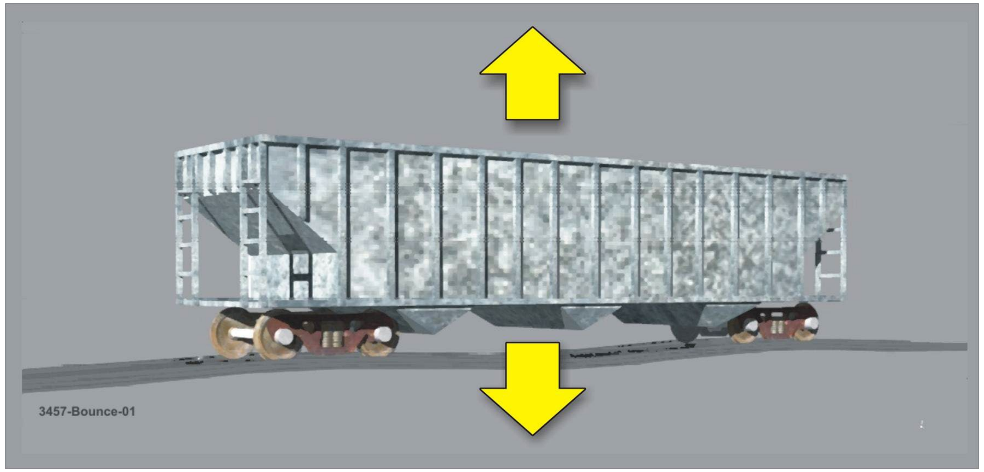
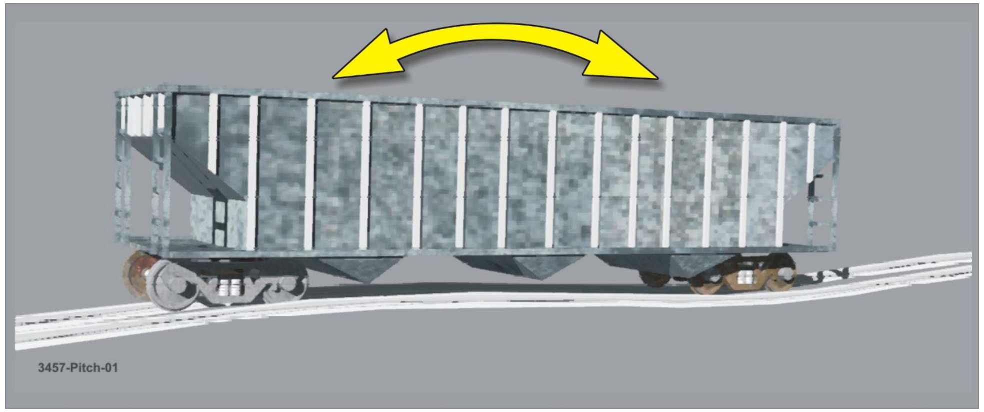
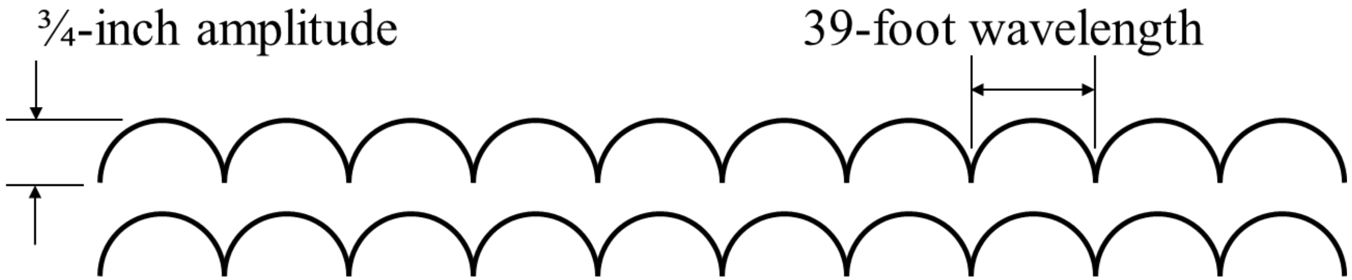
Chapter 11 Regimes Evaluated, cont’d.

- Pitch & Bounce
  - Testing of a railcar on a series of vertical perturbations that are aligned on each rail to excite the railcar in a pitch and/or bounce mode of vibration.
  - Testing starts at 30 mph and increases in 5-mph increments up to 70 mph.







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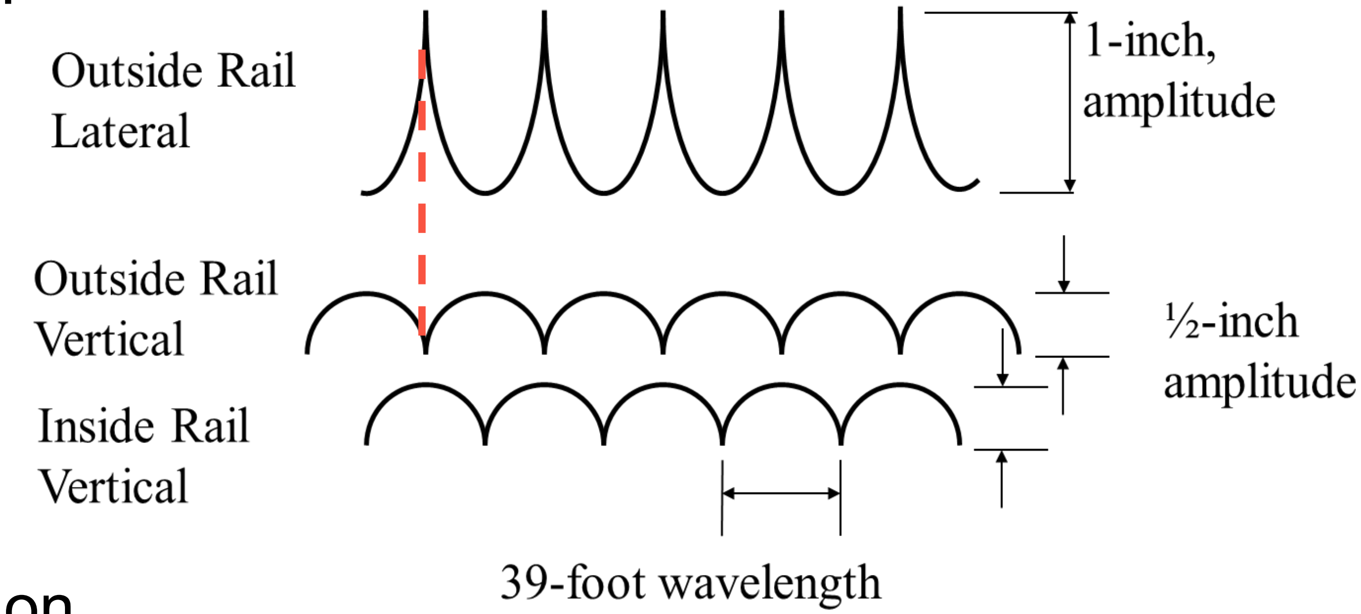
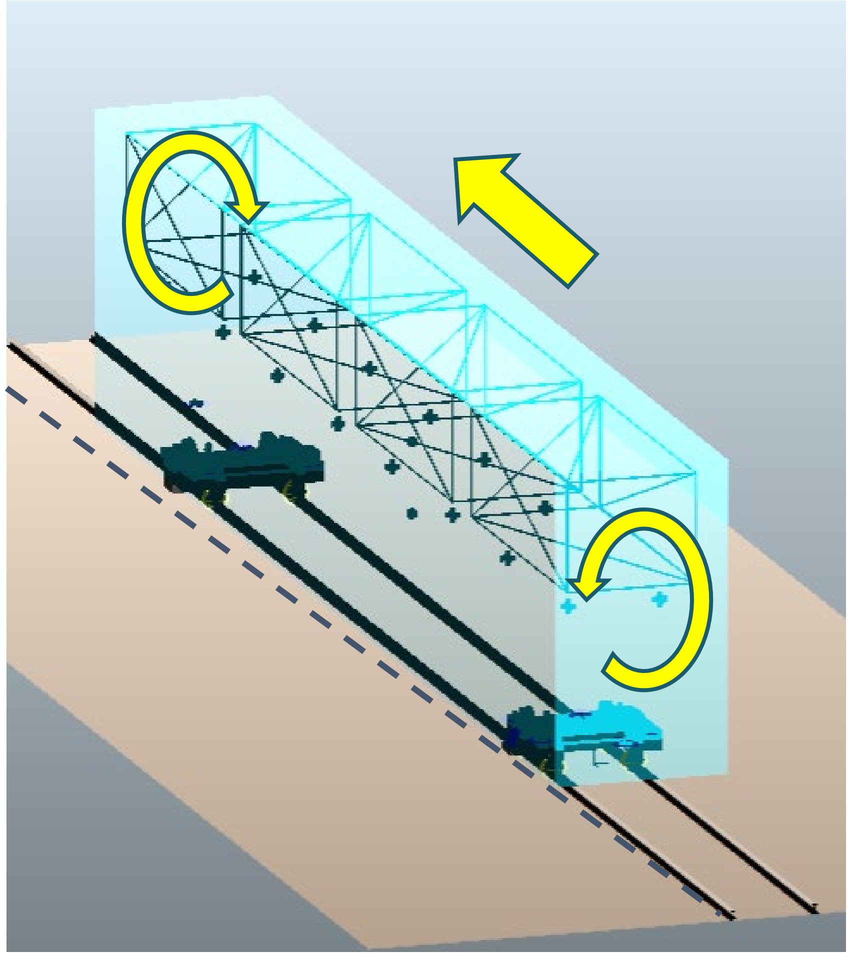
Chapter 11 Regimes Evaluated, cont'd.

- Dynamic Curving
  - 10-degree curve with 4 inches of superelevation
  - Alignment
    - Low-rail steady as the high-rail gauge widens to 57.5 inches.
  - Profile/Surface
    - Vertical perturbations that are staggered on each rail to excite the railcar in a roll mode of vibration
  - Speed
    - ±3 inches imbalance in 2-mph increments



Chapter 11 Regimes Evaluated, cont'd.

- Limiting Spiral
  - Testing of a railcar traveling through a spiral or transitioning from straight to curved track (entry and exit)
  - The twist rate of the spiral is 3 inches (76 mm) in 62 feet (18.9 m) over a minimum spiral length of 89 feet (27.1 m)
  - Speed corresponding to 3 inches underbalance, balance, and 3 inches overbalance



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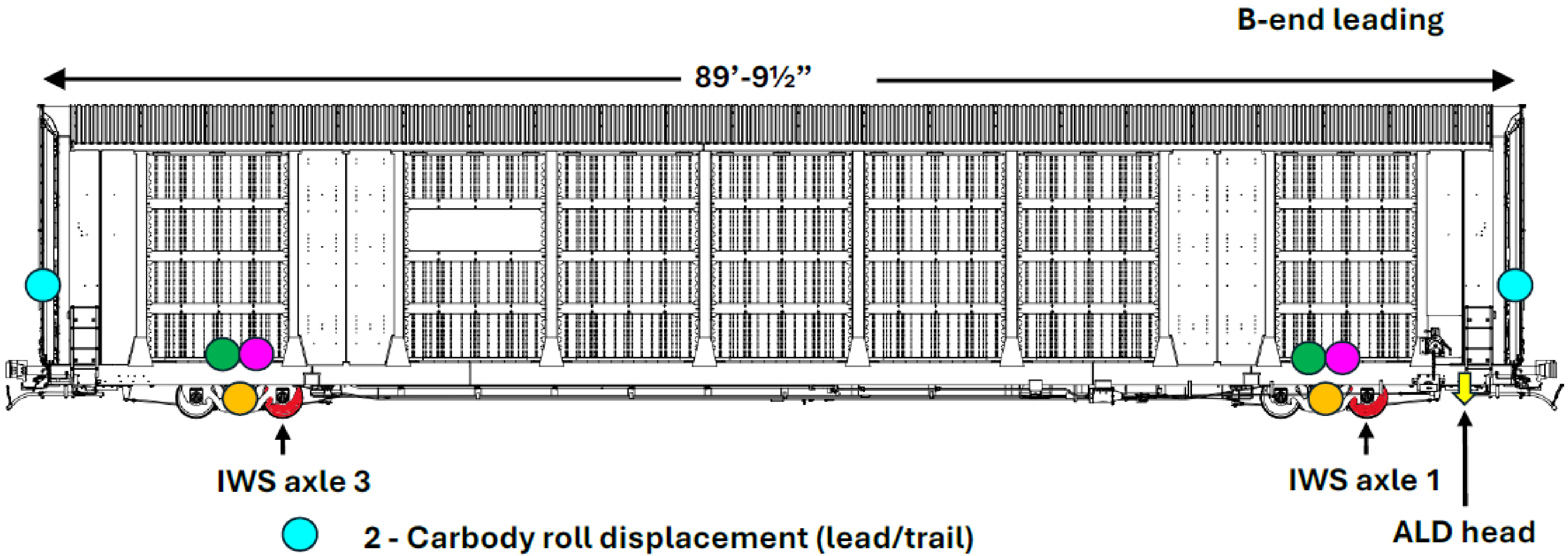
Measurements/Instrumentation



- 🔵 2 - Carbody roll displacement (lead/trail)
- 🟢 2 - Carbody lateral acceleration (lead/trail centered over each truck)
- 🟣 2 - Carbody vertical acceleration (lead/trail centered over each truck)
- 🟡 4 - Vertical spring nest displacement (lead/trail & left side/right side)
- 🔴 2 – Instrumented Wheelset (axle 1 & axle 3 position)

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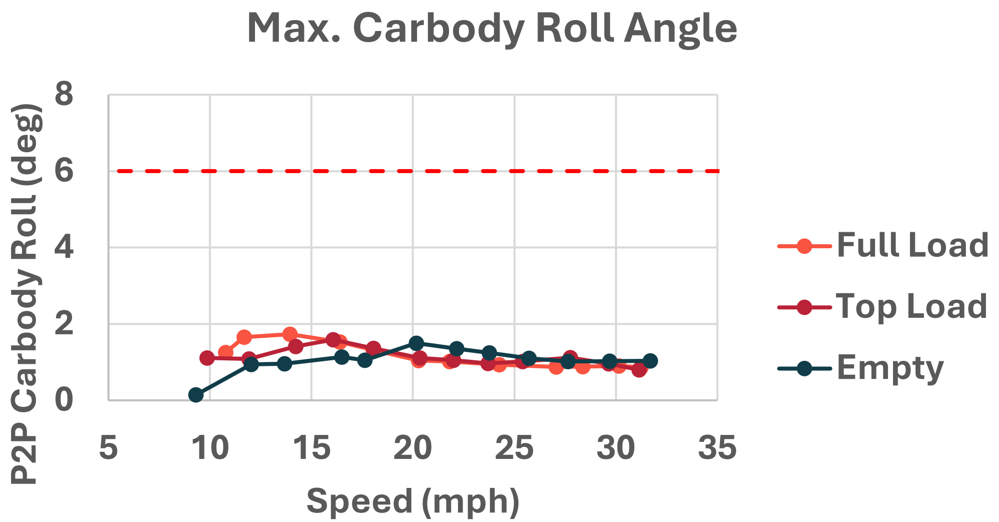
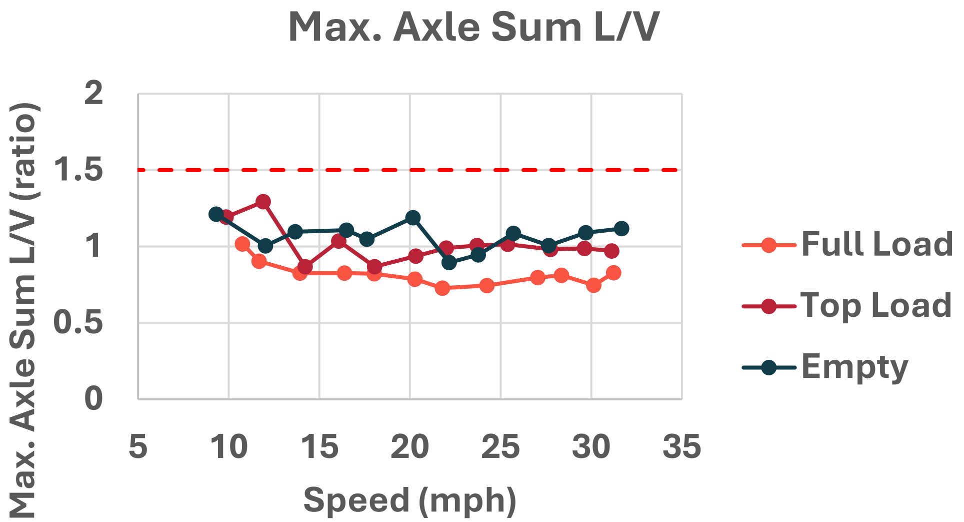
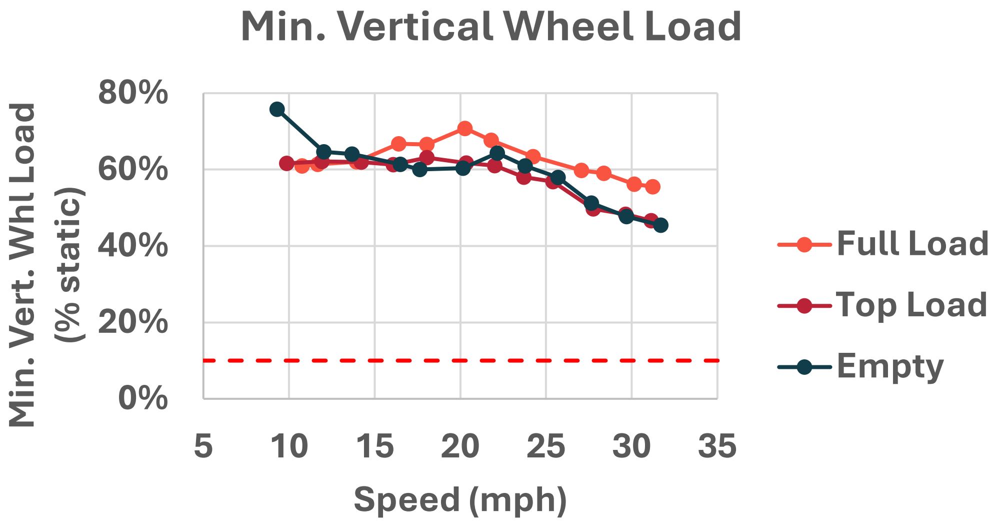
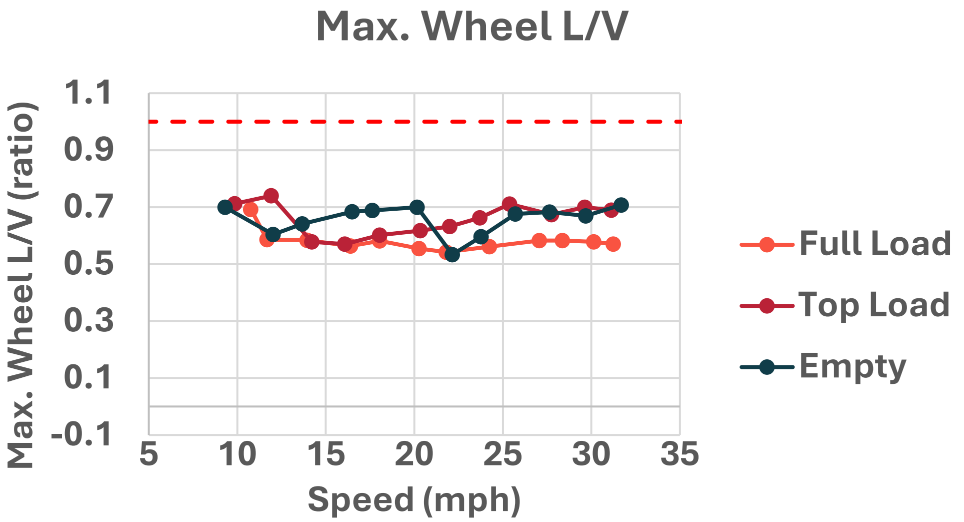
Test Results

Dynamic Curve – Clockwise (CW)









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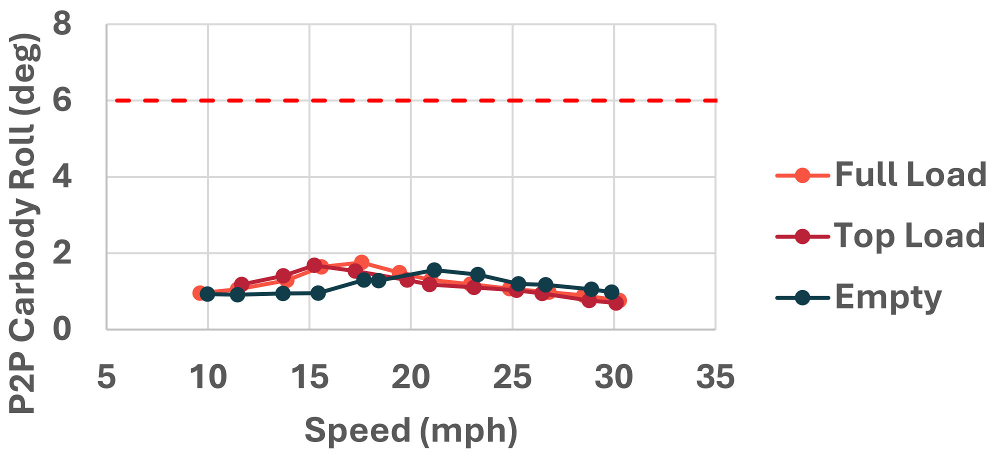
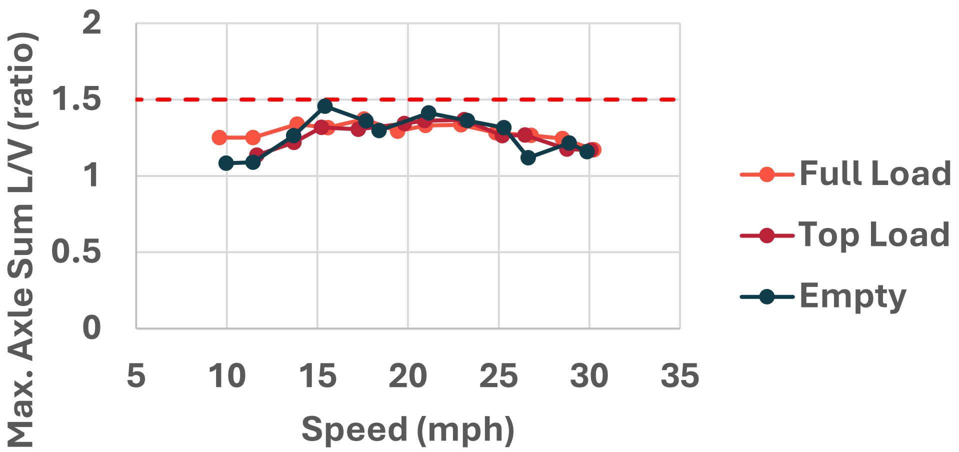
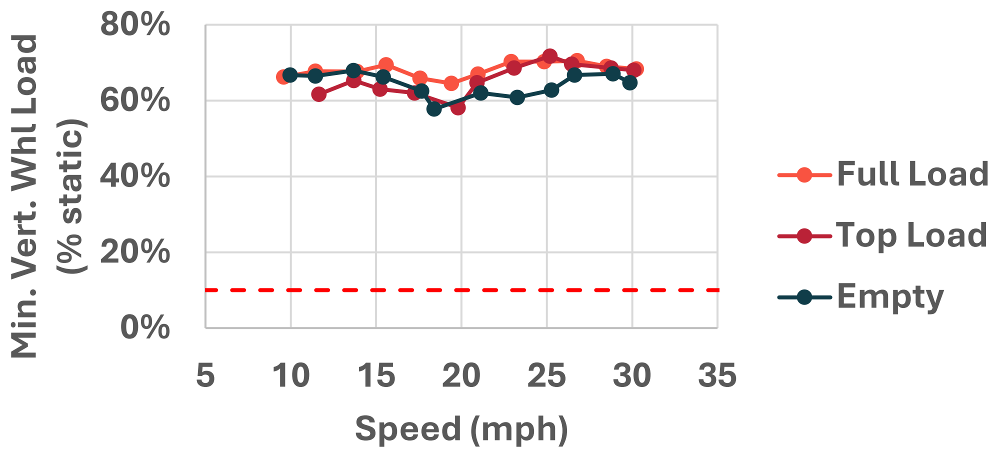
Dynamic Curve – Counterclockwise (CCW)



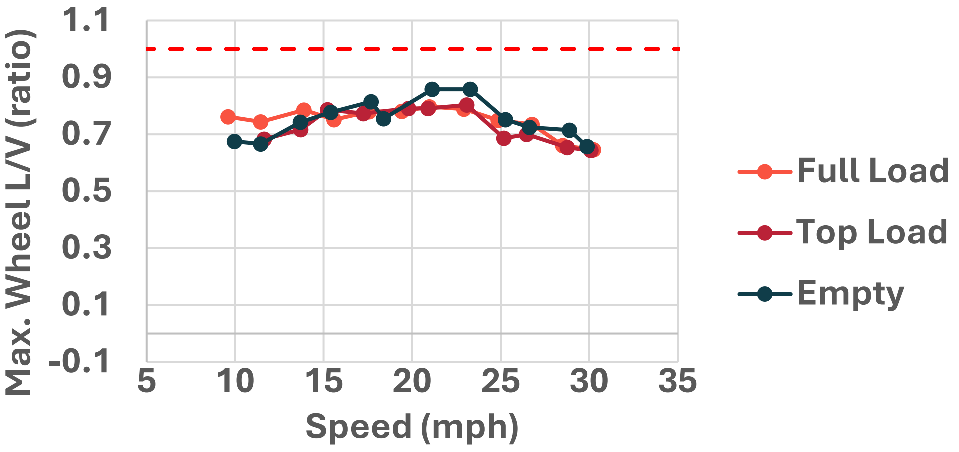
Max. Carbody Roll Angle



Max. Axle Sum L/V



Min. Vertical Wheel Load



Max. Wheel L/V

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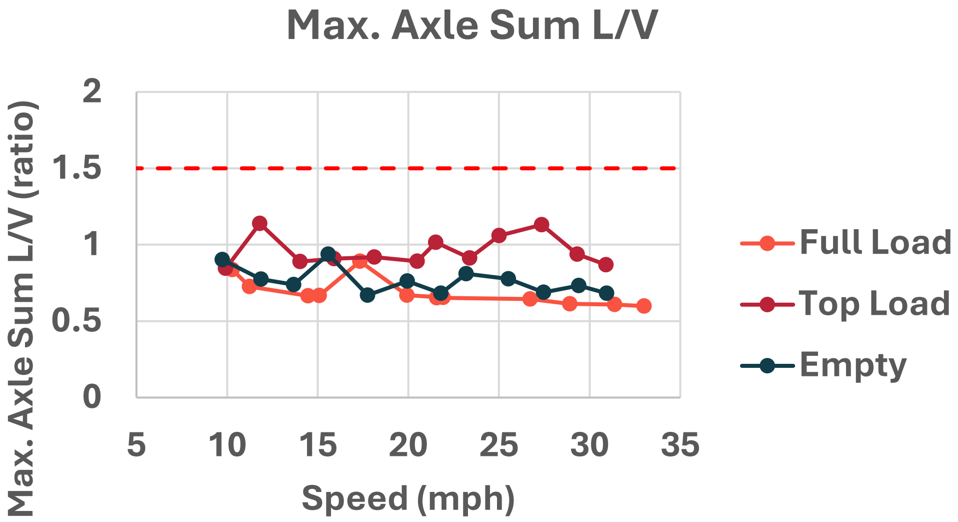
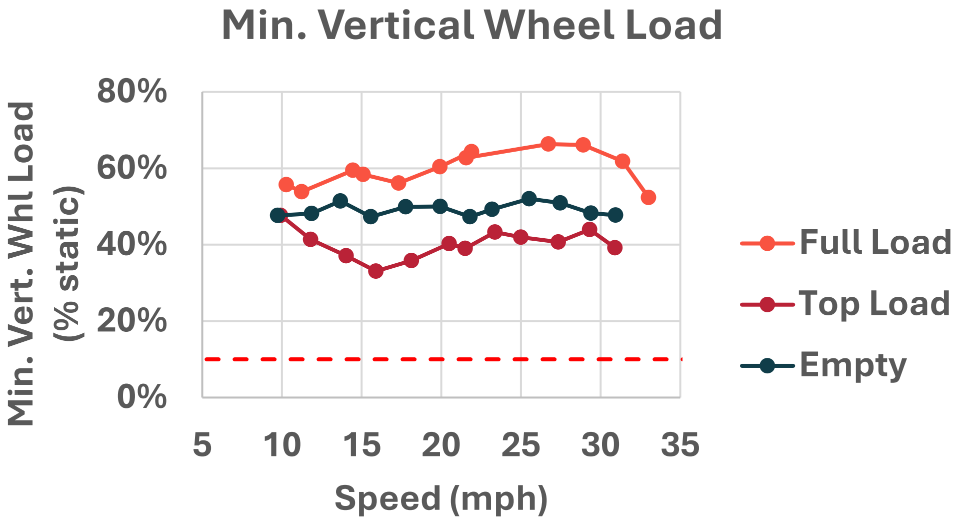
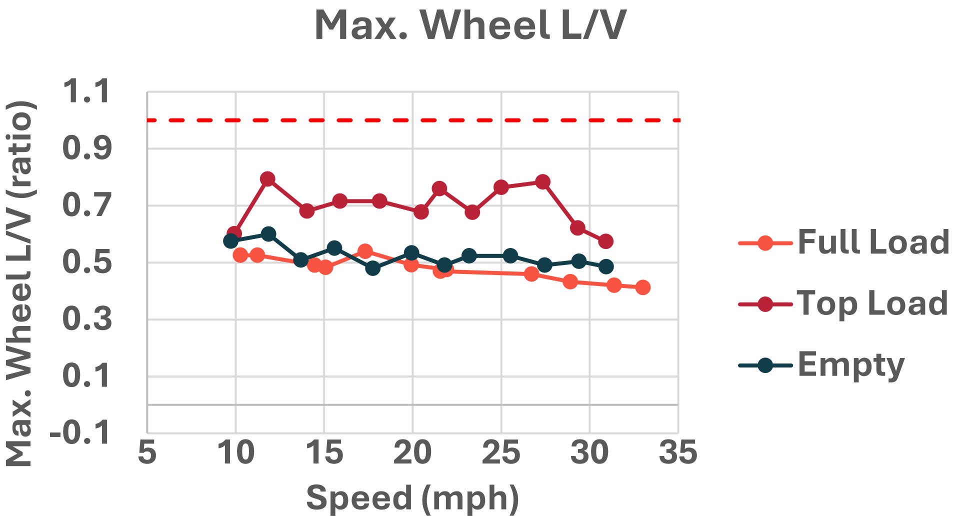
Limiting Spiral – Clockwise (Entry Spiral)


Max. Axle Sum L/V


Min. Vertical Wheel Load


Max. Wheel L/V

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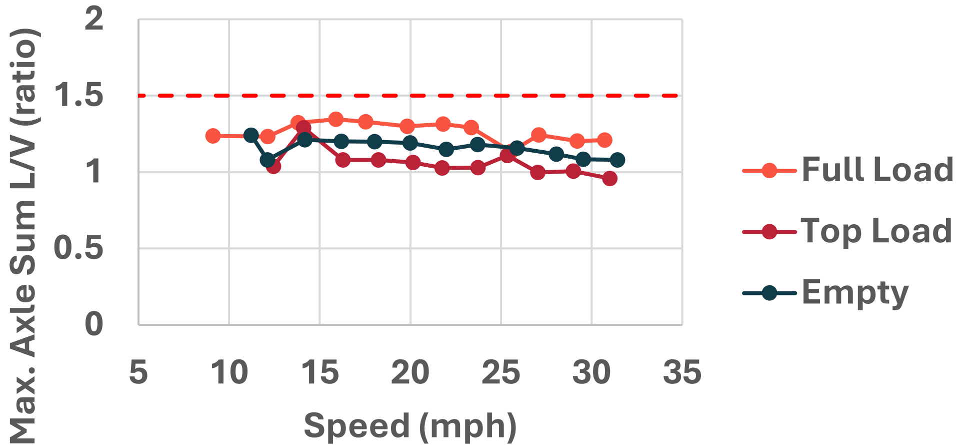
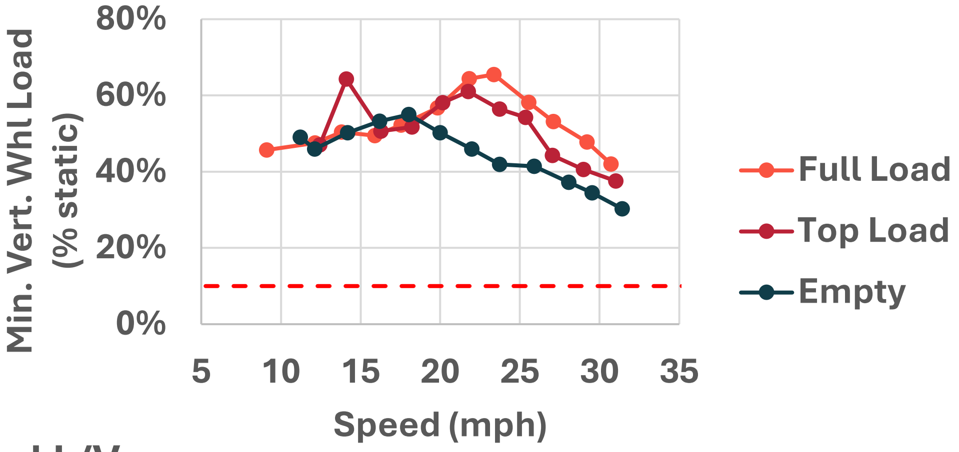
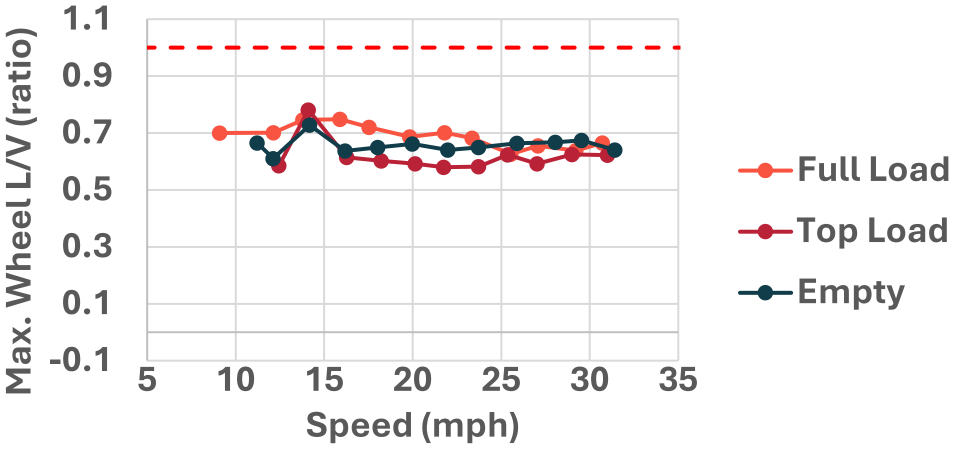
Limiting Spiral – Counterclockwise (Exit Spiral)



Max. Axle Sum L/V



Min. Vertical Wheel Load



Max. Wheel L/V

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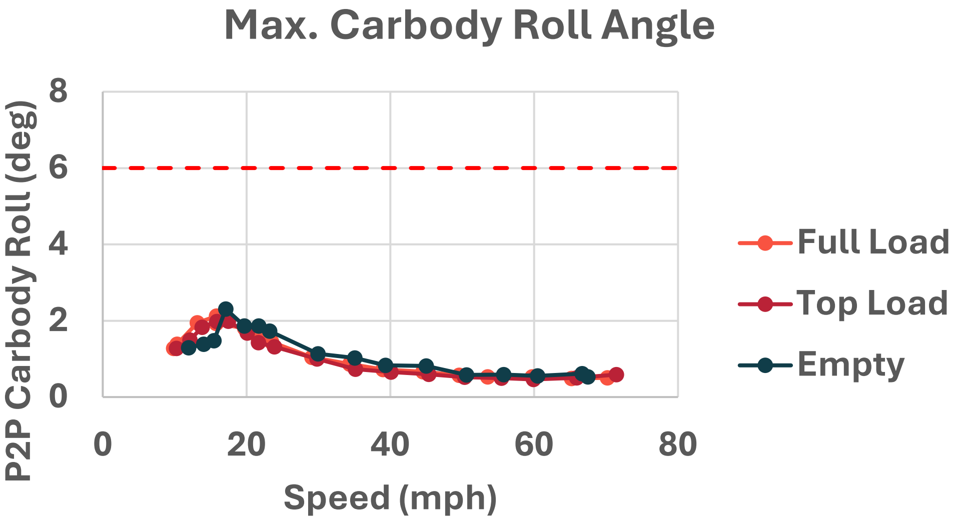
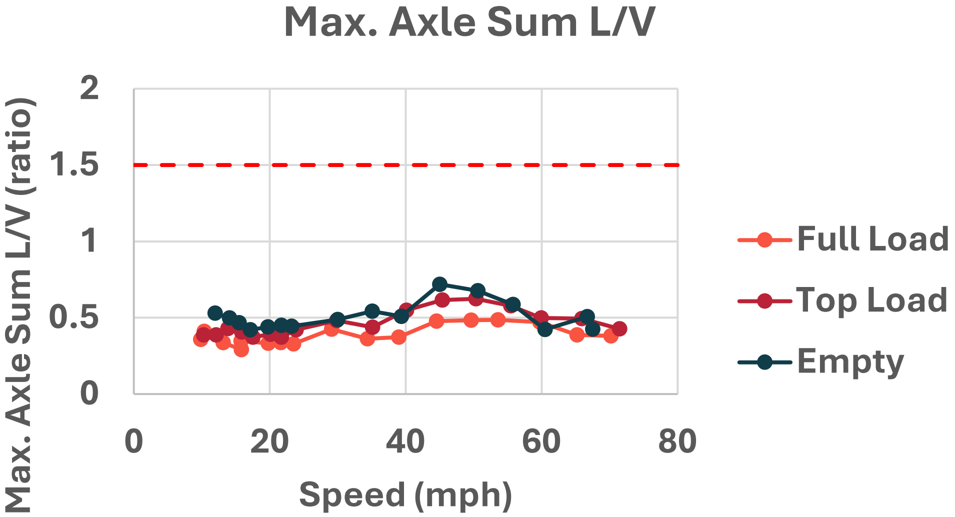
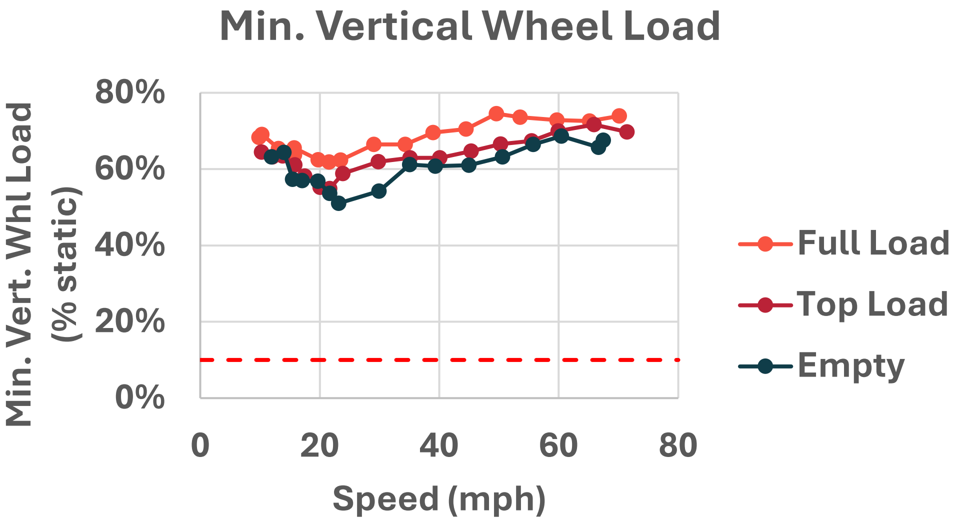
Twist & Roll







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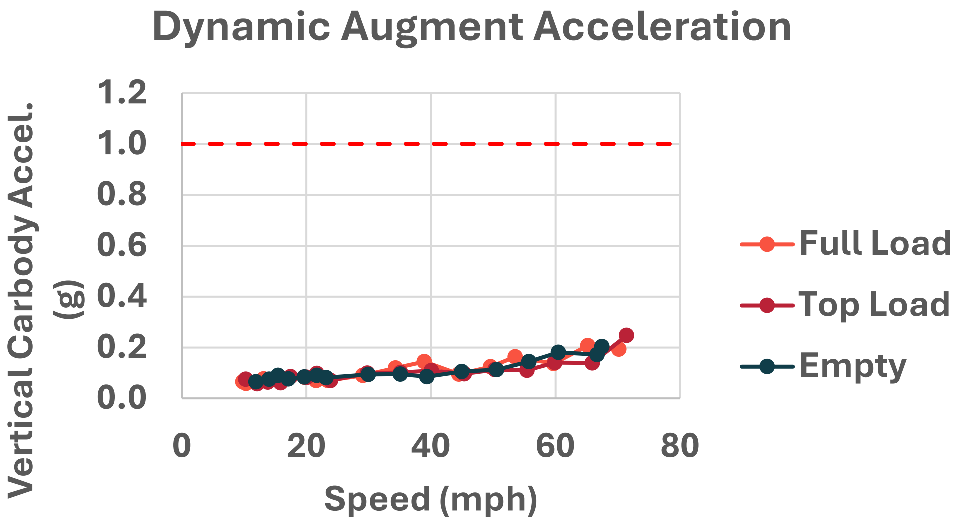
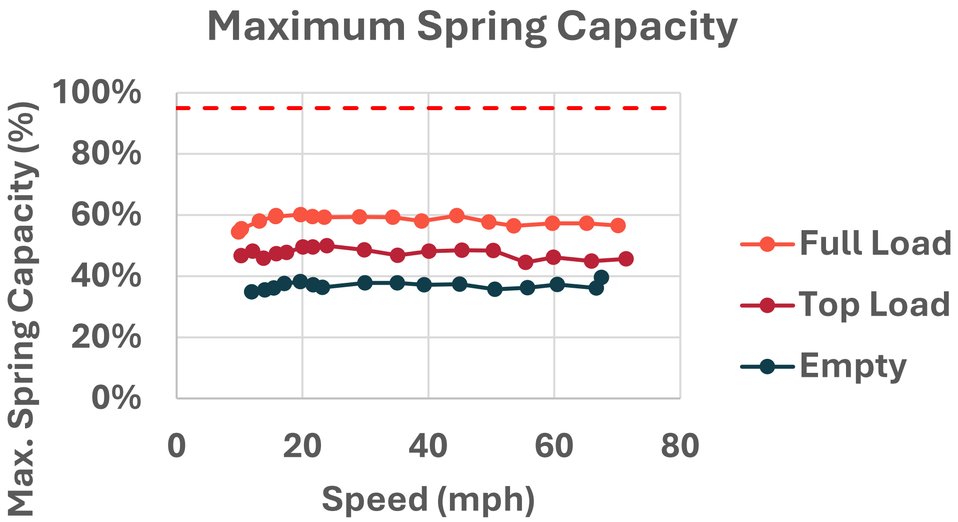
Twist & Roll, cont'd.





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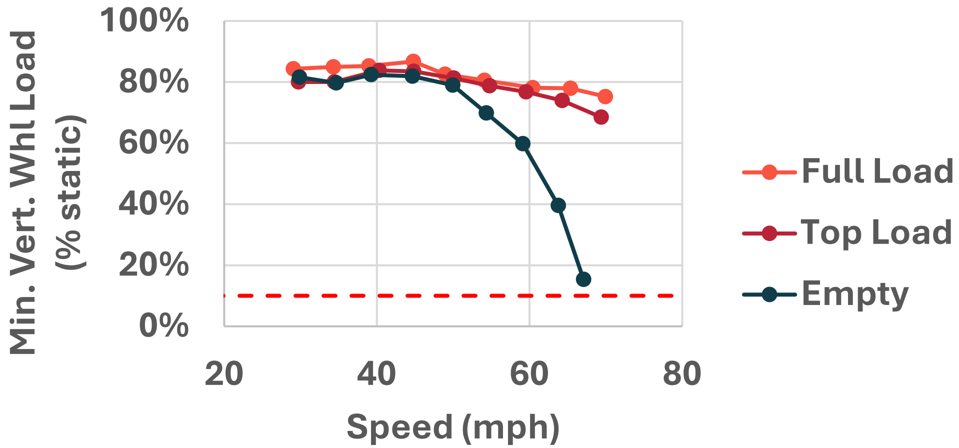
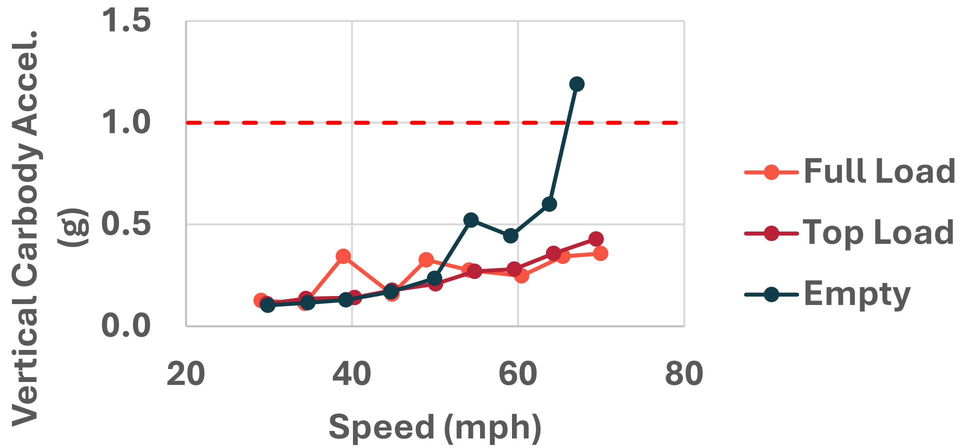
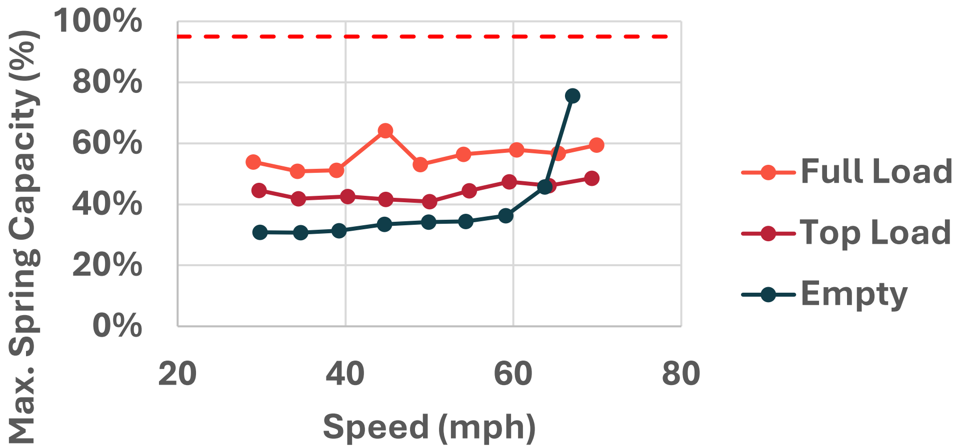
Pitch & Bounce



Min. Vertical Wheel Load



Dynamic Augment Acceleration



Maximum Spring Capacity

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Key Findings

- Autorack top-only loading scenarios have raised industry concerns. Modeling investigations for combined CG loading scenarios are all below the 98-inch AAR limit
- The task force concluded that operating bilevel autoracks with cars only on the upper deck does not pose additional risk, and all tested load scenarios met Chapter 11 requirements up to 65 mph

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Key Findings, cont’d.

- Recommendations for updating the NUCARS® model based on recent test results and sharing it with the AAR Research Committee
- Additional guidance suggests monitoring center-of-gravity limits, noting that future loading patterns exceeding 90 inches should undergo further research

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- **TTX**
- **Ford Motor Company**

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Back to Mechanical Agenda

Brake Systems Research

Yi Wang

Principal Investigator

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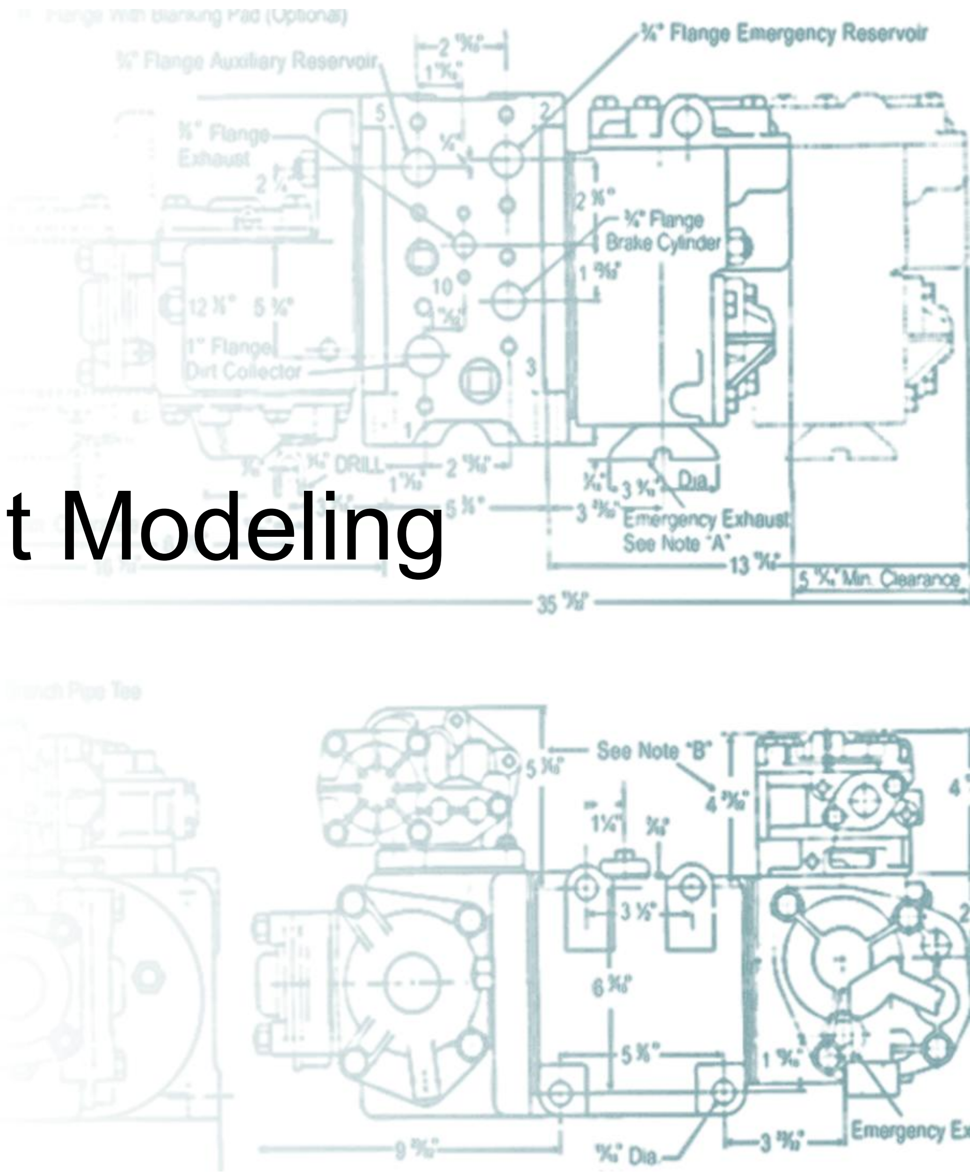
Overview

- **Introduction**
- Ongoing Topics
- Highlight: Secondary Securement Modeling
- Summary



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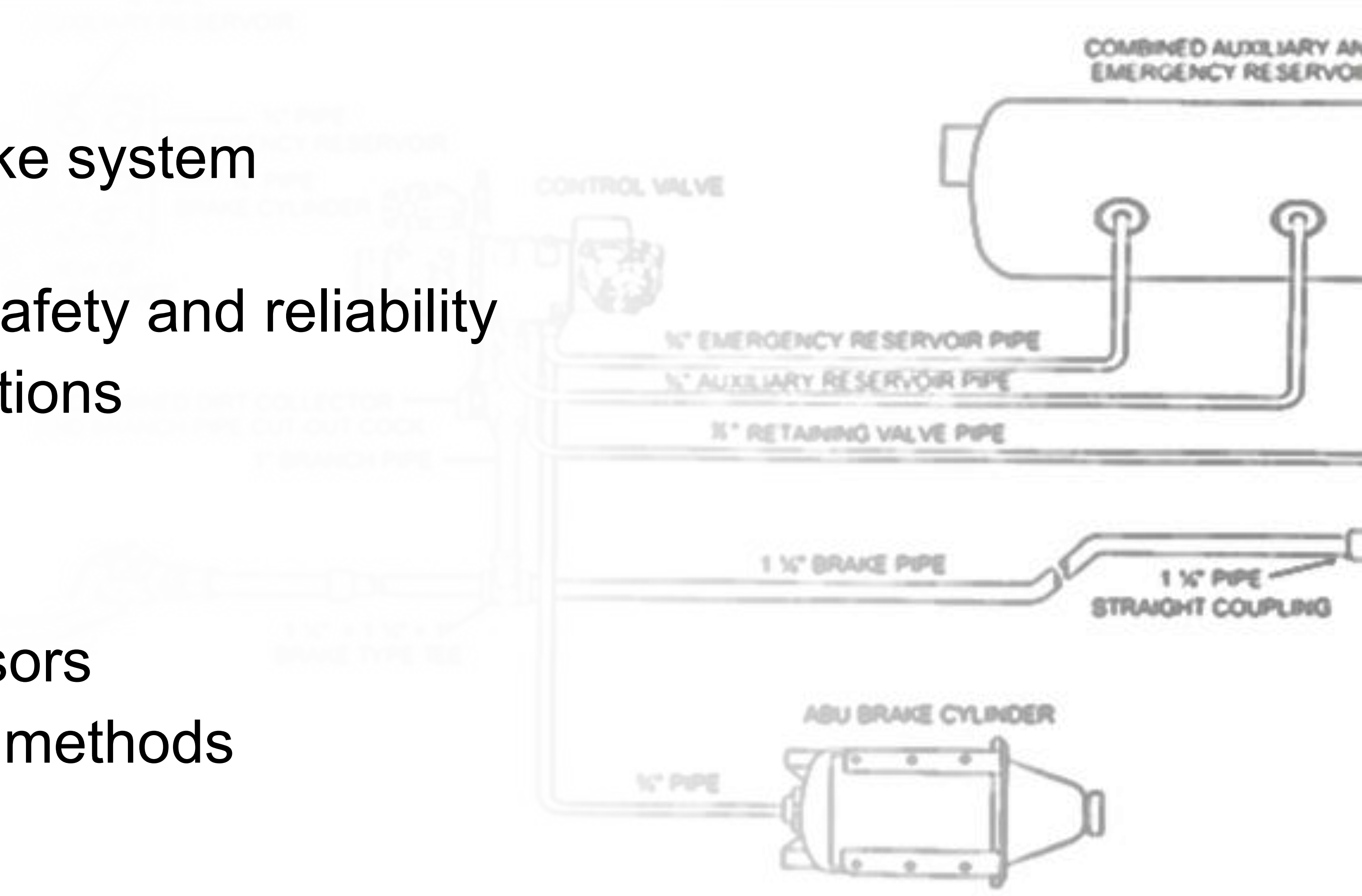
Introduction: Brake Systems Research



- **Objectives**
  - Detect and address brake system performance issues
  - Improve brake system safety and reliability
  - Reduce service interruptions
- **Approaches**
  - Improve understanding
  - Work with industry advisors
  - Explore novel tools and methods

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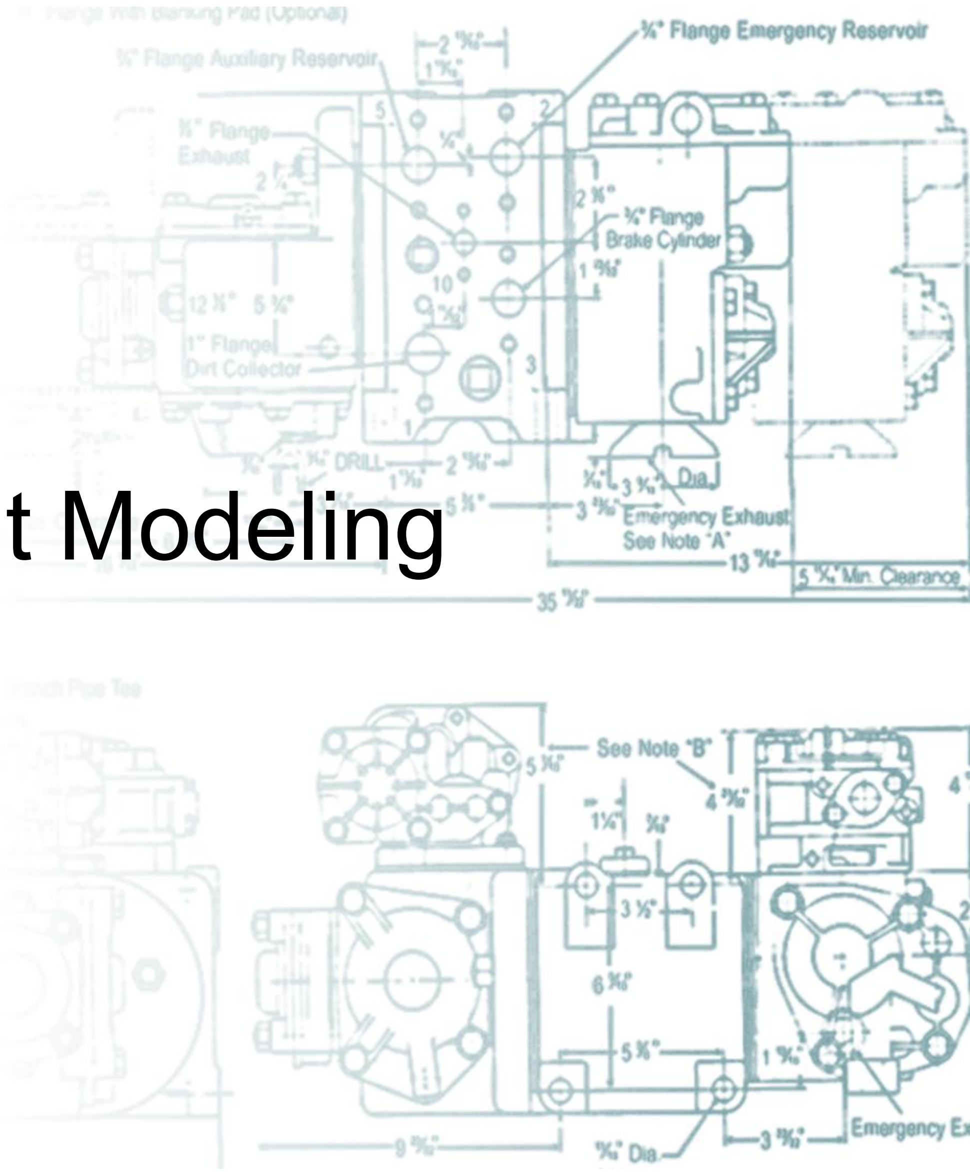
Outline

- Introduction
- **Ongoing Topics**
- Highlight: Secondary Securement Modeling
- Summary



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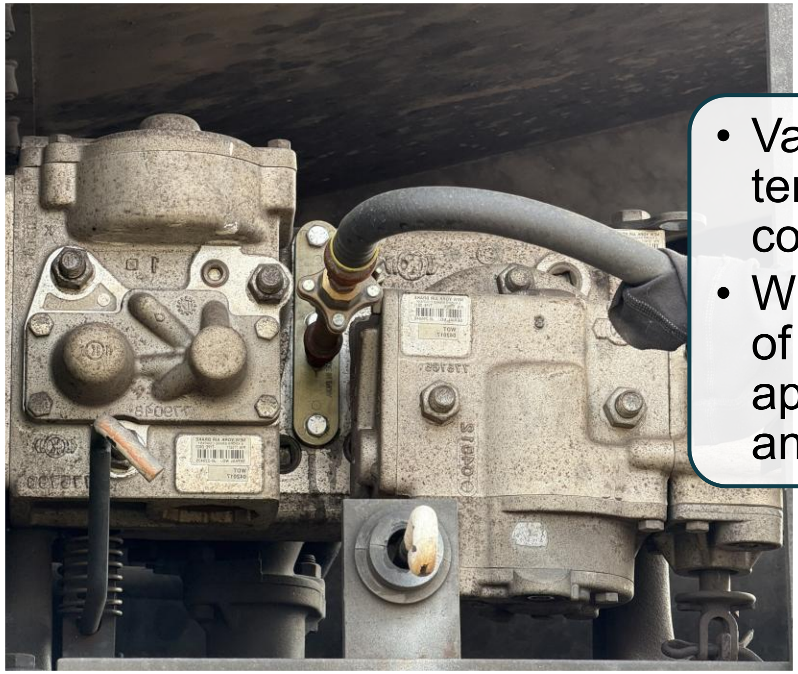
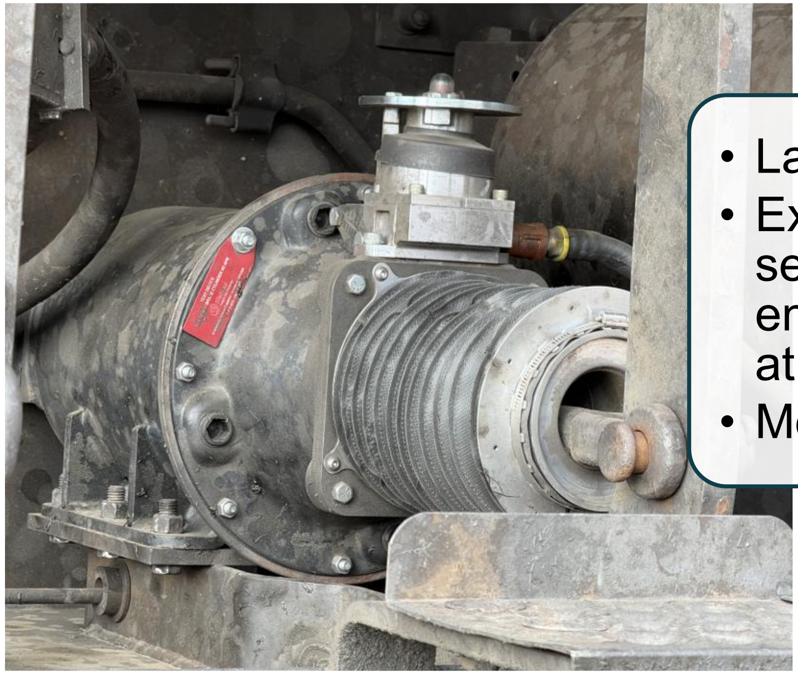
Ongoing Topics

Control valve testing



- Various temperature conditions
- Wide range of brake applications and releases

Automatic secondary securement devices



- Lab cycling
- Exposure to service environment at FAST®
- Modeling

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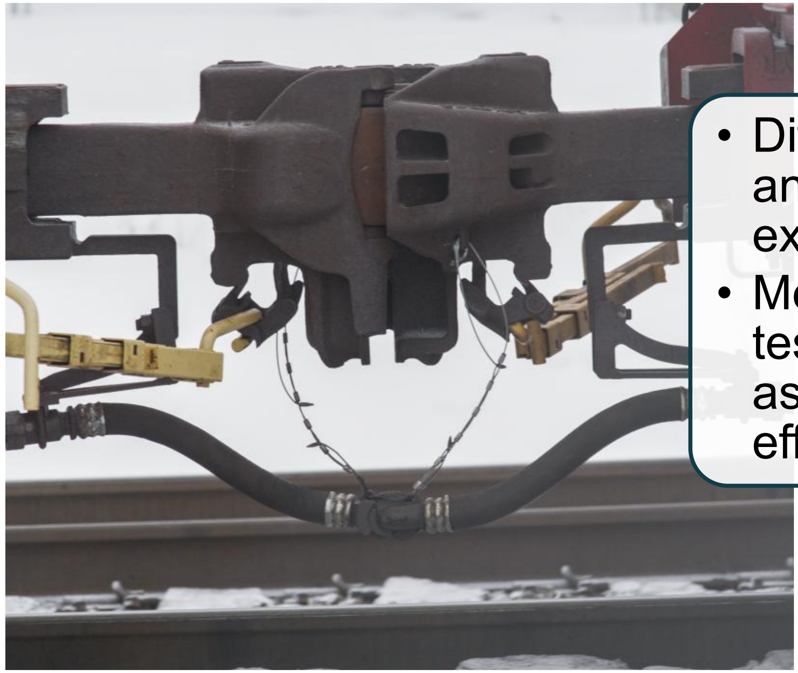
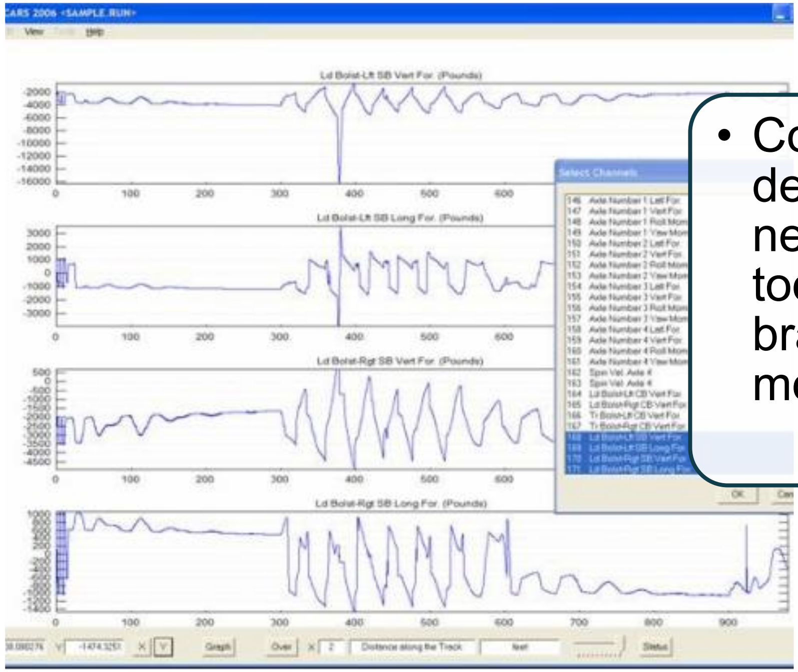
Ongoing Topics

End hose gasket



- Different light and oxygen exposures
- Mechanical testing assess effects

Model development



- Continue developing new/better tools for brake system modeling

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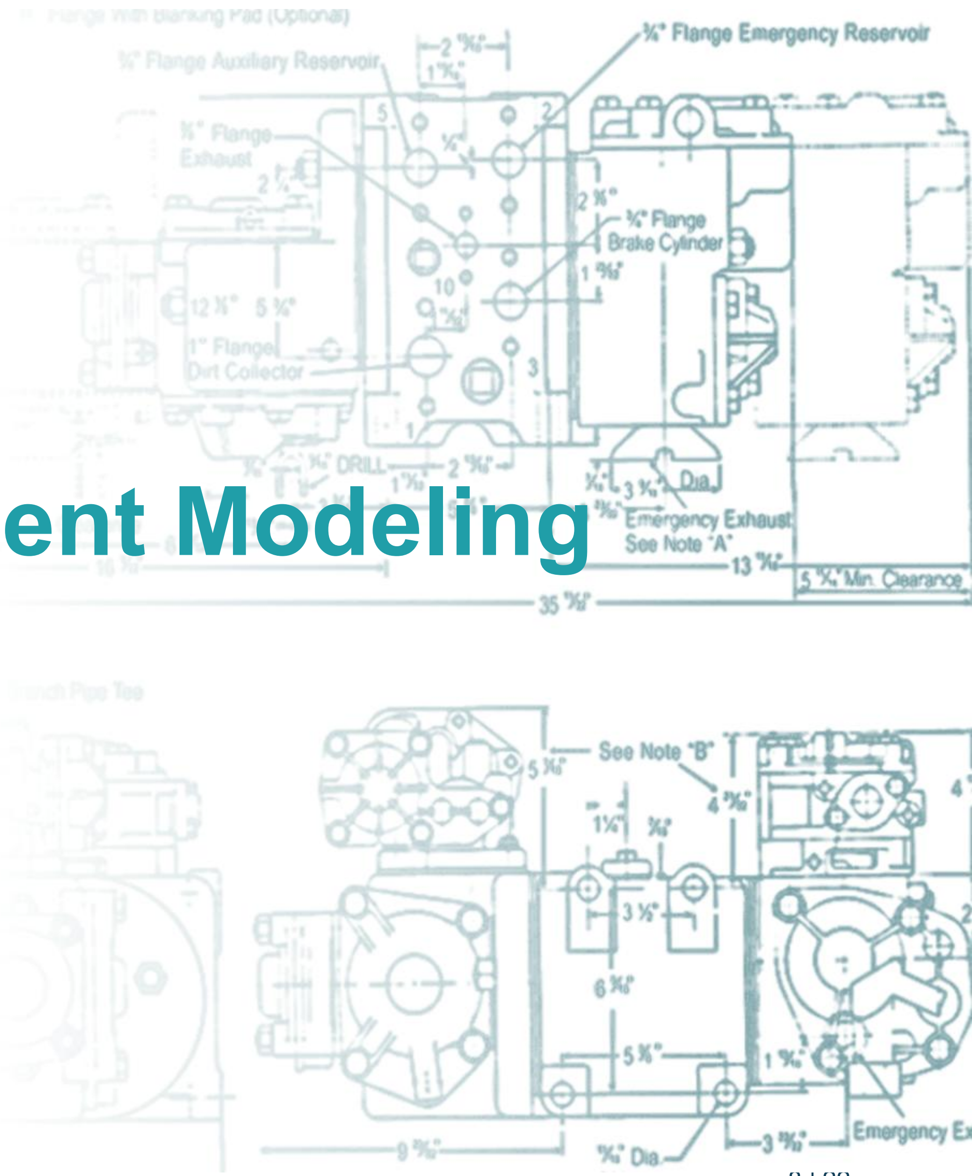
Outline

- Introduction
- Ongoing Topics
- **Highlight: Secondary Securement Modeling**
- Summary



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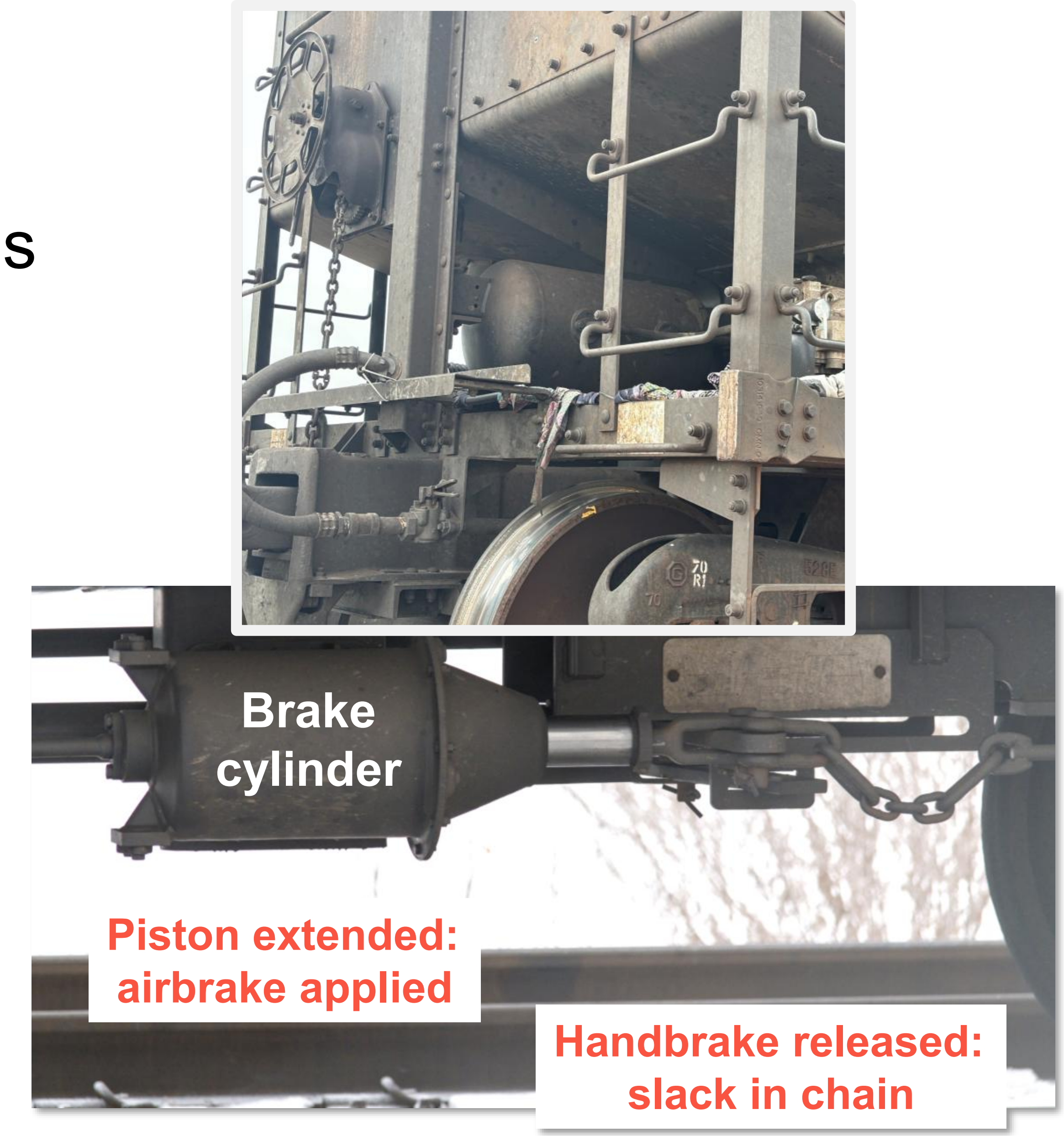
Train Securement

- **Securing a movement:**
  - When the train or equipment needs to be left unattended
- **Typical steps**
  - Stop movement with locomotive brakes or airbrakes
  - Apply handbrake
  - Release other brakes and test handbrake effectiveness



Piston extended: airbrake applied

Handbrake released: slack in chain

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Secondary Securement Modeling

- **Relies on airbrake to develop brake force**
- **Retains brake force mechanically**
- **Not yet adopted in North America – no industry standards**

Table: Snapshot of Transport Canada handbrake rule for after an emergency application

Total Tons:	Minimum Required Number of Handbrakes							
	Heavy Grade (%)				Mountain Grade (%)			
	1.01-1.2	1.21-1.4	1.41-1.6	1.61-1.8	1.81-2.0	2.01-2.2	2.21-2.4	> 2.4
…								
10,001 – 12,000	28	35	40	46	50	57	62	68
12,001 – 14,000	34	40	47	53	59	66	73	79
…								
26,001 – 28,000	70	83	95	107	119	134	147	159
28,001 – 30,000	75	89	102	116	128	143	157	170

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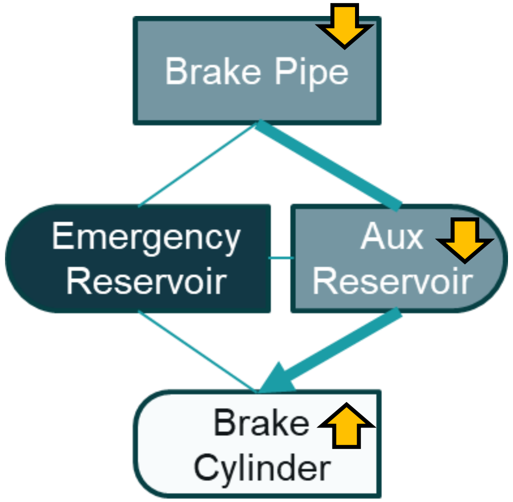
Brake System Background

- **AAR brakes system**
  - Brake pipe (BP) pressure is the control signal
  - Hand brake operates independently



Brake Pipe

Emergency Reservoir

Aux Reservoir

Brake Cylinder

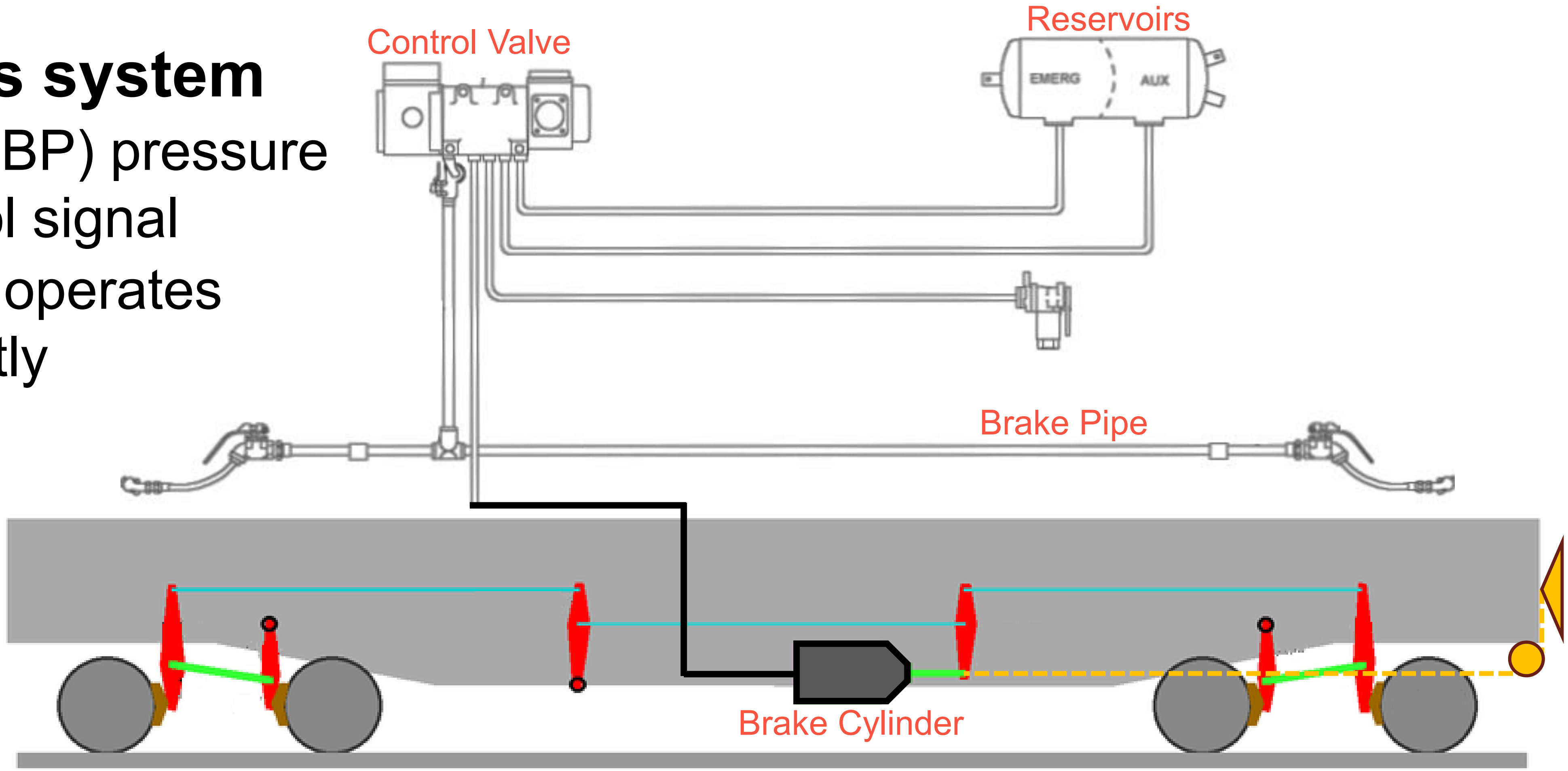


Figure adapted from: AAR Standard S-400 and Harpwolf at English Wikipedia, CC BY-SA 3.0, via Wikimedia Commons

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Brake Application and Release on a Train

- **Brake application depends on local BP pressure drop at the car control valve and its rate**
  - Emergency propagation rate is much faster than service rate
  - Distance from locomotives ∝ car brake reaction time
- **Limited ability to vent (application) or charge (release) BP locally to accelerate the action**
  - Allows more uniform brake application and release
  - During charging, BP pressure increase slows down significantly after initial accelerated release stage

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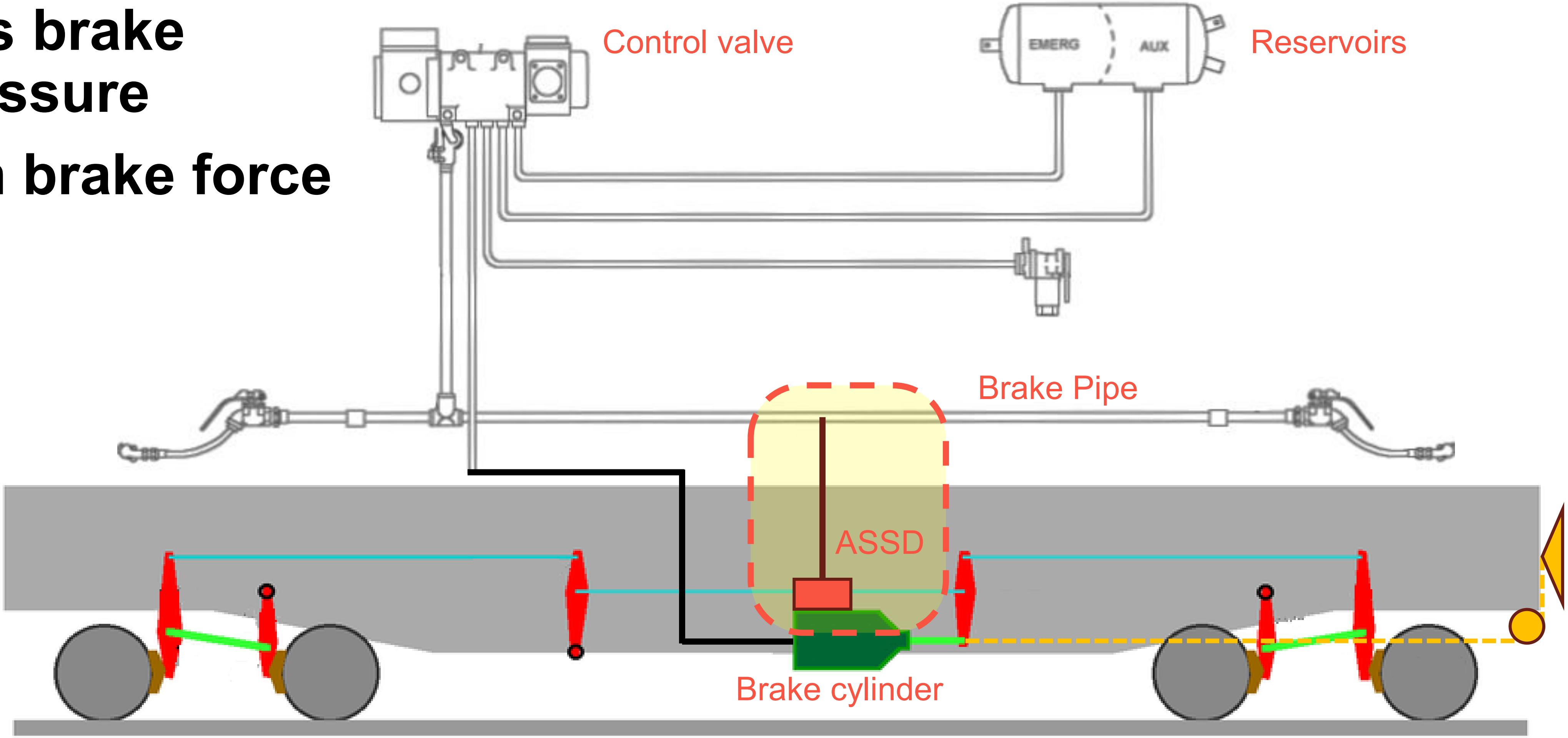
Automatic Secondary Securement Device (ASSD)

- **Monitors brake pipe pressure**
- **Locks in brake force**



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Questions Regarding ASSD Performance

- **When should the piston be locked?**
  - Locking threshold pressure, LTP [psig]
  - Locking delay [s]
- **How much force should be retained?**
  - Retained brake force, RBF [%]
- **When should the piston be unlocked?**
  - Unlocking threshold pressure, UTP [psig]

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TOES^{TM} Modeling

- **Simulations were performed to assess the effect of the selection of ASSD performance metrics**
- **Individual car performance were sampled from normal distributions representing the target performance**

Metric	Target (mean)	Tolerance (3σ)
Locking threshold	5 psi and 10 psi	$\pm$2 psi
Force retained	92.5% and 97.5%*	$\pm$2.5%
Unlocking threshold	40 psi and 60 psi	$\pm$2 psi

* The target minimum values are 90% and 95%

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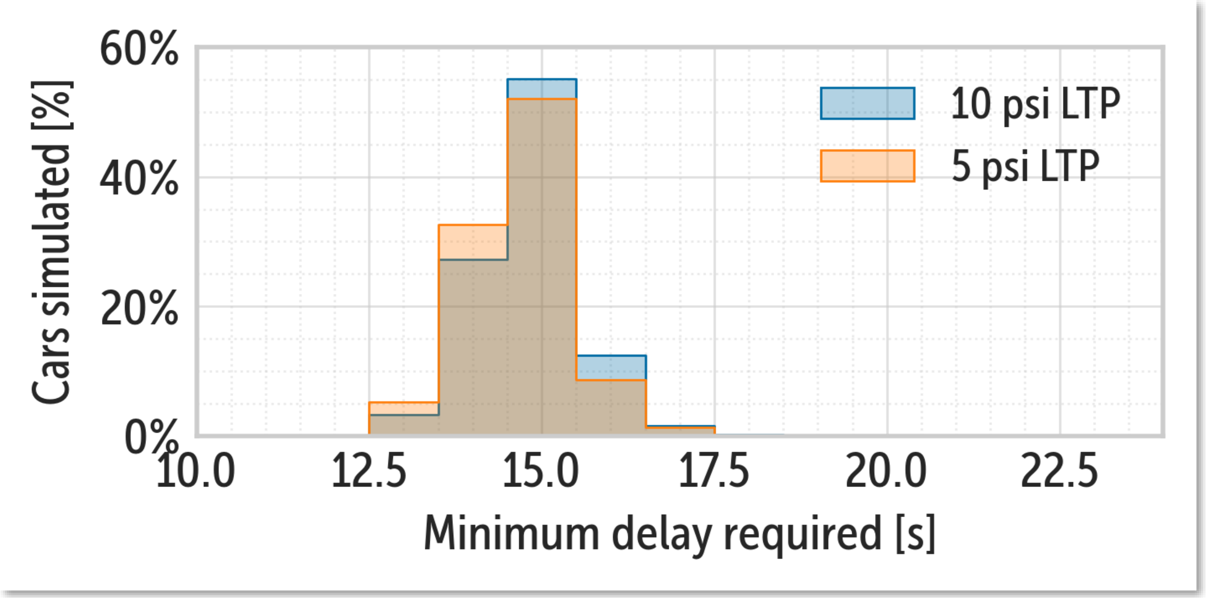
Piston Locking

- **Effect of locking threshold pressure not significant due to fast emergency venting**
- **Locking delay**
  - Allows brake cylinder pressure to reach maximum before locking
  - Especially important at the emergency BP reduction rate

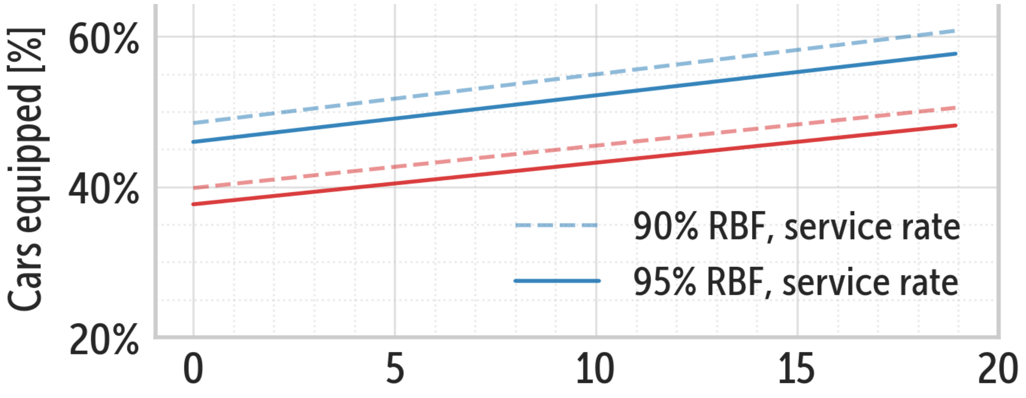
Second between BPP dropping below LTP and BCP reaching maximum



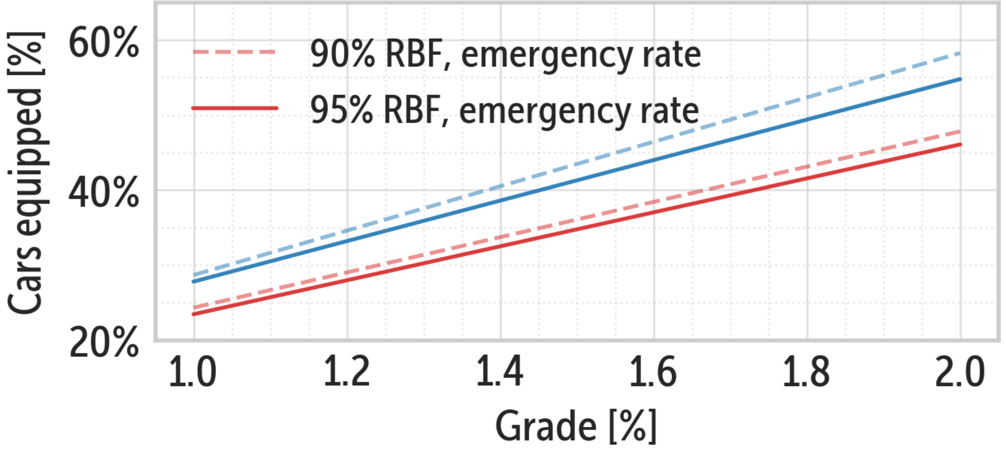
Force Retention

- **Short answer: The higher the better**
- **Caveats:**
  - Plots based on ideal conditions otherwise
  - Maximum performance is dictated by the pneumatic system
  - Leakage and airbrake handling both affect securement performance

Minimum percentage of cars equipped required for securement



(a) Average numbers required on 2% grade.



(b) Brakes applied with a 15 psi gradient.

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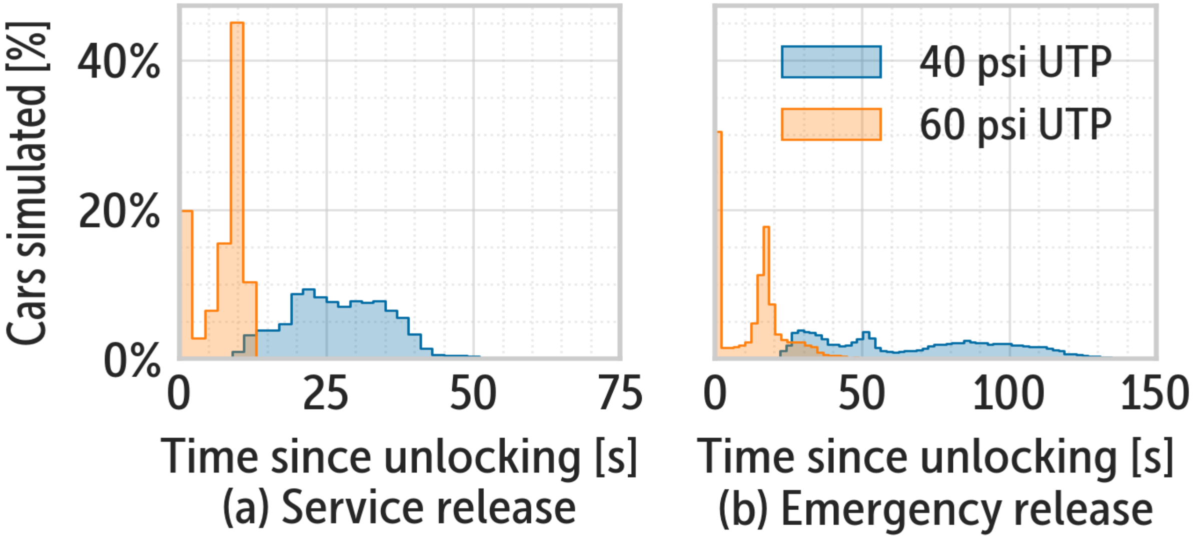
Piston Unlocking

- **Lower unlocking threshold pressure (UTP) does not change car behavior during brake release**
- **Higher UTP can result in less uniform brake releases and induce different in-train forces**



Example plot for securement on a 1% grade:
A zero value means that car is immediately overcome by grade force after piston unlocking

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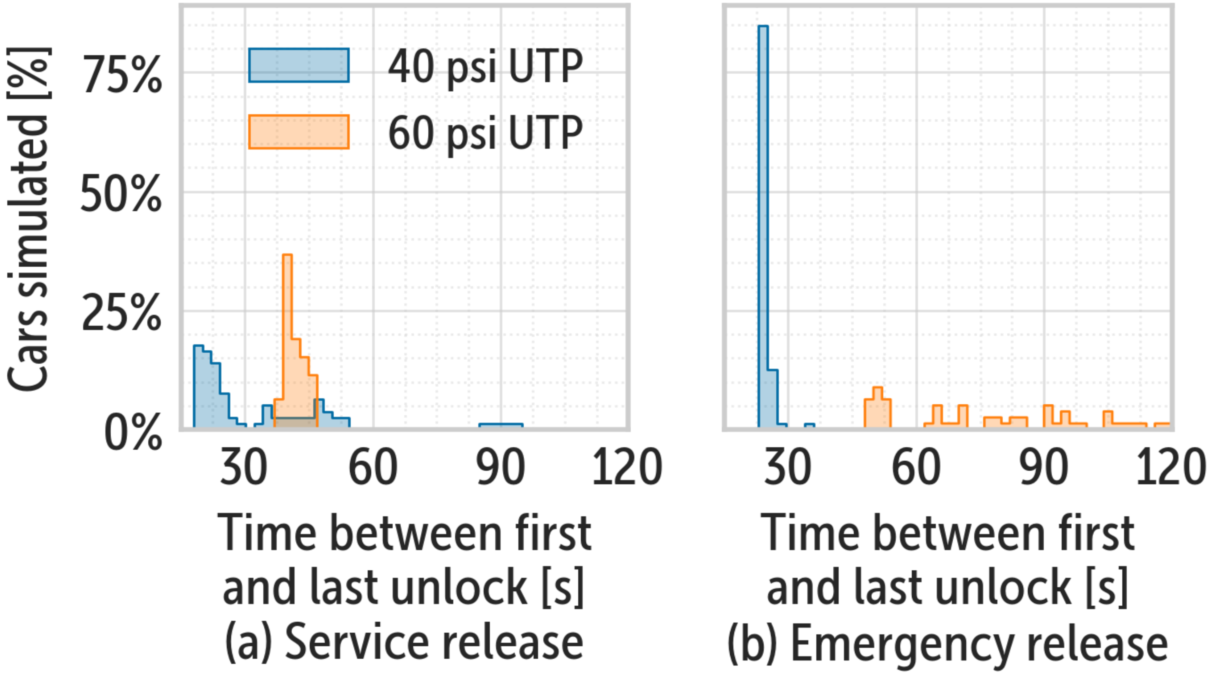
Piston Unlocking

- **High UTP can also result in significant delay between car brake releases on the same train**
  - Can result in cars moving with piston still locked on a grade under high BP leakage
- **UTP decision may need to involve other stakeholders**



Example plot for securement on a 1% grade: Higher value means longer delay between the first car unlocking and the last car unlocking on the same train.

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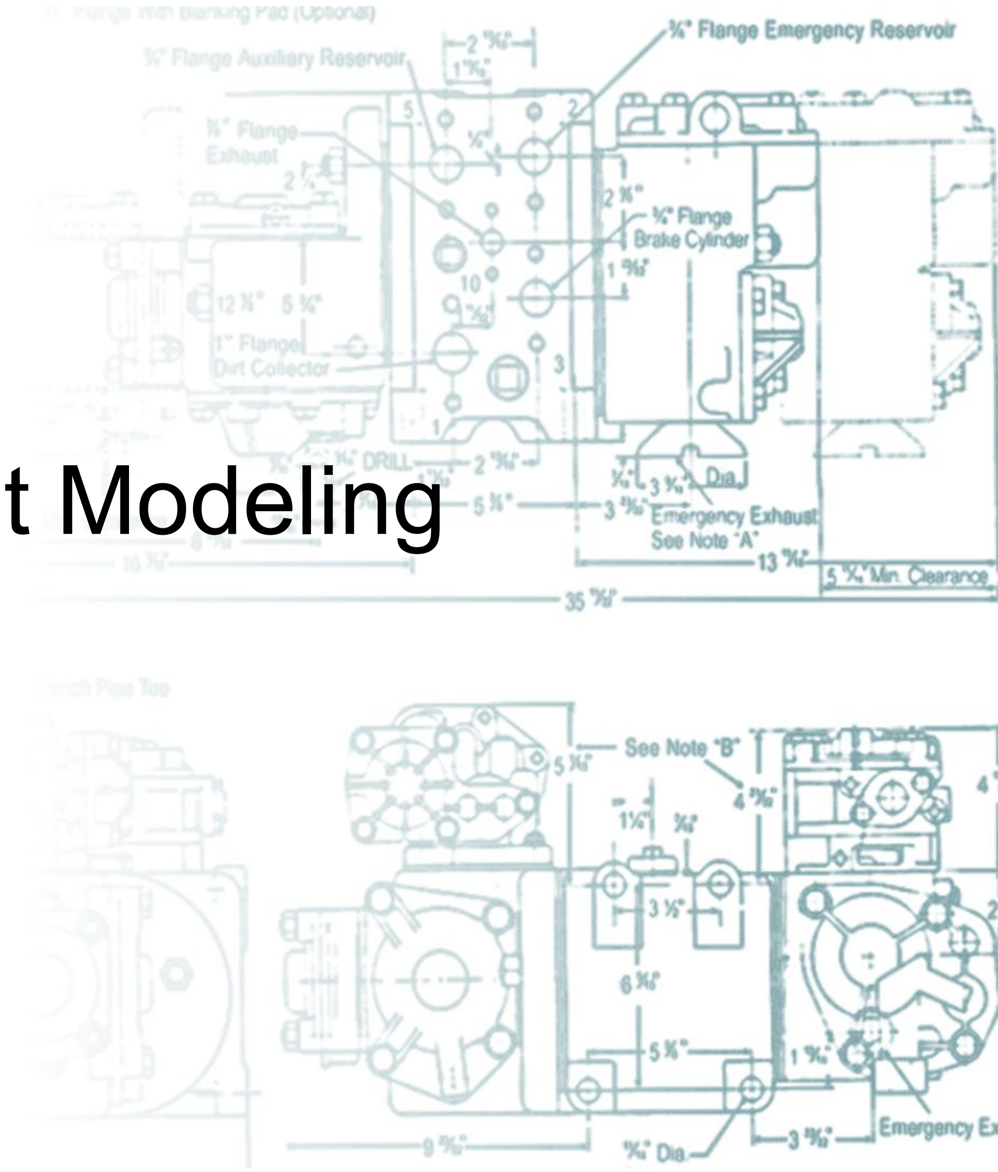
Presentation Outline

- Introduction
- Ongoing Topics
- Highlight: Secondary Securement Modeling
- **Summary**



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Summary

- **Research is ongoing:**
  - Control valve performance testing
  - ASSD testing in the lab and at FAST®
  - Environmental effects on end hose gaskets
  - Developing modeling tools
- **ASSD performance target selection can have impacts on train operations downstream and may require additional stakeholder input and analysis**

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- **AAR Brake Systems Committee**
- **AAR Rolling Stock TAG**
- **Railroad Supply Community**
- **Matt DeGeorge and other members of MxV Rail's VTI&I and Operations Teams**

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Railcar Axle Inspection Technologies

Anish Poudel, Ph.D.
Scientist

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Overview

- **Cracked Axles – Why They Matter**
- **Journal Fillet Radius Cracks**
- **Microstructural Evaluation**
- **AAR-Approved Inspection**
- **Future Inspection Technology: Wheel Shops**
- **Eddy Current Testing**
  - Laboratory demonstration
  - Future work
- **Acknowledgements**

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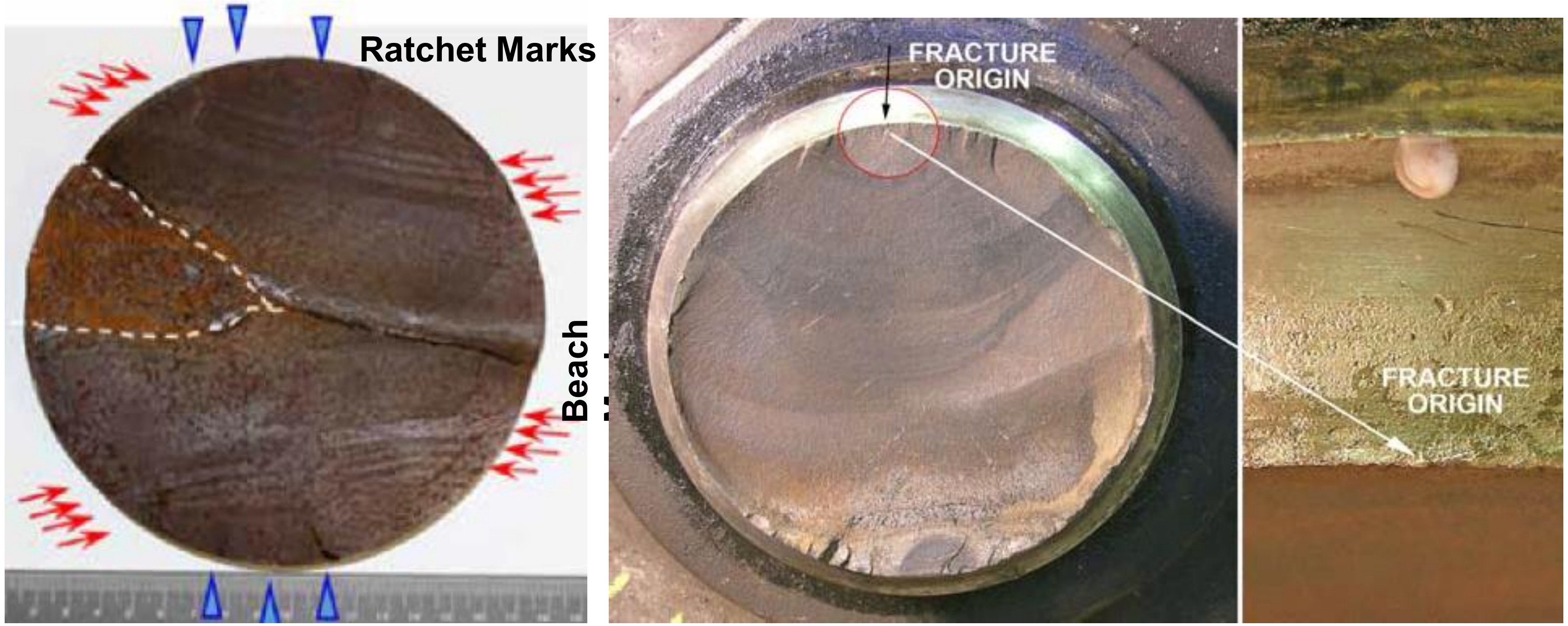
Cracked Axles – Why They Matter

- **In-service axle failures are very rare**
  - Common causes include fatigue, surface damage, corrosion pits, ductile failure due to overheating, and manufacturing-related anomalies

Axle Journal Fillet Radius Failures



Axle Body Failure

Source: Railway Investigation Reports, Transportation Safety Board of Canada

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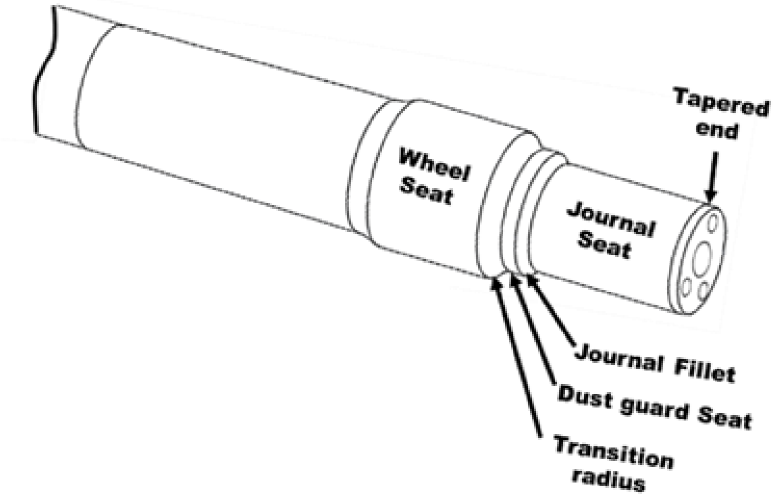
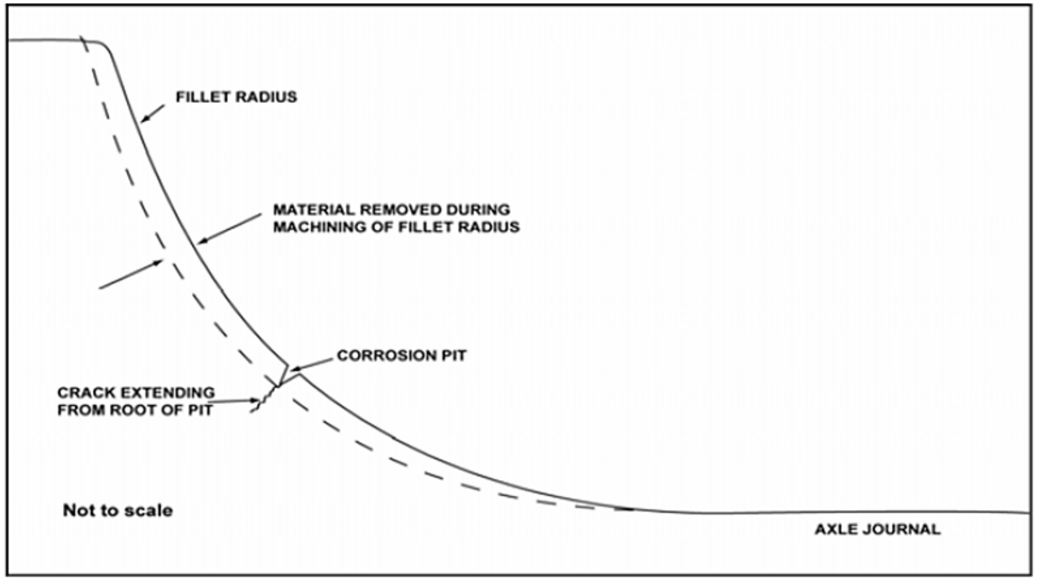
Journal Fillet Radius Cracks

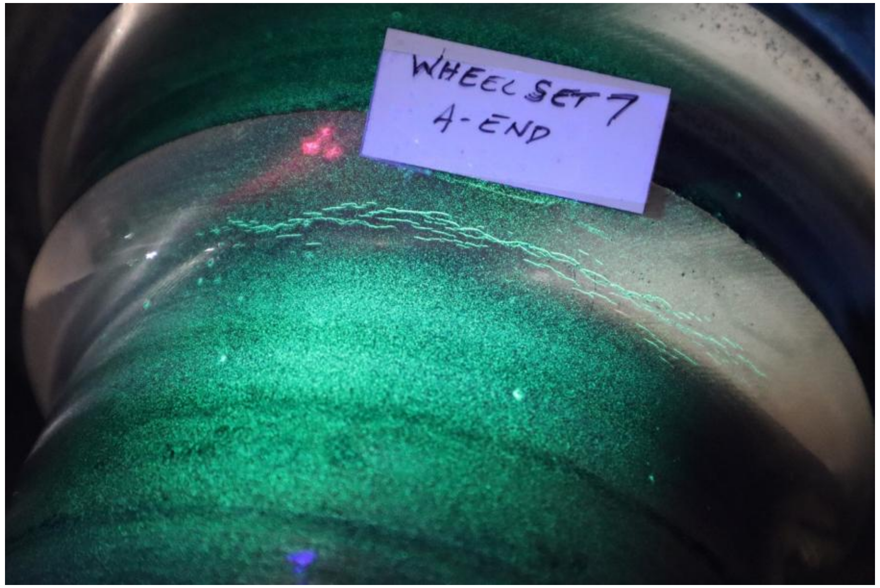
- **Axle journal fillet radius is a critical transition area subject to high loading/flexing**
  - Due to the loading, the fillet radius is notching sensitive
- **Applied loads tend to focus on the root of the crack, which becomes the fatigue initiation point**
  - Machining may or may not fully remove existing pitting/cracks in the fillet radius

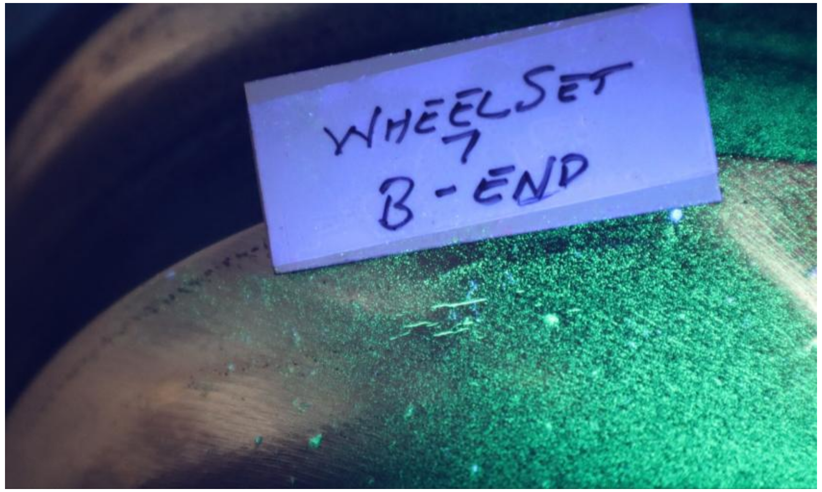


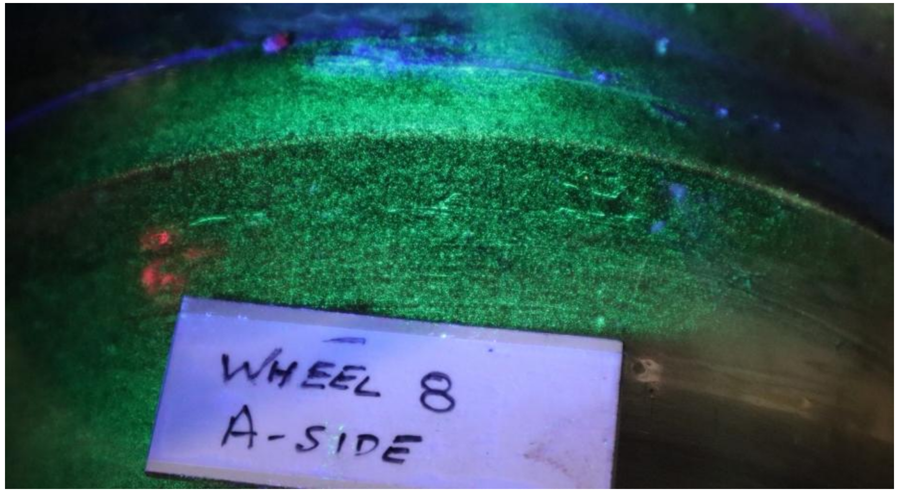


Source: Railway Investigation Report R07T0240, Transportation Safety Board of Canada

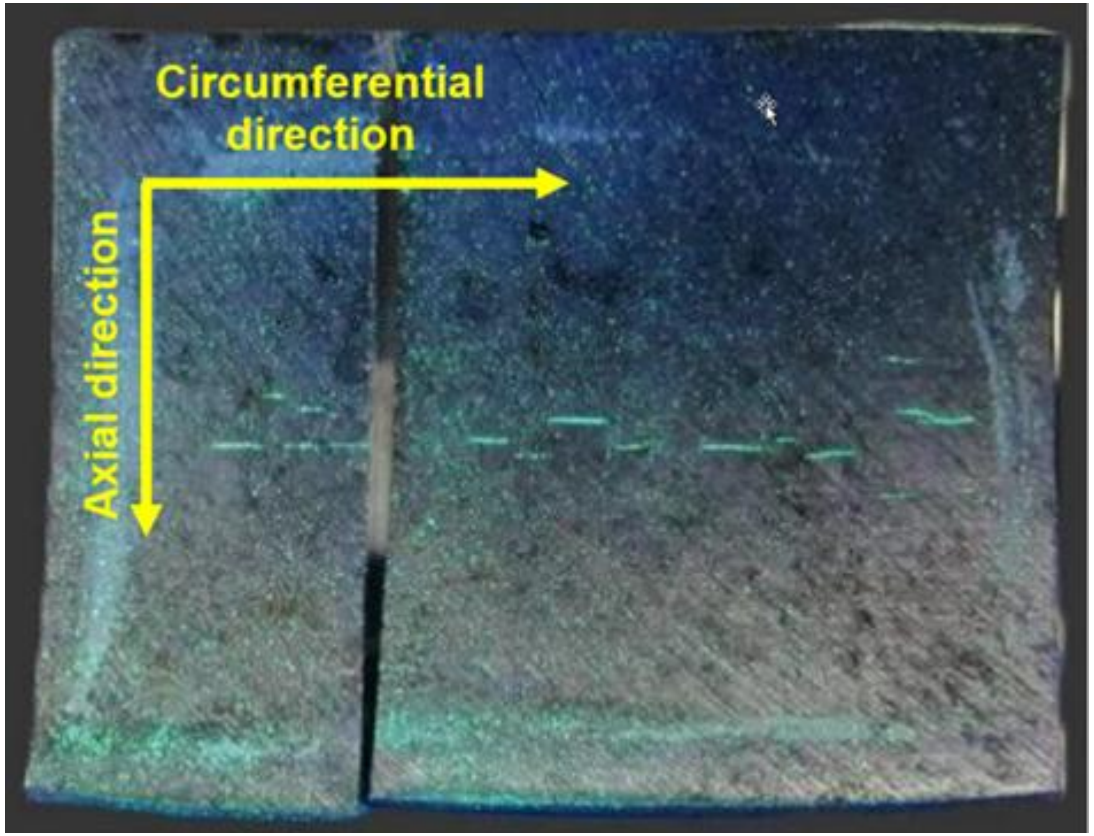
Journal Fillet Radius Cracks







Cracks Characterization



- **Evaluated four freight car axles**
  - Inspected at repair facility; condemned per AAR standards
  - Manufactured between 1965 and 1999
- **Multiple crack clusters in the journal fillet area**
- **Several samples sectioned for analysis**
  - Cuts made along planes with cracks
  - Visible surface breaking cracks

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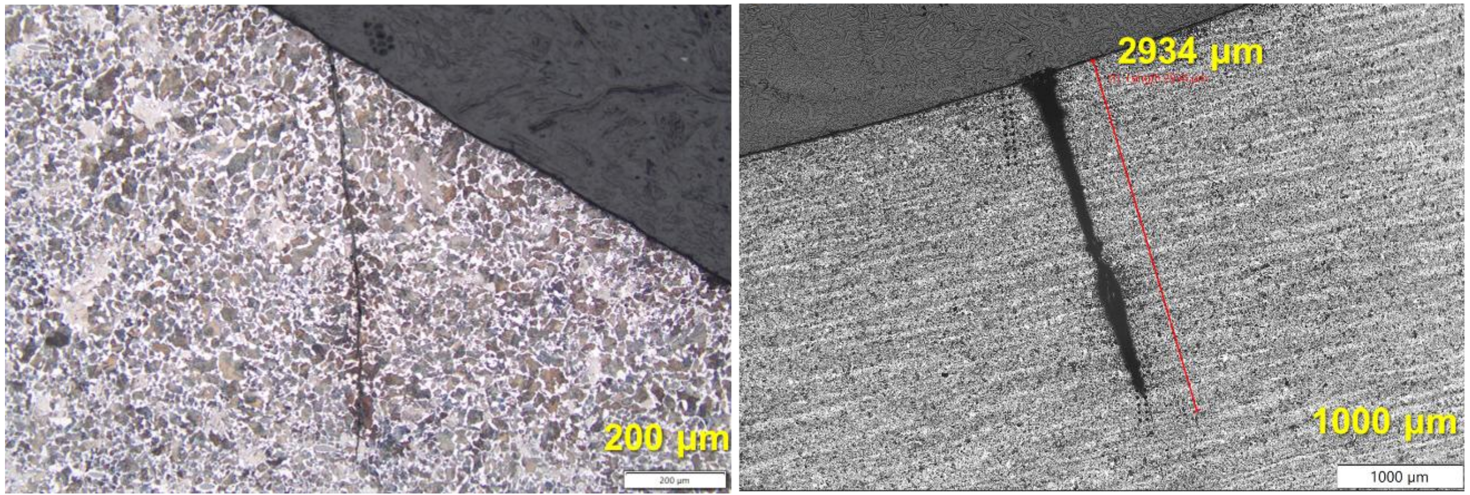
Crack Morphology

- **All observed surface cracks were transgranular, cutting through material's grain**
- **Crack lengths (depths) were measured along the radial direction on each sample**

Axle No.	No. of Samples	No. of Cracks	Min. Length µm	Max. Length µm	Median Length µm
3	9	9	221	929	716
6	6	7	137	1,131	348
7	9	22	134	2,934	450
9	6	15	110	960	334

Photo micrographs



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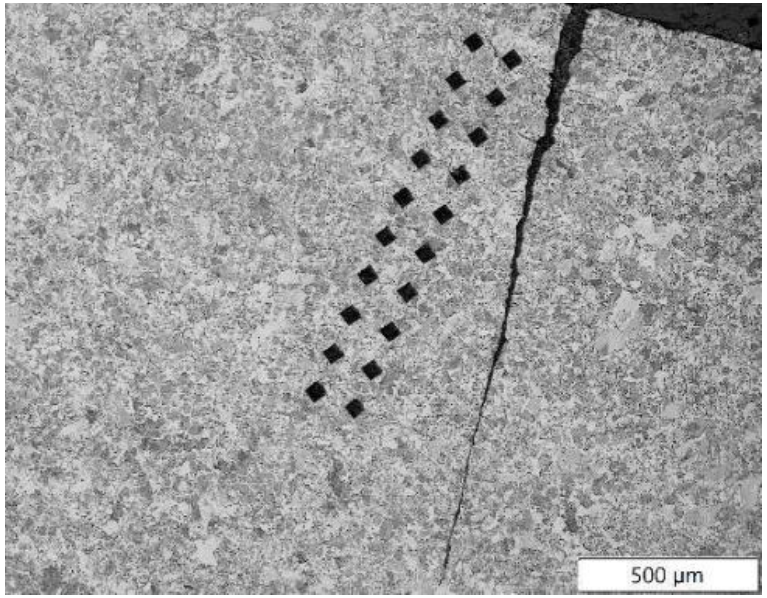
Hardness Measurement

- **Microhardness measurements were also taken near the surface and approximately parallel to the cracks**
  - The original values were in the Vickers scale but were converted to Rockwell B (HRB) per ASTM E140 standard
  - Approximate tensile strengths were also estimated for the median hardness value for each axle based on ASTM A370 standard



Axle #	Min. Hardness (HRB)	Max. Hardness (HRB)	Median Hardness (HRB)	Approximate Tensile Strength (psi)
3	91	95	93	94,000
6	90	105	98	109,000
7	89	101	93	94,000
9	87	103	93	94,000

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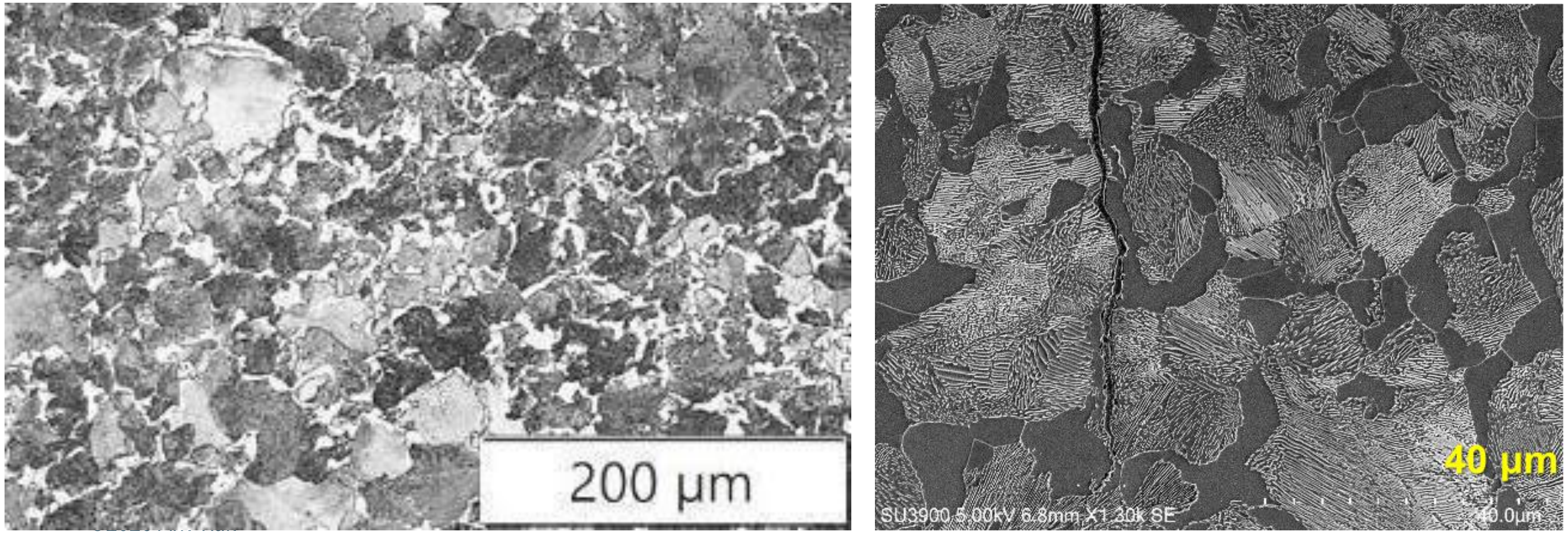
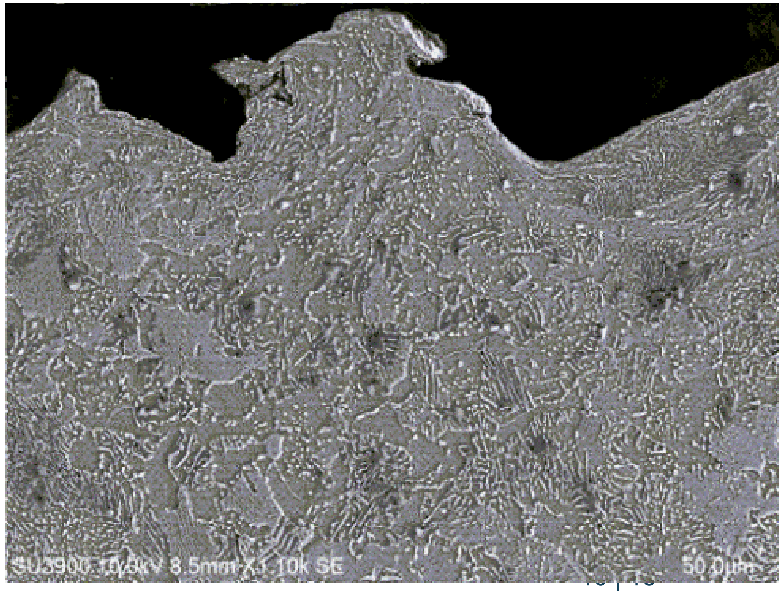
Microstructure Analysis

- Axle microstructure contain a mixture of ferrite and pearlite
- Two samples had rough areas on their radii due to plastic deformation that could have come from handling or from being struck by an object during operation

Typical ferrite-pearlite microstructure



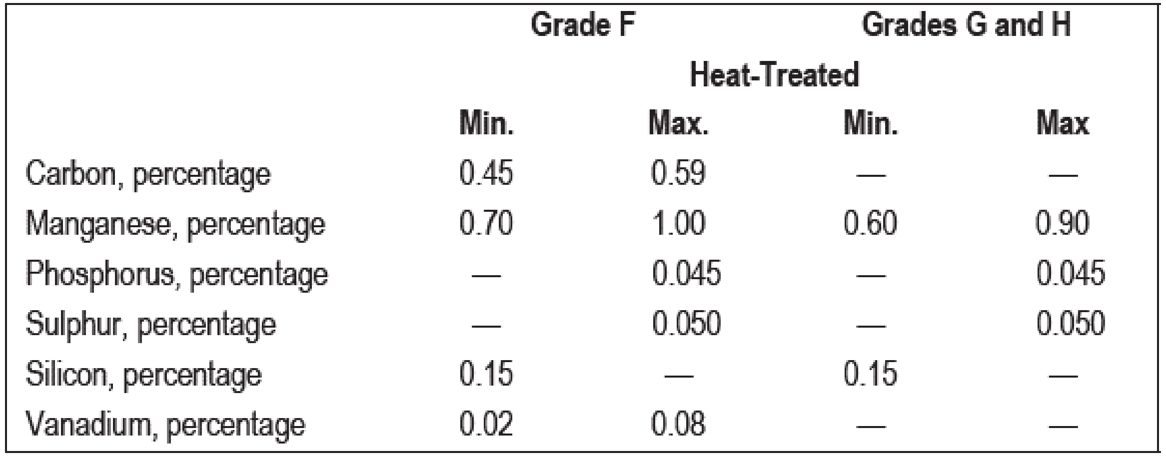
Plastically deformed microstructure from gouge



Chemical Analysis

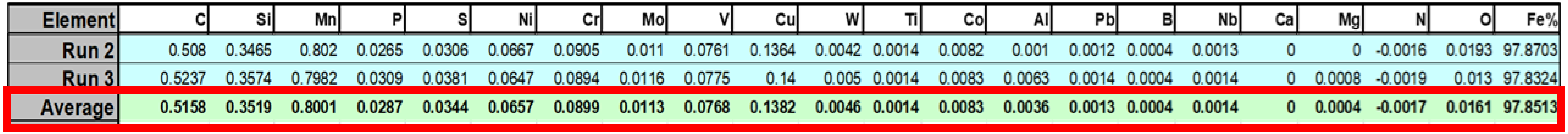
- **Chemical composition meets AAR *Manual of Standards and Recommended Practices (MSRP)* – Section G: Wheels and Axles requirement**

Table 7.1 Chemical composition



	Grade F		Grades G and H	
	Heat-Treated			
	Min.	**Max.**	**Min.**	**Max**
Carbon, percentage	0.45	0.59	—	—
Manganese, percentage	0.70	1.00	0.60	0.90
Phosphorus, percentage	—	0.045	—	0.045
Sulphur, percentage	—	0.050	—	0.050
Silicon, percentage	0.15	—	0.15	—
Vanadium, percentage	0.02	0.08	—	—

Chemical composition measured values in laboratory



Element	**C**	**Si**	**Mn**	**P**	**S**	**Ni**	**Cr**	**Mo**	**V**	**Cu**	**W**	**Ti**	**Co**	**Al**	**Pb**	**B**	**Nb**	**Ca**	**Mg**	**N**	**O**	**Fe%**
Run 2	0.508	0.3465	0.802	0.0265	0.0306	0.0667	0.0905	0.011	0.0761	0.1364	0.0042	0.0014	0.0082	0.001	0.0012	0.0004	0.0013	0	0	-0.0016	0.0193	97.8703
Run 3	0.5237	0.3574	0.7982	0.0309	0.0381	0.0647	0.0894	0.0116	0.0775	0.14	0.005	0.0014	0.0083	0.0063	0.0014	0.0004	0.0014	0	0.0008	-0.0019	0.013	97.8324
Average	**0.5158**	**0.3519**	**0.8001**	**0.0287**	**0.0344**	**0.0657**	**0.0899**	**0.0113**	**0.0768**	**0.1382**	**0.0046**	**0.0014**	**0.0083**	**0.0036**	**0.0013**	**0.0004**	**0.0014**	**0**	**0.0004**	**-0.0017**	**0.0161**	**97.8513**

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Microstructural Evaluation – Key Takeaways

- **Microstructure was normal, showing typical ferrite-pearlite**
- **Mechanical properties (i.e., hardness, tensile strength, and chemical composition) were within AAR MSRP specification**
- **No signs of plastic deformation, corrosion, or fretting at the journal radius**
- **The exact crack-initiation mechanism could not be determined**
  - MxV Rail could not confirm whether the axles considered in this work had been reconditioned previously
  - **Hypothesis:** Machining removed corrosion pits in the fillet radius but left tiny crack tips that could propagate with repeated loading
  - Enhanced inspection technology is needed to detect small cracks and address these challenges

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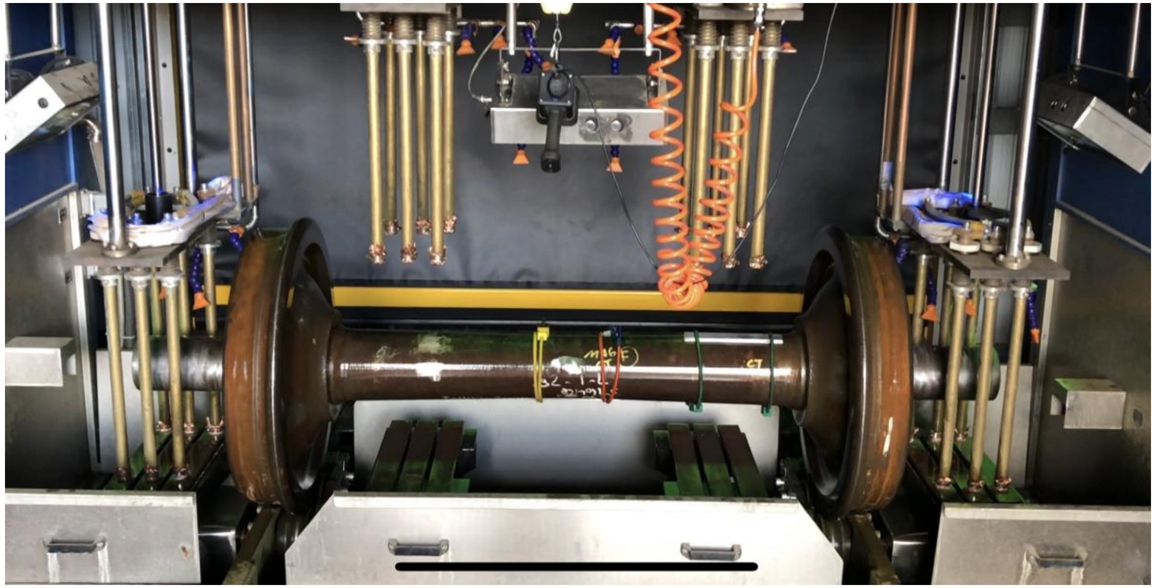
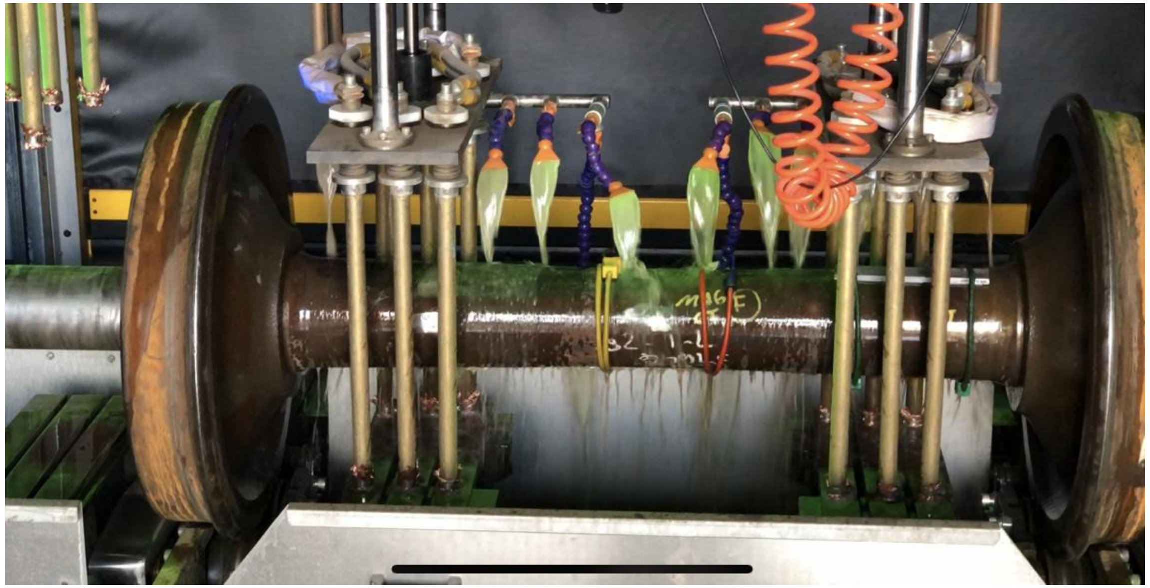
Current Inspection Technologies

- **Current AAR Field Manual Rule 43-Axle prescribes that all repairs on axles that have been in service must be magnetic particle tested by the wet method and shall be <u>completely free of defects</u>**





Future Inspection Technology

- **Implement an alternative automated nondestructive evaluation (NDE) inspection method for axles**
    - Compliment/improve on current wet-magnetic particle testing (MT)
    - Demonstrate the performance with low false positives
    - Digital inspection records and traceability
    - Reduce operator subjectivity

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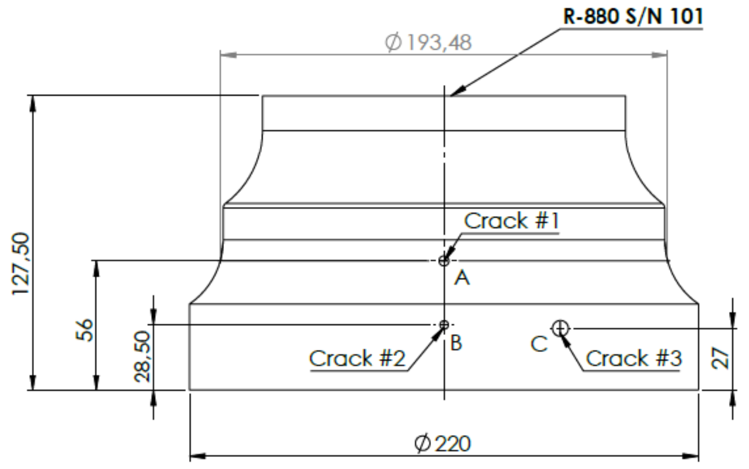
Eddy Current Testing (ET)

- All notches were detected with ET method with reasonable signal-to-noise ratio



Crack #1: Circumferential

depth: 1,0 +/- 0,03 mm
width: 0,15 +/- 0,03 mm
length 3,0 +/- 0,05 mm

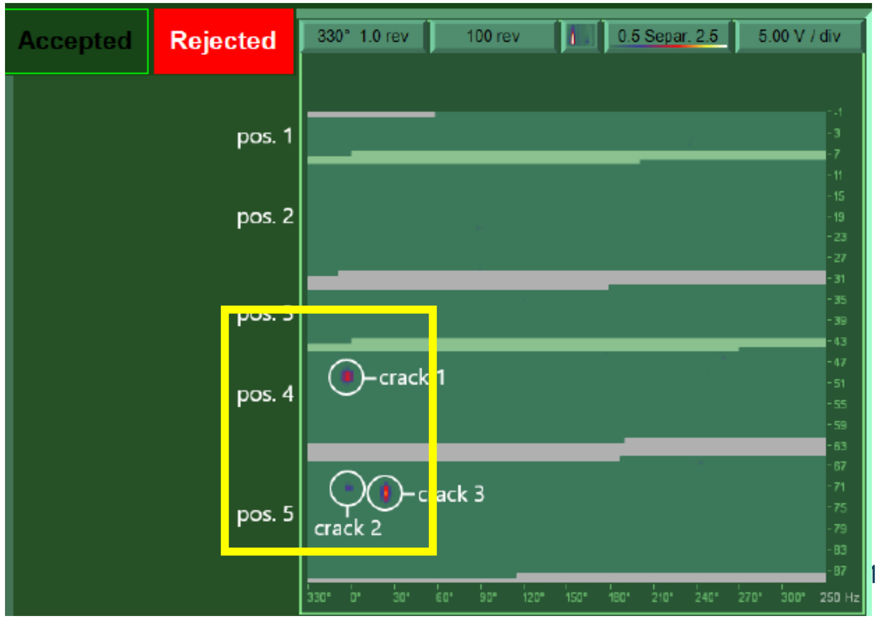
Crack #2: Longitudinal

depth: 1,0 +/- 0,03 mm
width: 0,15 +/- 0,03 mm
length 3,0 +/- 0,05 mm

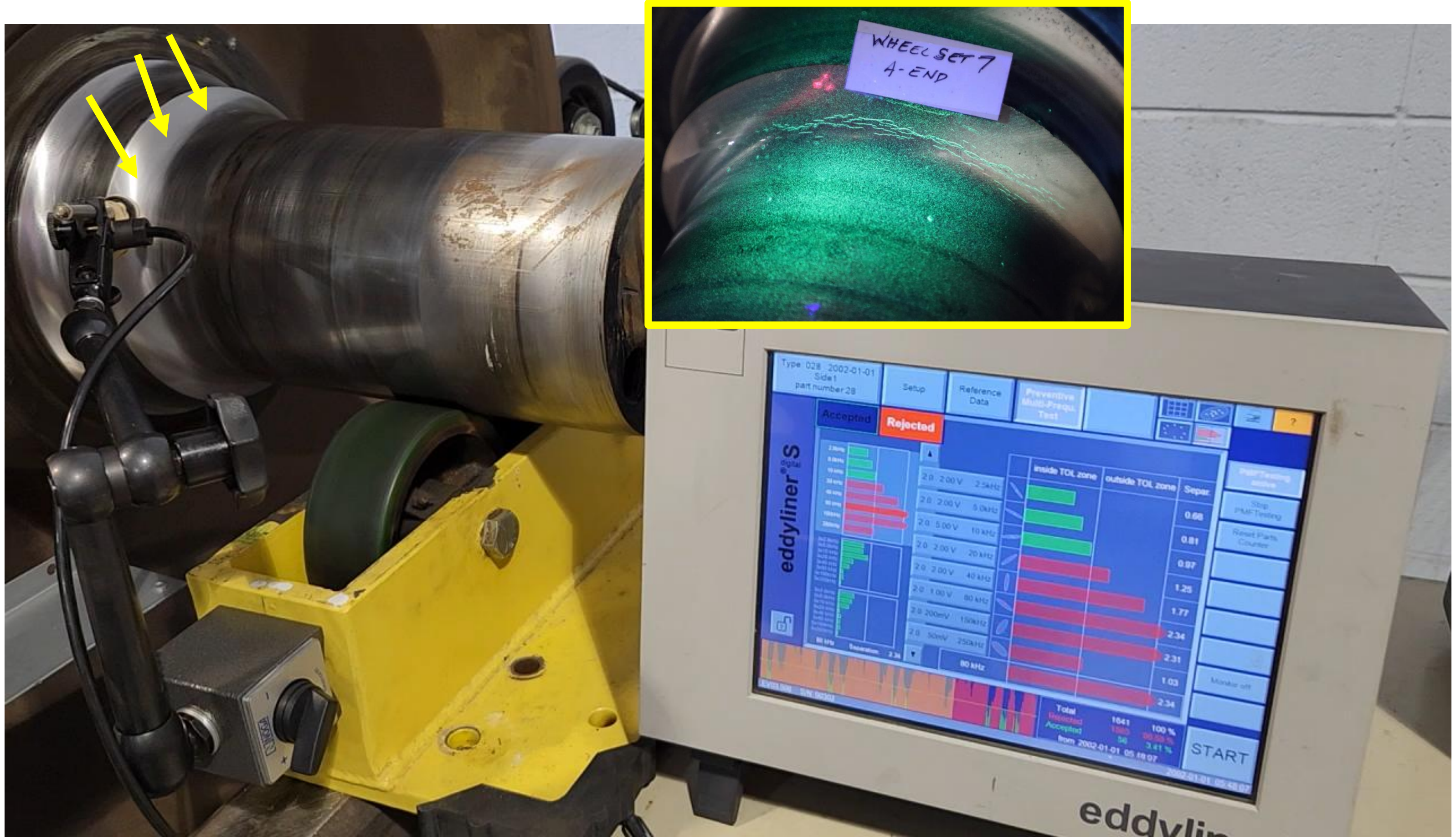
Crack #3: Longitudinal

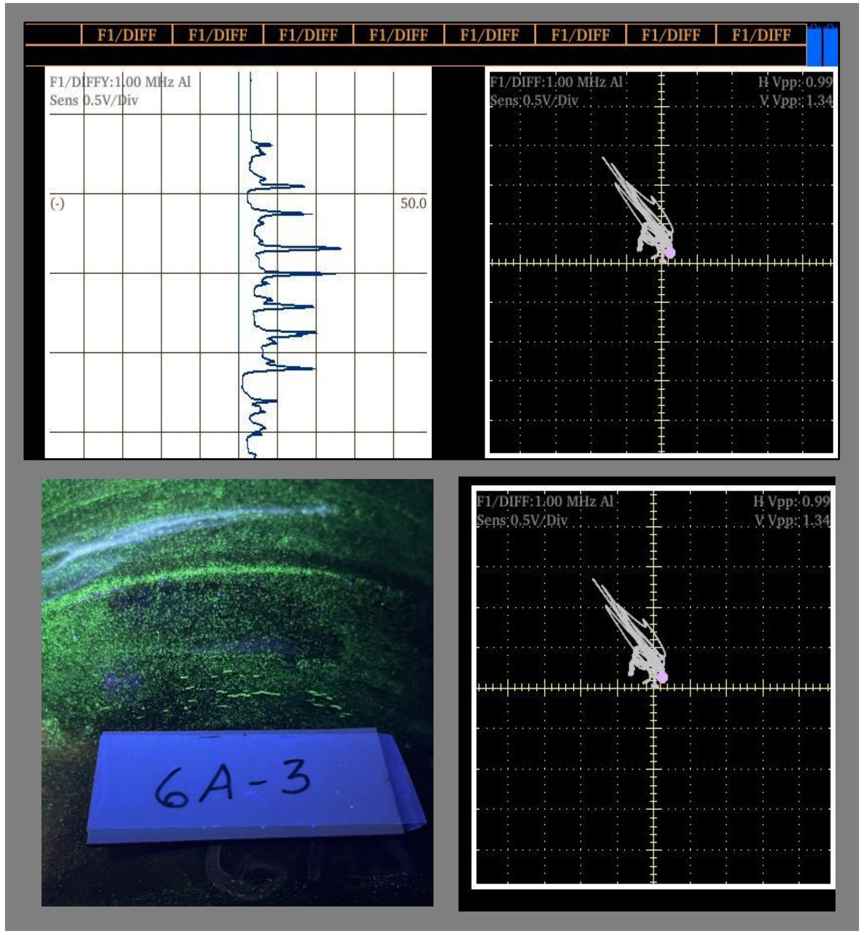
depth: **2,0** +/- 0,03 mm
width: 0,15 +/- 0,03 mm
length **6,0** +/- 0,05 mm

Notches	Frequency	SNR
Crack #1	250 Hz	3.6: 1
Crack #2	600 Hz	3.4: 1
Crack #3	600 Hz	6.3: 1



Laboratory Demonstration





ET technology shown belongs to ibg NDT Systems

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Eddy Current Technology

- **Detects surface and near-surface cracks**
- **Strong potential for automation and objectivity**
- **Digital tracking and data retention**
- **Areas requiring further development**
  - Probe design
  - Compensation for surface finish variations
  - Automated scanning fixtures
  - Signal processing algorithms for axle health tracking

ET technology shown belongs to Ether NDE

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- **NDE-Met Team**
    - Brian Lindeman
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    - Survesh Shrestha
    - Denise Valdez
    - Kerry Jones
- **Progress Rail & BNSF Wheel Shops**
- **AAR Rolling Stock TAG & WABL**
- **AAR Research Committee**

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Back to Mechanical Agenda

Bearing Performance and Integrity

Matt Wenger

Senior Engineer III

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Project Objective

- Improve the overall reliability and safety of bearings
- Investigate the root causes of bearing performance degradation
- Evaluate methods to improve the reconditioning process

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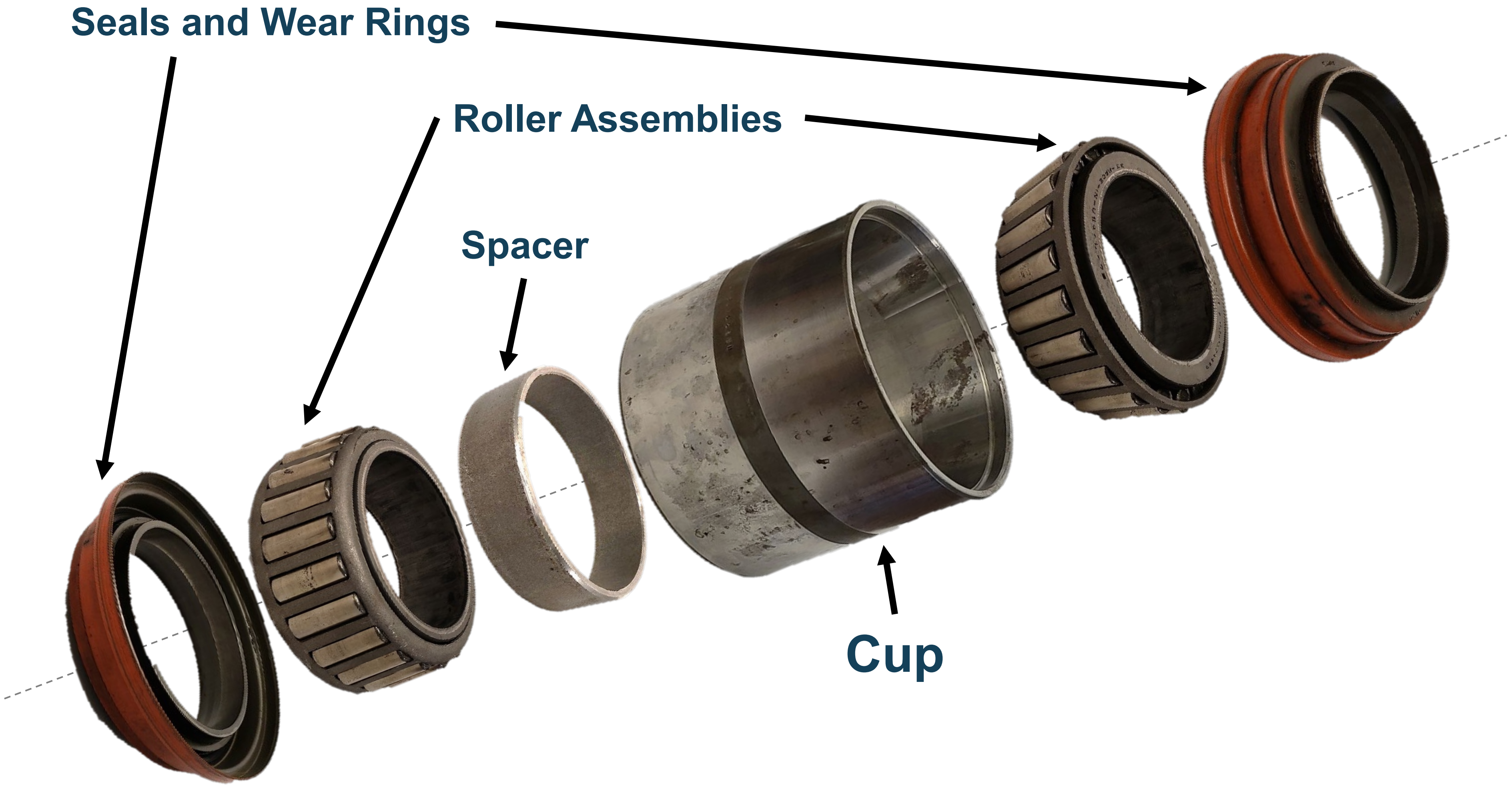
Bearing Assembly Overview



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Reconditioning Process

- **Reconditioning criteria are defined in MSRP H-II**
- **Teardown ▶ Washing ▶ Inspection / Repair ▶ Reassembly**
- **Cup inspection includes:**
  - Outer diameter measurement
  - Seal counterbore (diameter and out-of-round)
  - Visual inspection of raceway surfaces
- **Current research aims to help find small defects that may go unseen**

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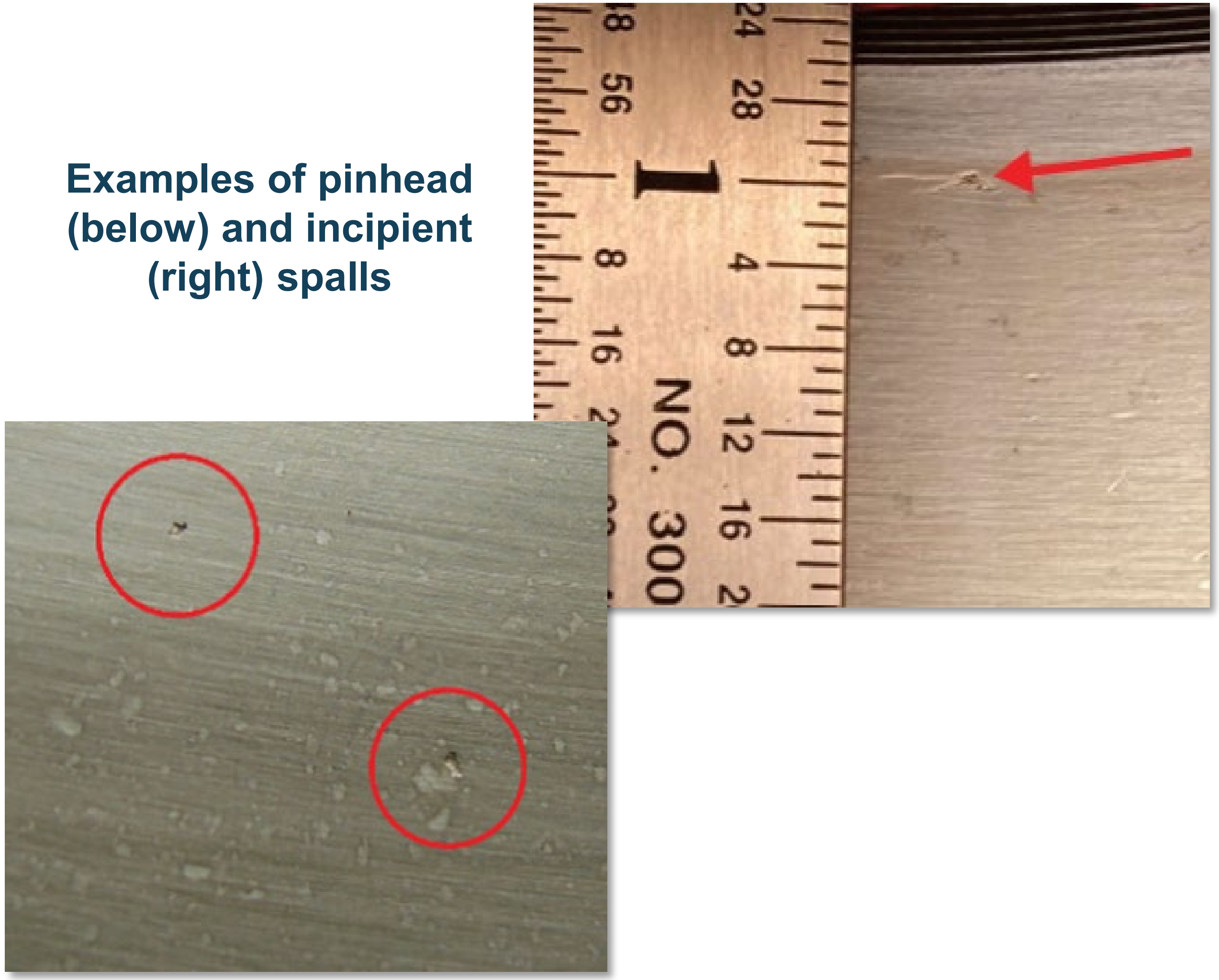
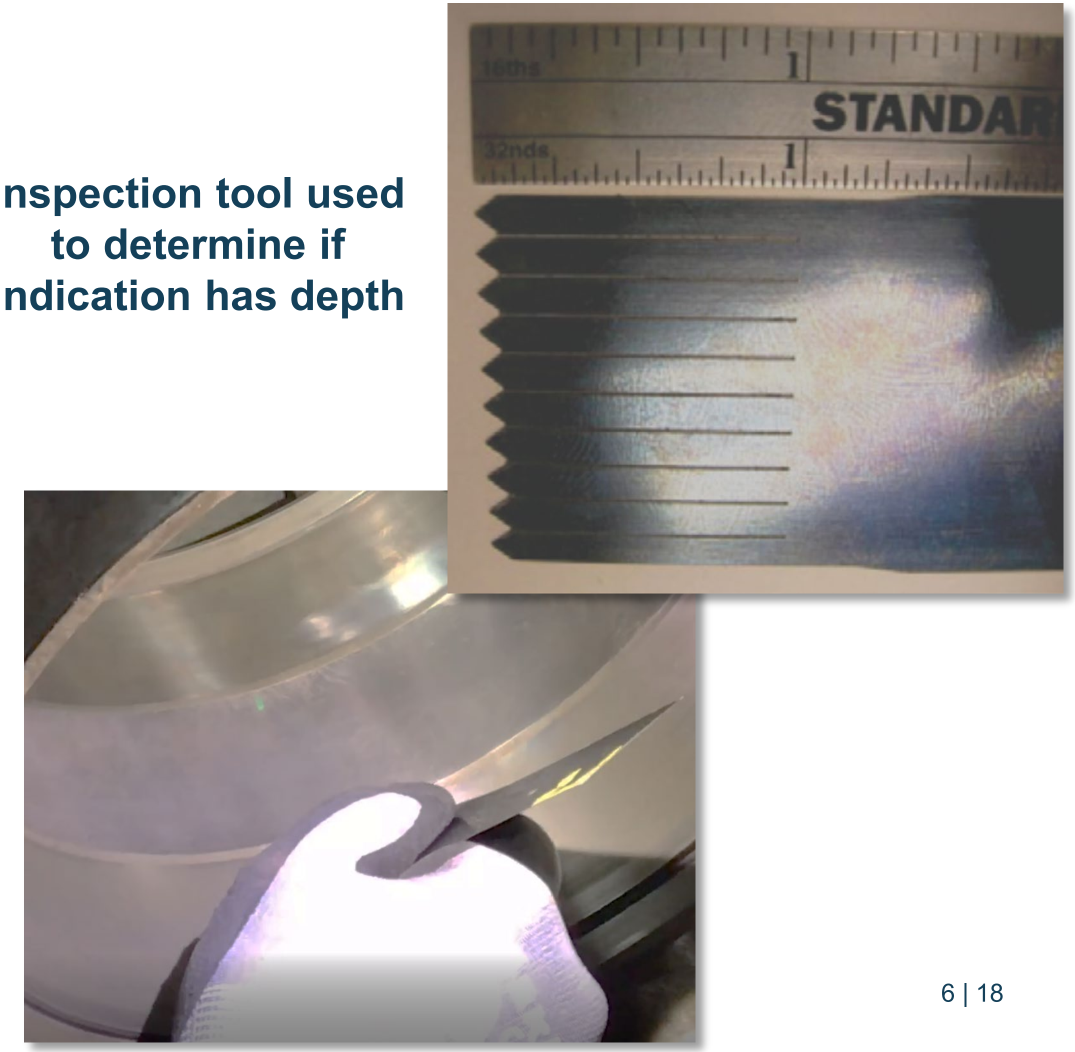
Reconditioning Inspection

Examples of pinhead (below) and incipient (right) spalls



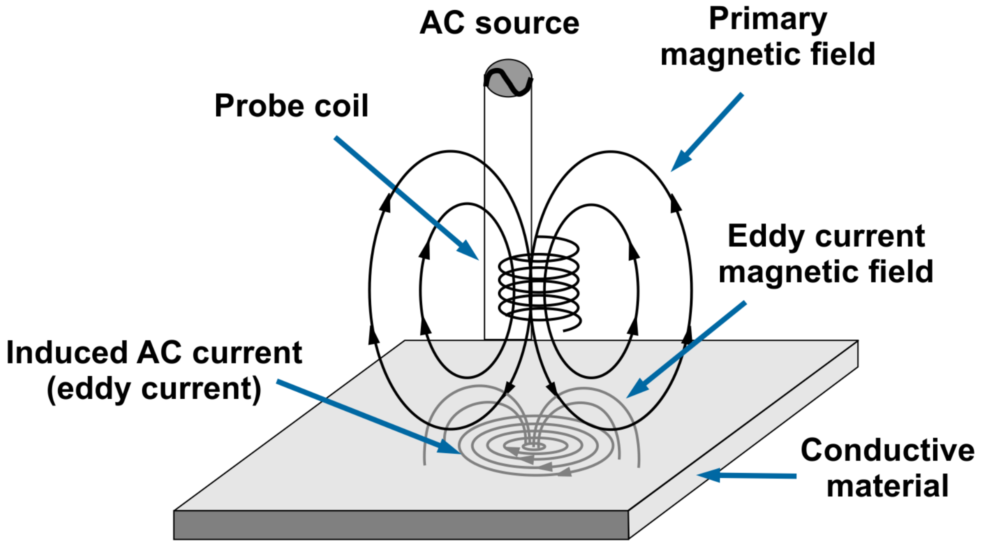
Inspection tool used to determine if indication has depth



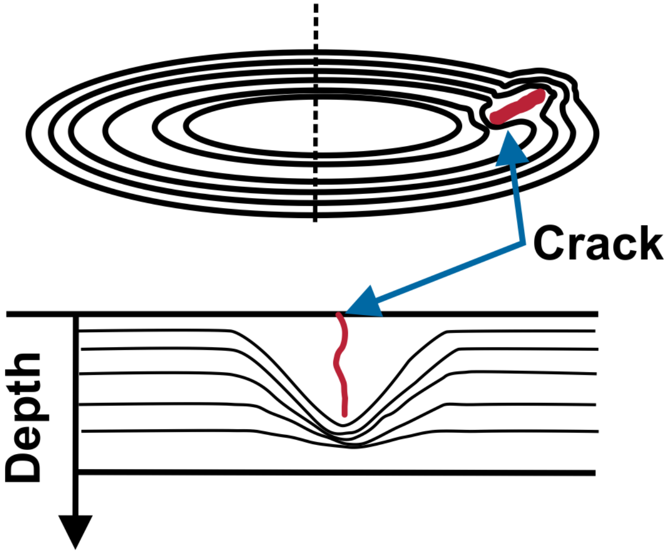
Eddy Current Fundamentals

- **Eddy current testing (ET) uses electromagnetic induction principles**
  - A coil within a probe is excited with alternating current
  - Eddy currents are induced within the conductive sample material
  - Any discontinuities in the sample material impede eddy current flow
  - Changes in material impedance are detected by probe

Principle of ET



Distortion of eddy current in presence of crack



Single coil "pencil" probe

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Eddy Current Array

- **Eddy Current Array (ECA) technology uses several coils simultaneously**
  - ECA can inspect one cup raceway in approximately 30 seconds
  - Results are color-coded C-scans
  - Flexible ECA probes allow scanning of complex surfaces

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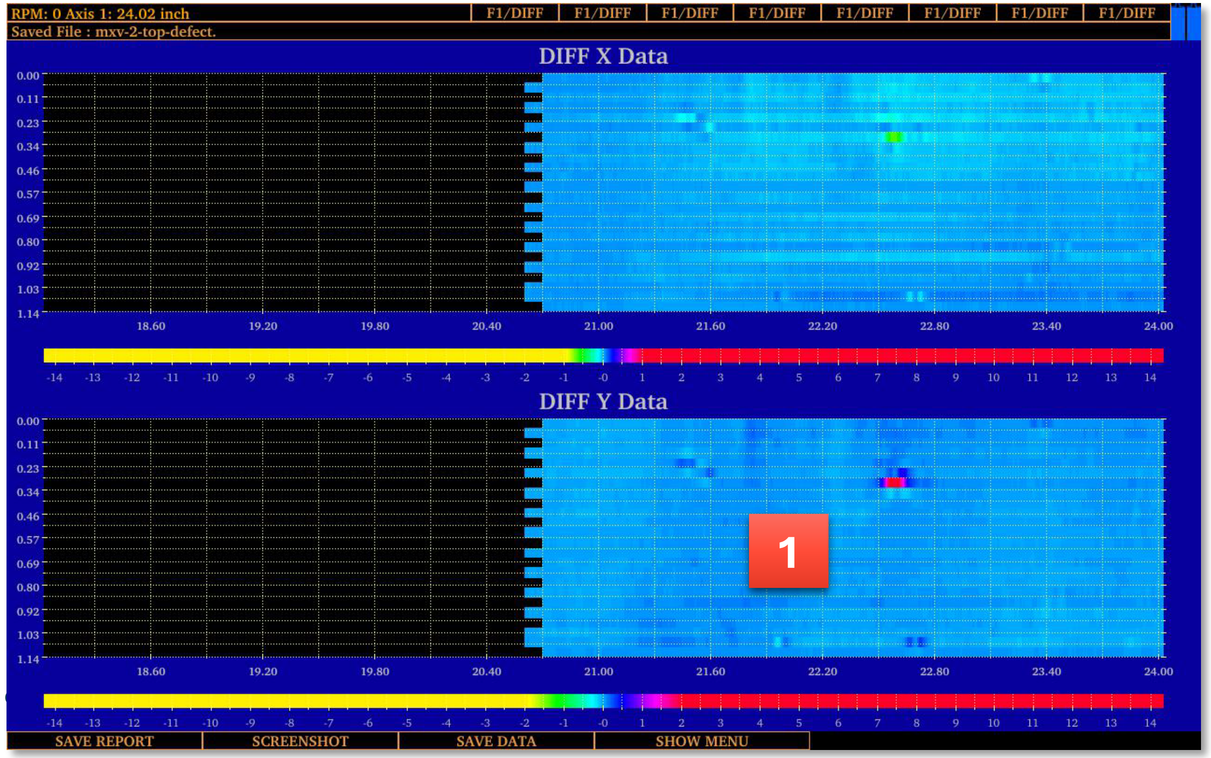
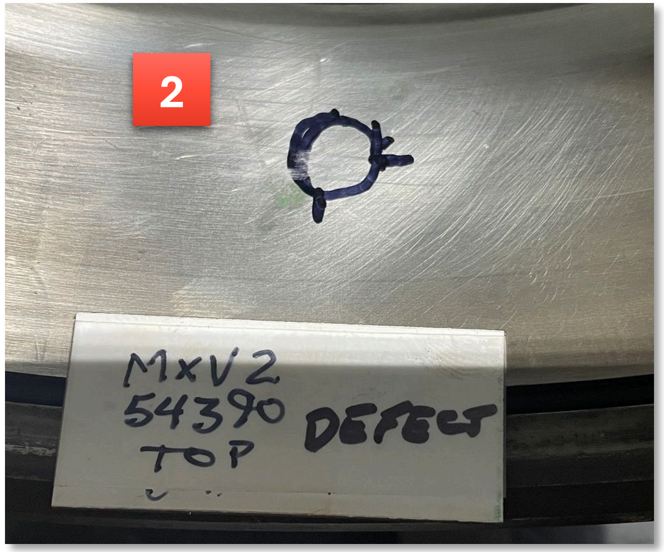
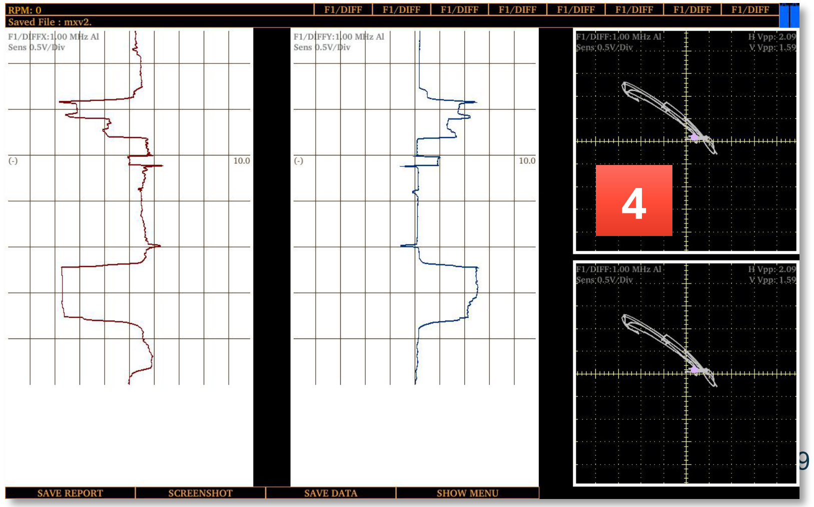
Combined ET Procedure

1. ECA scan entire raceway
2. Mark indicated areas
3. Follow up with pencil probe
4. Confirm defect signature on impedance plane plot

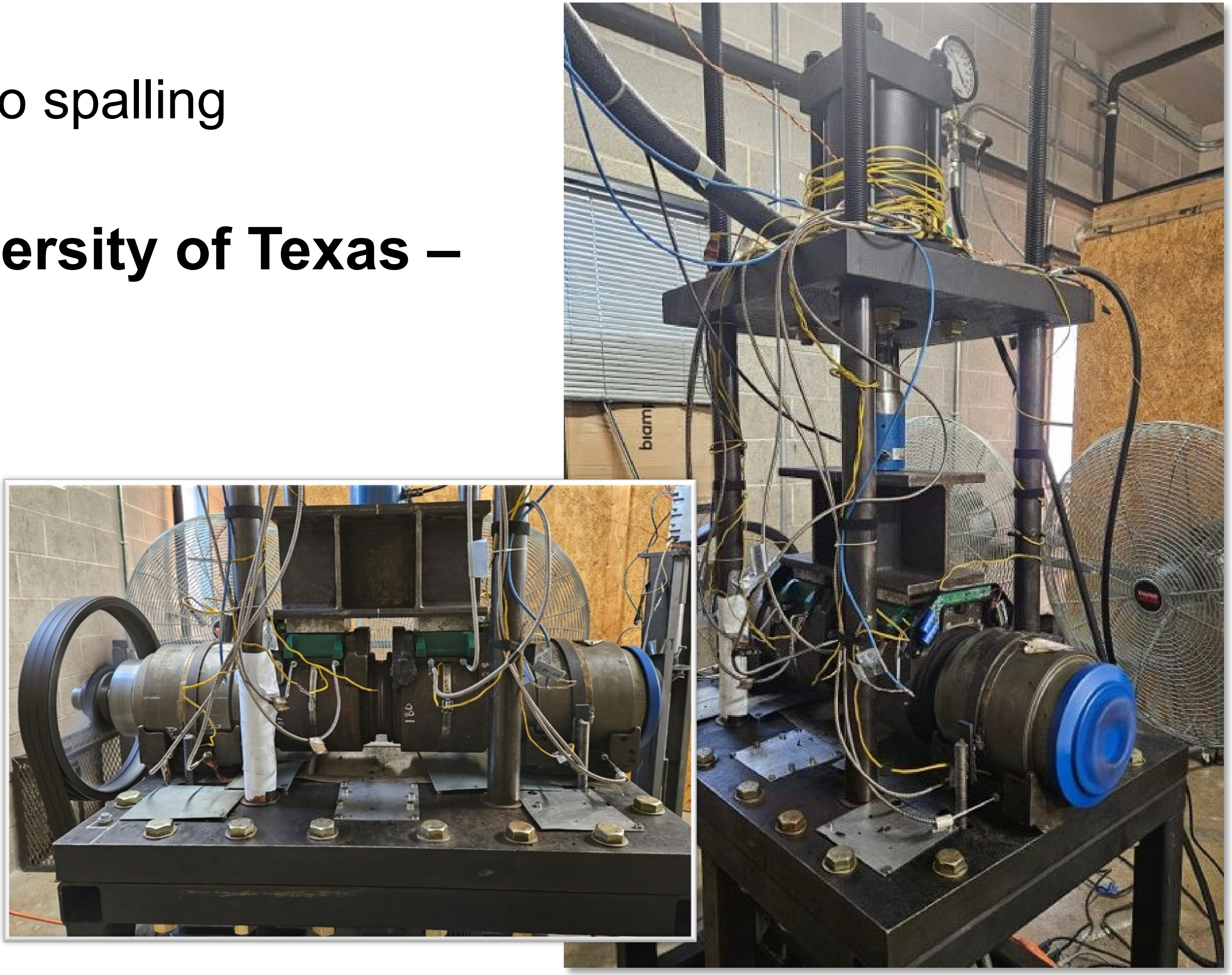






ECA Validation through Rig Testing

- **Hypothesis:**
  - ECA indications will develop into spalling early in service
- **Method: Rig Testing at University of Texas – Rio Grande Valley (UTRGV)**
- **Parameters:**
  - Test duration: 120,000 miles
  - Vertical load: 34,400 lbf
  - Speed: 85 mph
  - Cups prevented from indexing
  - Temperature and vibration monitored



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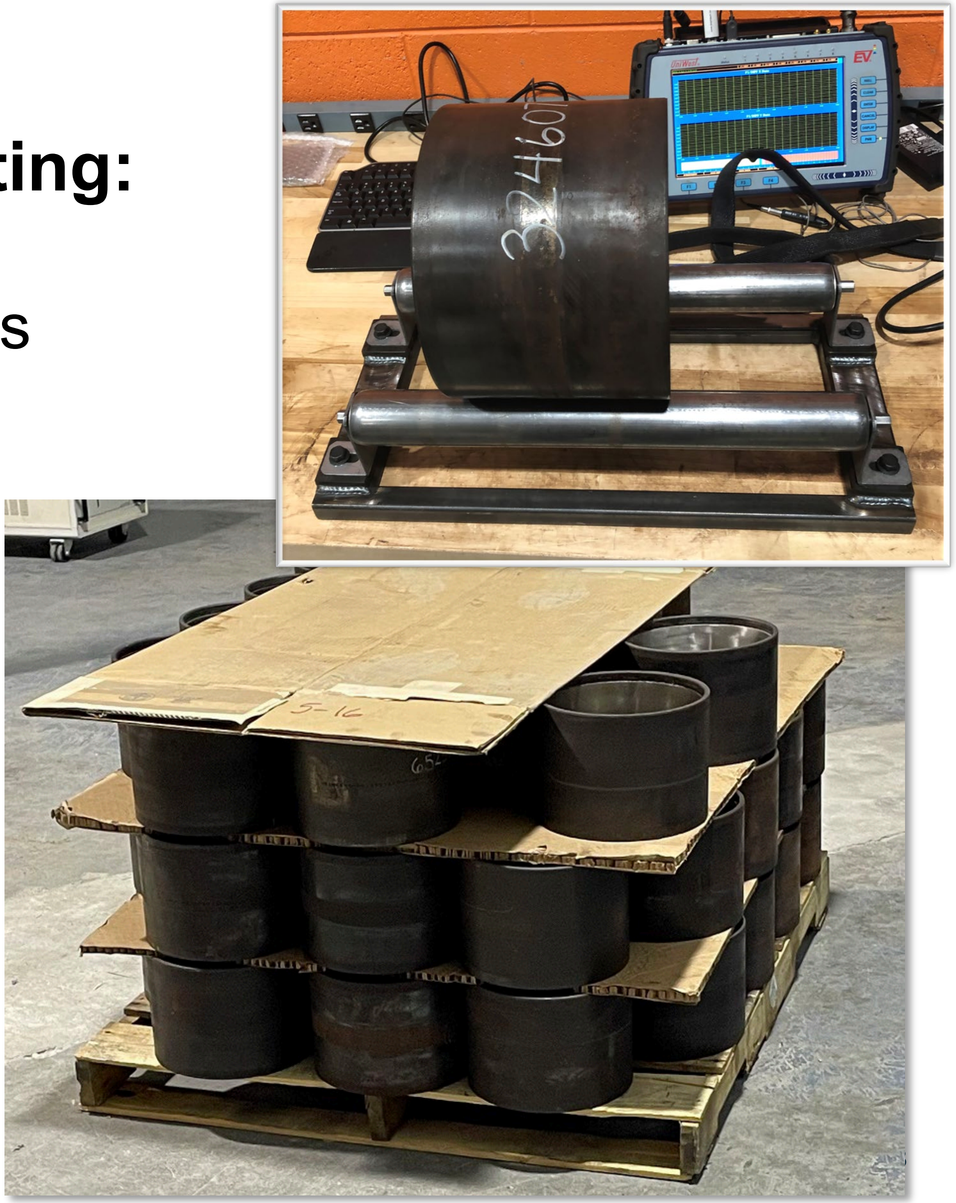
Selection of Cups

- **Two sample sets were selected for rig testing:**
  - Eight cups with ECA indications
    - All eight happened to be very small indications
  - Eight cups without ECA indications (controls)
- **Cups were freshly reconditioned upon ECA inspection**
- **Required 252 cups to find eight with ECA indications (3.2% rate)**
  - Previous study shared similar indication rate:
    - Phase 3: 7 of 192 (3.6%)



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ECA Validation Results

- **Total accuracy of ECA in predicting rig test outcome: 94% (15/16)**
    - Eight of eight cups with indications spalled
        - True positive rate: 100% (8/8)
    - Seven of eight control cups did not spall
        - True negative rate: 88% (7/8)
- **Results published recently in TD26-005**

Rig Test Error Matrix

Bearing Outcomes	Spall During Test	No Spall During Test	Total
ECA Indication	8	0	8
No ECA Indication	1	7	8

Results of Cups with ECA Indications

Cup #	ECA Indication Size (in^2)	Spall Area (in^2)	Spall Initiation Mileage (x/1000)	Total Test Mileage (x/1000)
1	0.007	0.36	60.5	120.3
2	0.005	0.01	60.5	120.3
3	0.005	1.19	96.4	96.4
4	0.005	0.96	62.3	62.3
5	0.010	1.51	118.9	151.1*
6	0.010	0.33	32.7	38.1
7	0.005	0.02	111.9	120.1
8	0.005	1.46	31.0	41.2

**Exceeded 120,000 miles to allow mate bearing to finish testing*

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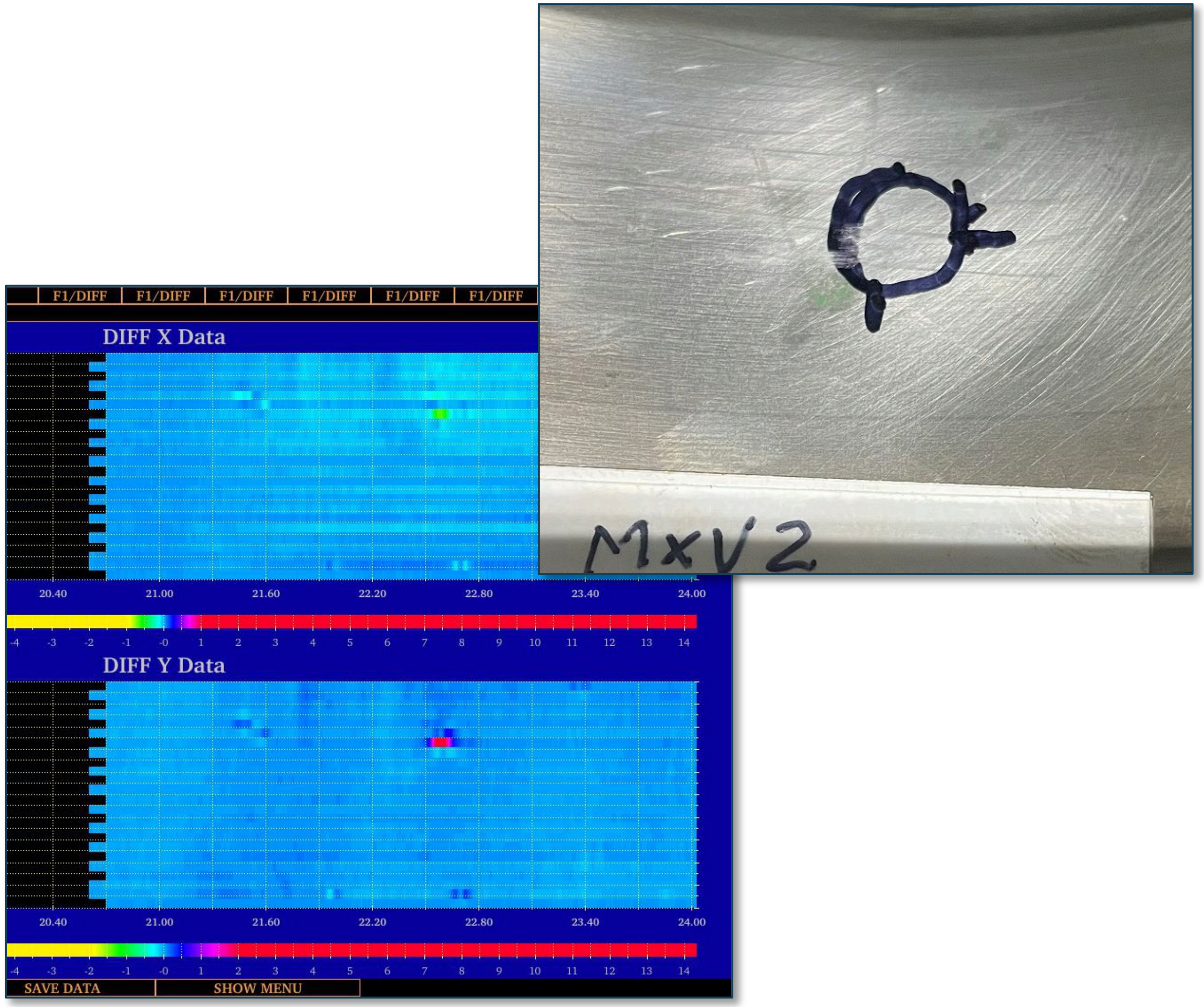
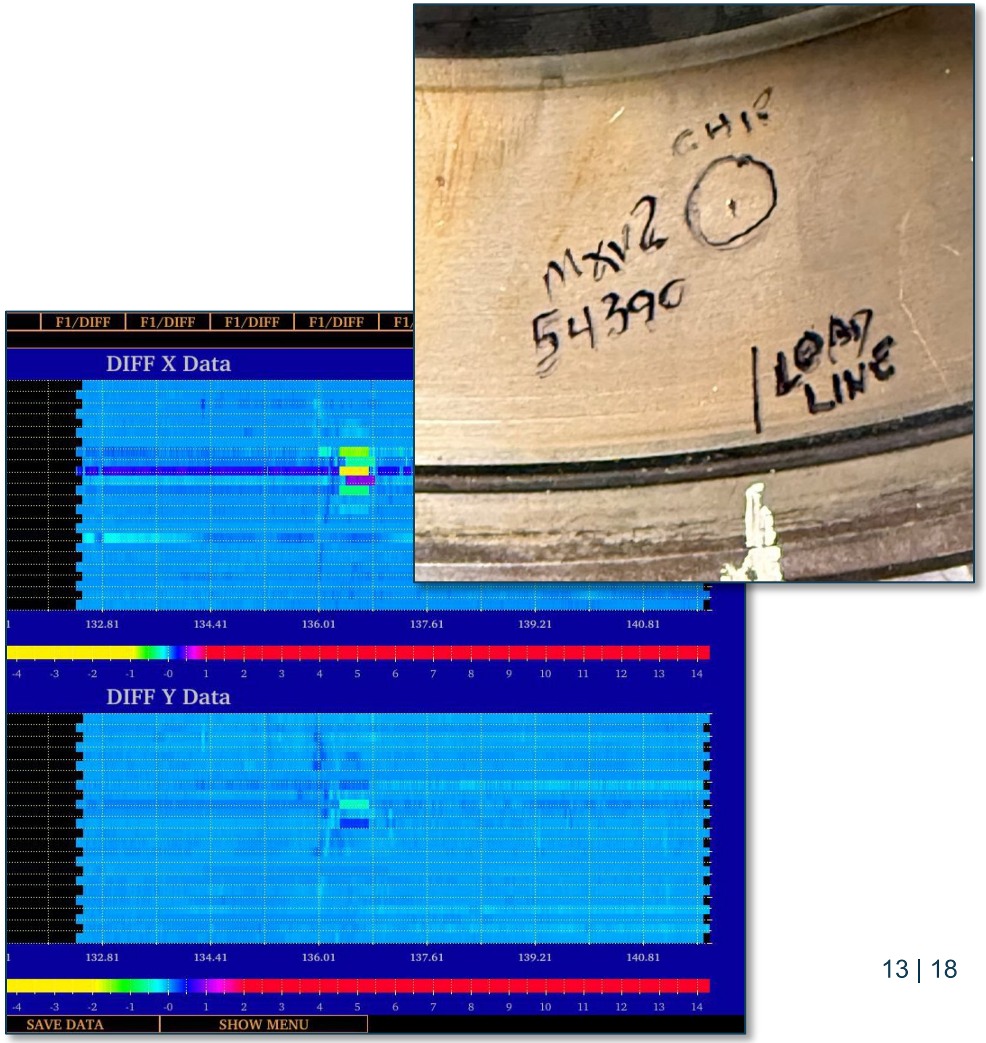
Cup 2 Spall: 0.01 in^2

Pre-Test

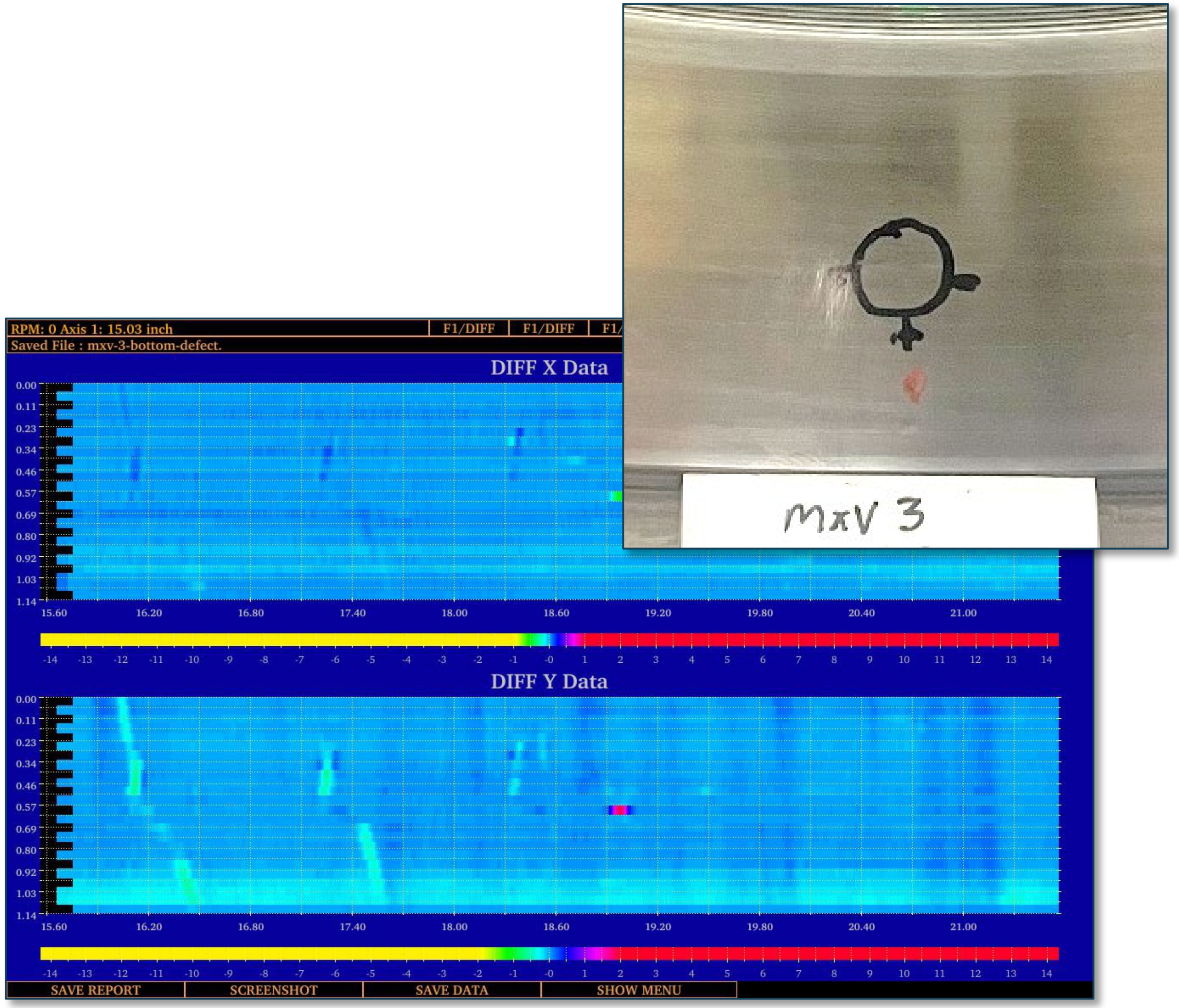


Post-Test (120,300 miles)

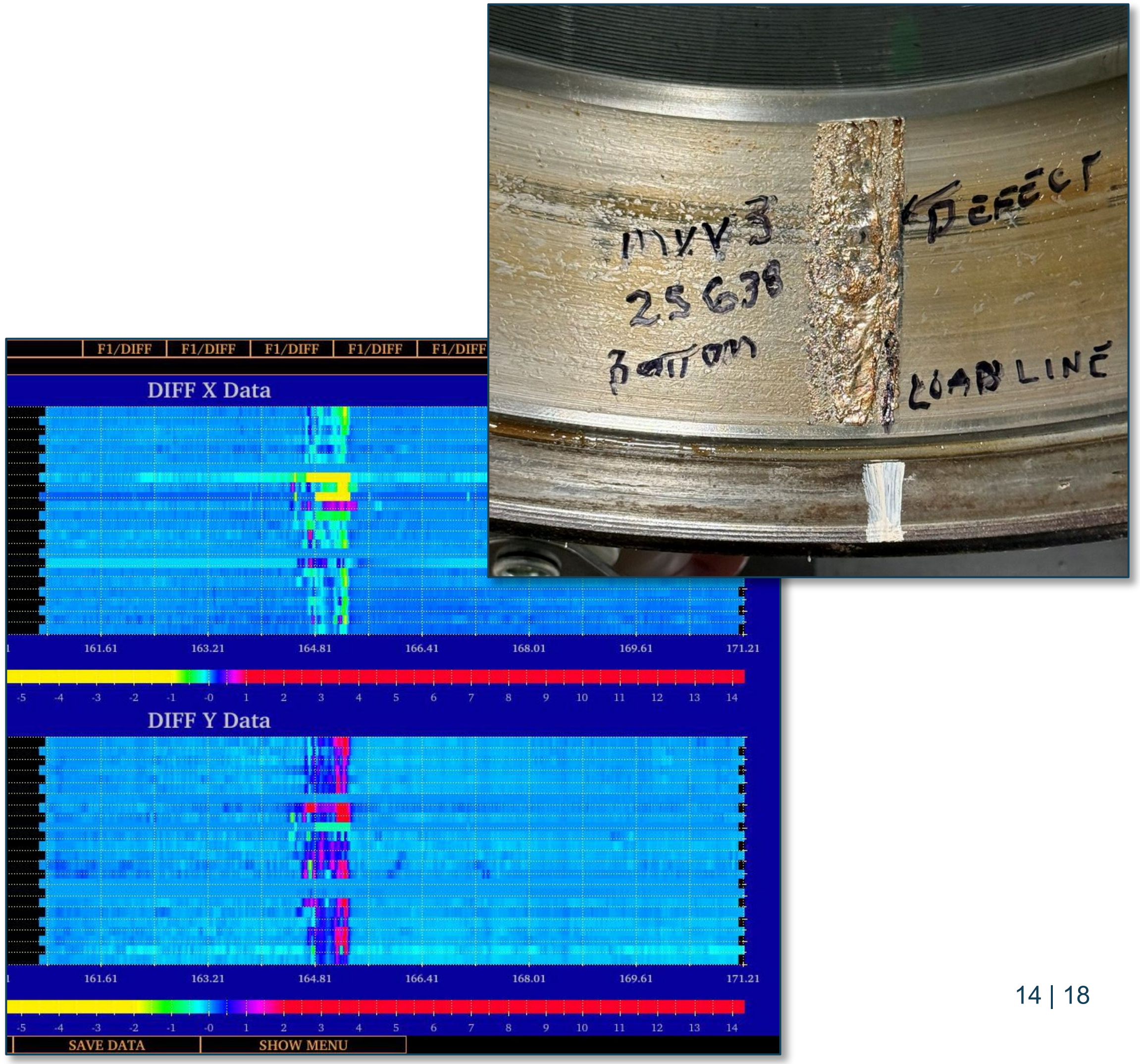


Cup 3 Spall: 1.19 in^2

Pre-Test

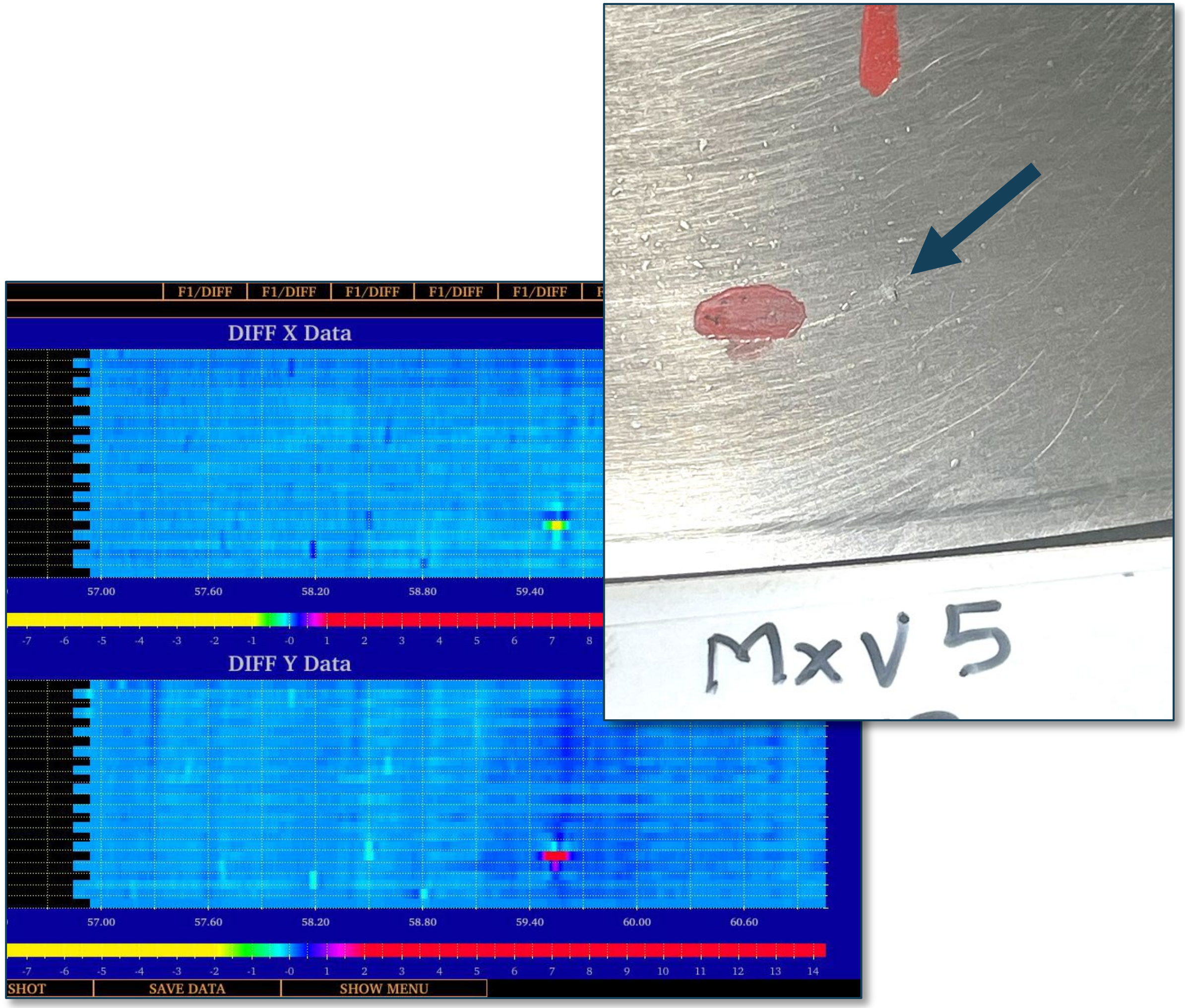

RPM: 0 Axis 1: 15.03 inch
Saved File : mxv-3-bottom-defect.

Post-Test (96,400 miles)



Cup 5 Spall: 1.51 in^2

Pre-Test



Post-Test (151,100 miles)

Historical ECA Results

- **47 cups total have undergone rig testing in three studies**
- **Prediction accuracy and true-positive rate has improved drastically**
  - Using pencil probe to confirm proper defect signature was the key
- **Phase 4 had improved results despite shorter test mileage**

Historical ECA Validation Results

Study #	Technology Digest	Overall Prediction Accuracy	Check ECA with Pencil Probe?	Rig Test Mileage (x/1000)	Average ECA Indication Area (in^2)
Phase 1	TD21-023	N/A	N/A	N/A	N/A
Phase 2	TD23-010	56%	No	240	Unavailable
Phase 3	TD25-005	87%	Yes	240	0.0317
Phase 4	TD26-005	94%	Yes	120	0.0065

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Path Forward

- Provide procedural and technical support to WABL for potential implementation into MSRP H-II
- Explore and validate technologies for the inspection of roller assemblies

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- **University of Texas – Rio Grande Valley (UTRGV)**
- **Progress Rail**
- **MxV Rail: Brian Lindeman and Anish Poudel**

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Water Ingress Bearing Testing (WIBT)

Matt Wenger

Senior Engineer III

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Introduction to the WIBT TAG

- **Comprised of passionate bearing experts dedicated to improving reliability and safety:**
  - Numerous WABL and RBMEC members
  - MxV Rail to facilitate water spray rig testing

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WIBT Objectives

Three main goals:

1. **Identify conditions that allow water ingress.**
2. **Make meaningful, data-driven improvements to the *Manual of Standards and Recommended Practices* (MSRP).**
3. **Harness the expertise of the WABL committee, manufacturers, and reconditioners to maximize research.**

MxV Rail’s bearing rig with water spray system

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The Need for WIBT

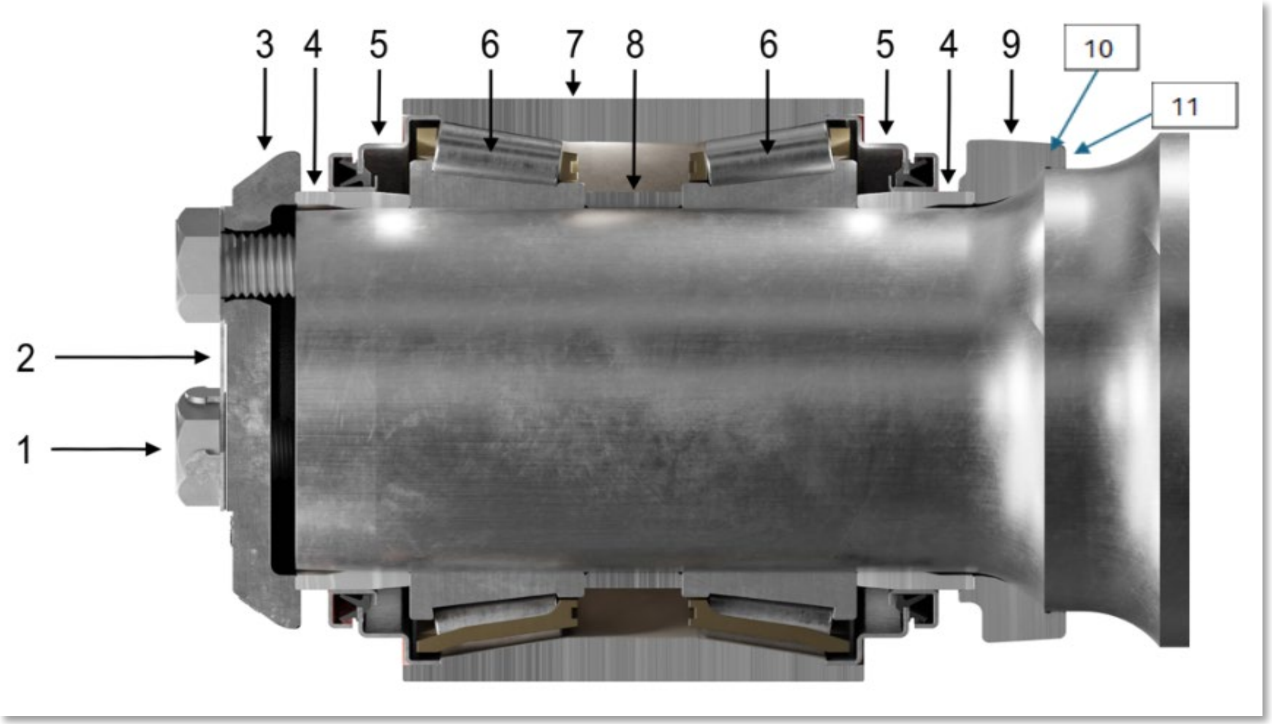
- **Water etch is historically in the top three failure progression modes (FPM) from MD-11 inspections.**
- **It is not uncommon to find evidence of water inside non-MD-11 bearings.**
- **Minimizing water ingress is essential for longevity and safety**

Examples of water etch on cup raceways in varying severity

The WIBT Method

- **Isolate and evaluate individual leak paths.**
- **Test numerous allowable component conditions per current MSRP specs.**
  - Minimum and maximum diameters
  - Maximum out-of-round
  - With and without nicks, gouges, etc.
- **Use existing water spray requirements**

Individual WIBT Test Zones



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Water and Rig Parameters

- **Tests adhere to existing requirements in M-934E and M-959:**
  - Water nozzle orientation
  - 0.8 gpm flow at 100 psig nozzle pressure
  - 80-degree flat fan spray pattern
  - 21 hours at 60 mph
- **Non-MSRP parameter:**
  - Full vertical load (34,400 lbf) applied throughout tests

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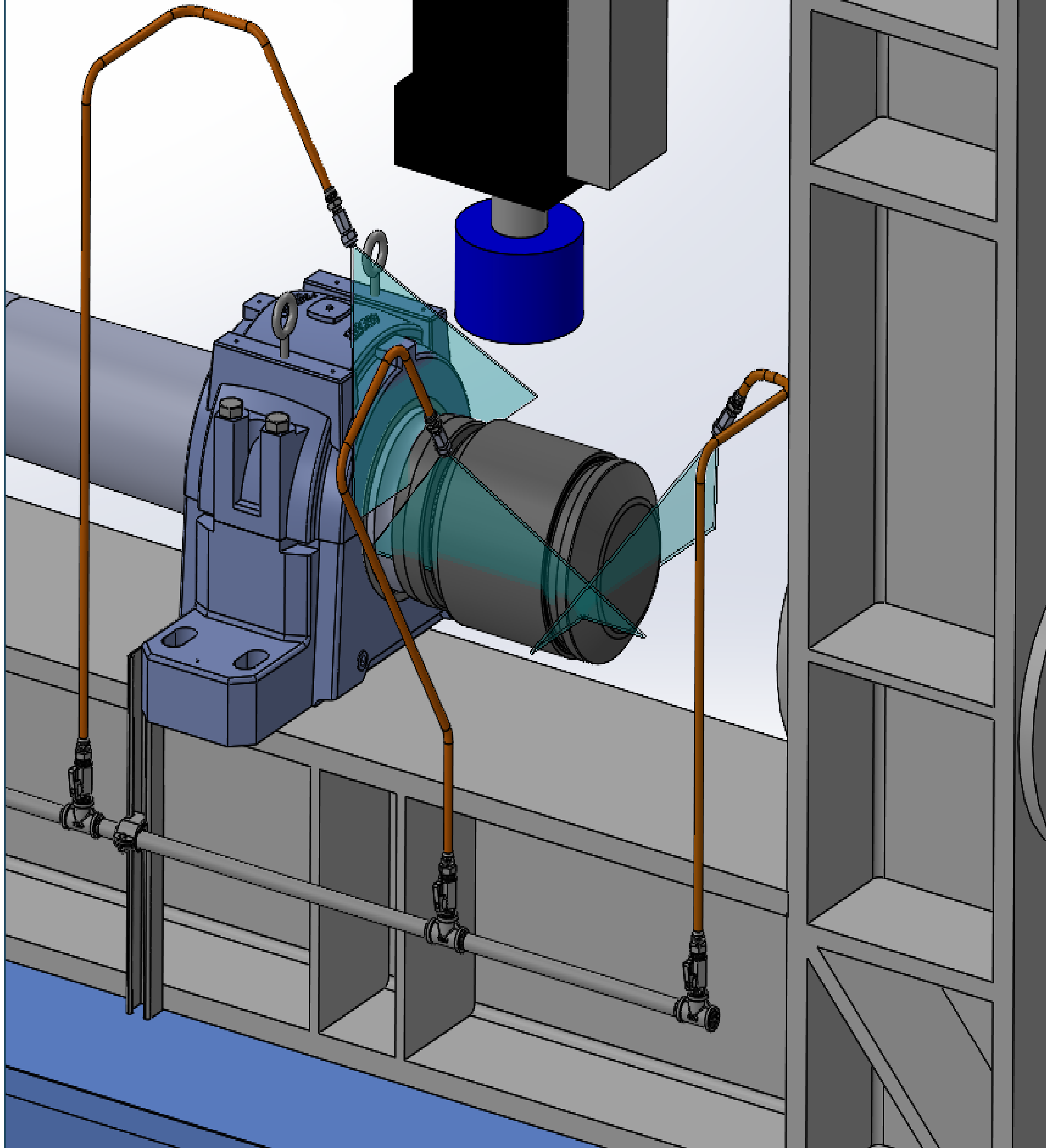
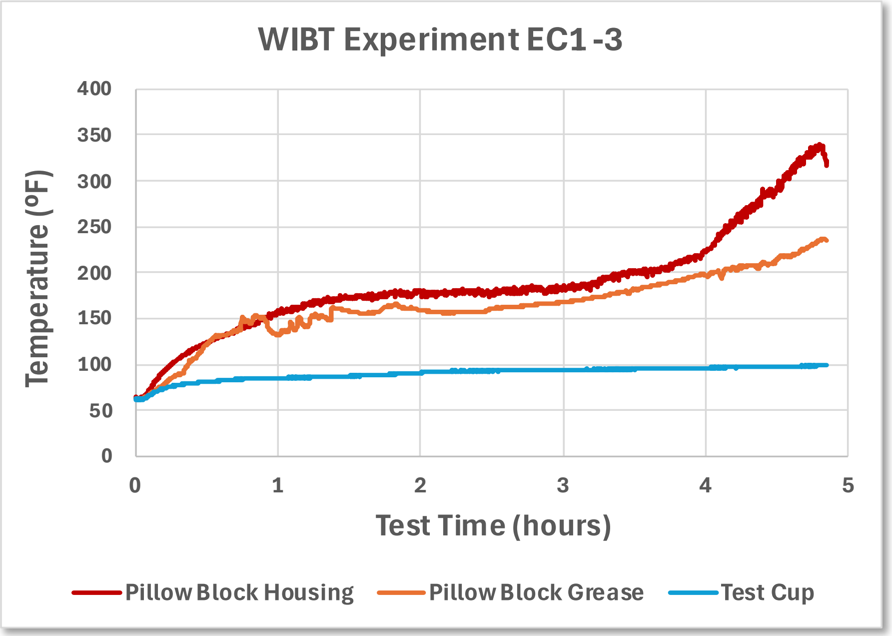


Data Collection

- **Developed techniques to accurately measure ingress.**
    - Accounting for journal lubricant and sealants used
- **Record the following:**
    - Vertical load
    - Torque
    - Bearing temperatures
    - Axle speed
    - Water pressure

Example of thermal excursion (top) and water etch found in pillow block bearings following the excursion (bottom)



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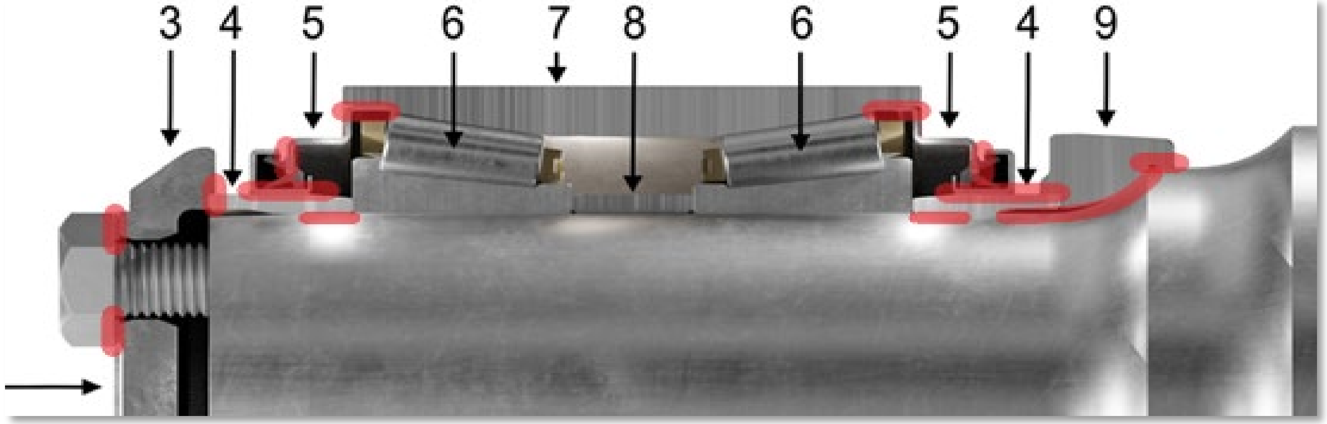
Control Bearing Tests

- **Initiated testing with control bearings to understand vulnerability of all leak paths.**
- **Three cases:**
  1. Brand new bearing assembly
  2. Best-case reconditioned components
  3. Worst-case reconditioned components

Leak paths highlighted in red



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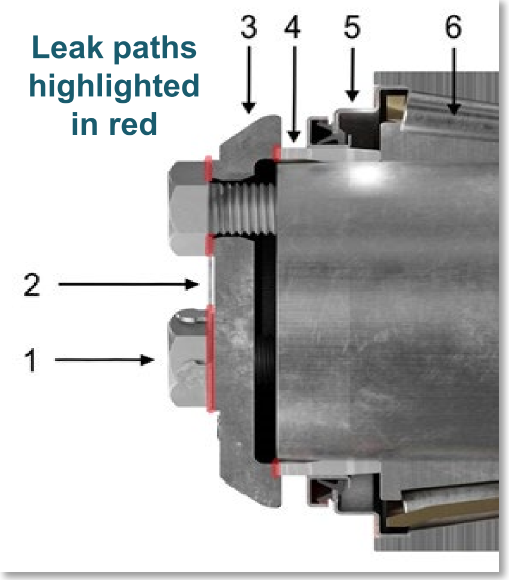
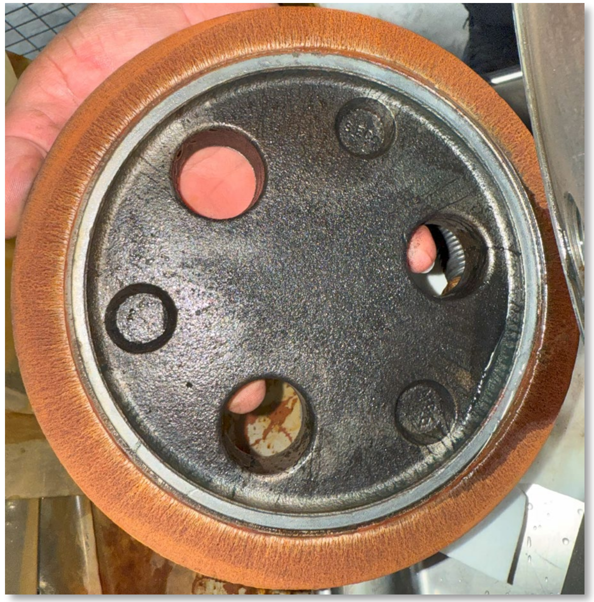
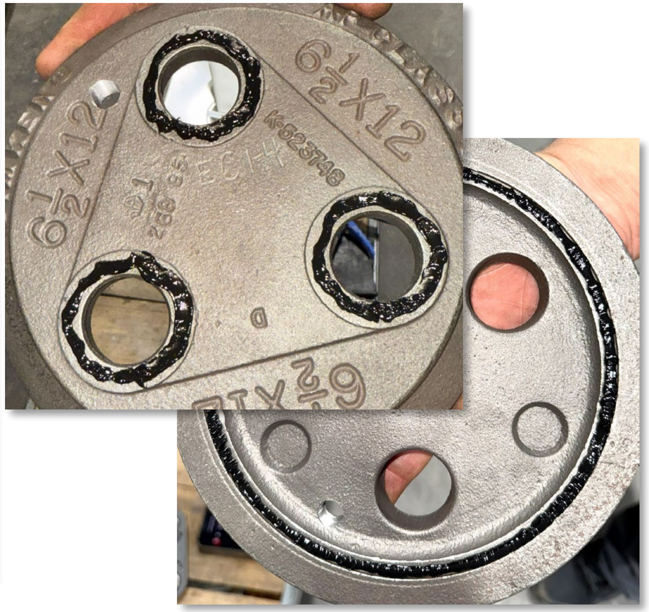
End Cap Tests

- **Three unique leak paths to address:**
  1. Cap screws to locking plate
  2. Locking plate to end cap
  3. End cap to seal wear ring
- **Performed duplicate tests and observed sporadic results**
- **Currently:**
  1. Investigating repeatability
  2. Isolating each unique leak path with silicone sealant



Leak paths highlighted in red





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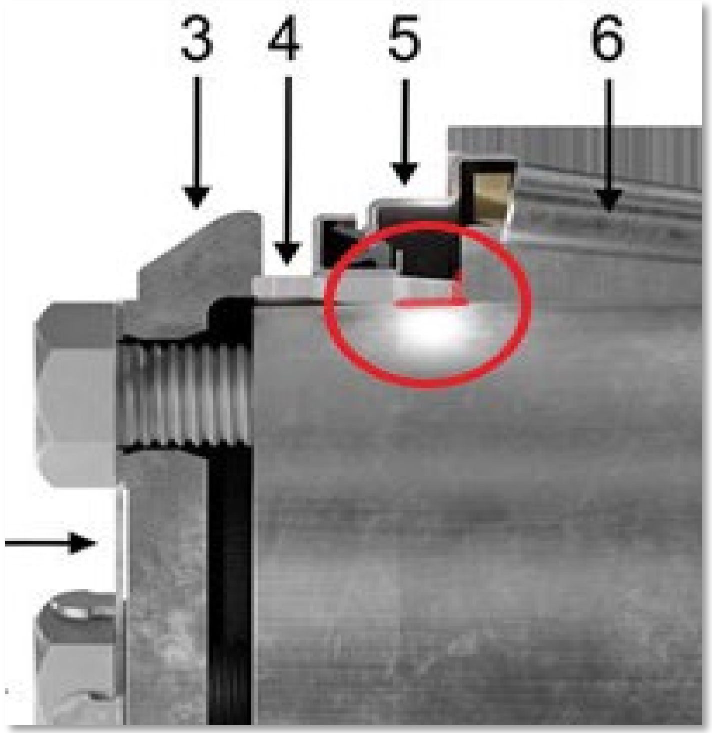
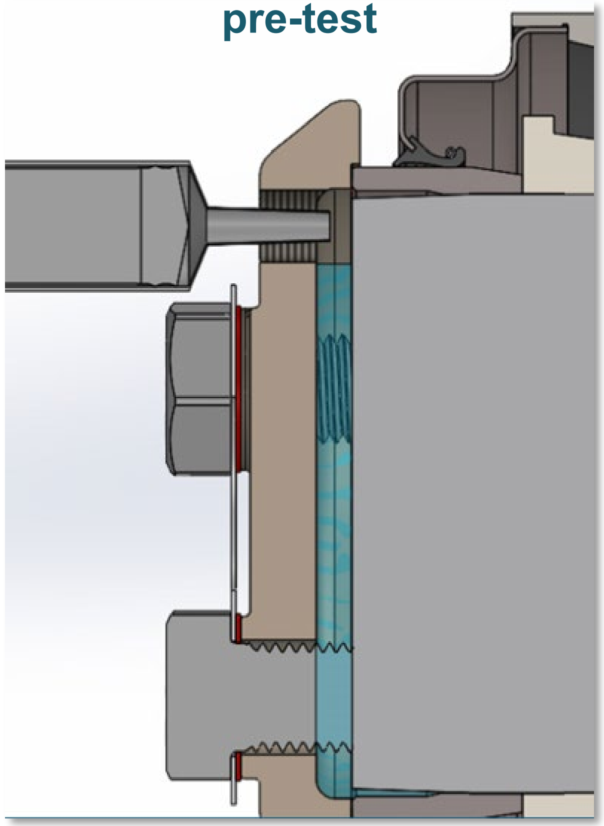
Seal Wear Rings (SWR)

- **Tested journal-to-SWR interface**
  - Sealed known mass of water behind end cap pre-test
  - Captured remaining water post-test
    - Any difference in collected water was assumed as ingress past SWR
- **Tested inboard and outboard SWR**

Leak path highlighted in red



Water injected into cavity pre-test



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Used Seal Tests

- **WIBT TAG worked with Railinc to acquire mileage of used candidate bearings**
- **RBMEC members made procedures to carefully re-install used seals and wear rings**
- **Have tested cases from 48,000 to 429,000 miles of prior service**
- **During testing, all other leak paths sealed with silicone**
- **Testing conventional rubbing lip and non-contact labyrinth seals**

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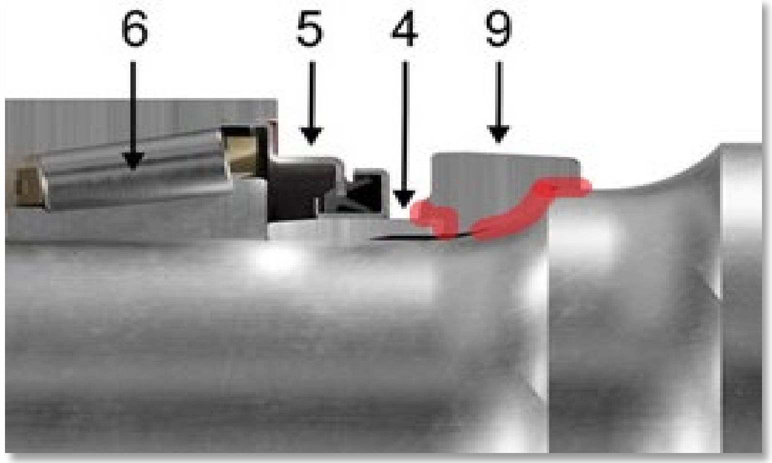
Fitted Backing Rings (FBR)

- Testing journal fillet-to-FBR interface
- Investigating various nicks/burs on FBR
- Have encountered cases of damaged dust guards from FBRs

Leak path highlighted in red



Dust guard gouge left by FBR

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Summary of Testing to Date and Future Testing

Completed Tests (41):

- 3 control bearings
- 18 end caps
- 8 seal wear rings
- 4 fitted backing rings
- 8 rubbing lip seals

Upcoming Tests:

- Labyrinth seals
- Dust guard defects
- UFBR
- Tectyl

Path Forward:

- Finalize testing (2026)
- Aid WABL in updating MSRP Section H-II
- Publish detailed report of findings

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- **Progress Rail**
- **Timken Company**
- **Brenco (Amsted Rail)**
- **MxV Rail Laboratory Team**

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